Assessing Native American Mobility versus Permanency at Mission San Juan de Capistrano through the Use of Stable Isotope Analysis

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ABSTRACT

Carbon and nitrogen stable isotope analyses were conducted on 19 individuals and six faunal species from Mission San Juan de Capistrano in San Antonio, Texas. The carbon and nitrogen values are most similar to prehistoric Texas coastal hunters and gatherers and least similar to South Texas inland hunters and gatherers. While the observed carbon isotopic values may reflect maize consumption, the nitrogen values are more positive than those typical of maize-dependent populations, and more closely resemble those found in populations consuming freshwater or near-shore marine resources. This suggests that mission residents may have had pre-mission locations near the coast and that their isotopic signatures remained unaffected by a mission diet, indicating that Native residency was intermittent or of short duration.

INTRODUCTION

Colonial mission research currently includes two main perceptions regarding Native American sedentism at Spanish missions in Texas. The first view is that numerous small hunting and gathering groups settled permanently at the missions because these institutions provided a secure subsistence and a safe haven from enemy raiders (John 1991). Implicit in this perception is the idea that the Native Americans who entered the missions became acculturated and eventually integrated into the larger Spanish community (Habig 1968). This view is currently popularized in the movie "Gente de Razon" or People of Reason, shown daily at the Mission San Jose Visitor's Center. The second perception is that the length of Native residency at Spanish missions was limited due to multiple factors. These include an unwillingness of neophytes to enter and remain at missions (Hinojosa 1991); high infant and maternal mortality and death from European diseases (Schuetz 1980a); and the Native use of missions on an intermittent basis coincident with seasonal food procurement strategies (Ricklis 1996). There is evidence supporting both perceptions in the ethnohistorical literature of the San Antonio missions (Hinojosa 1991; Schuetz 1980a). These two alternatives are not mutually exclusive; however, there were at least a few individuals who were permanent mission residents (Schuetz 1980a). Rather, the question is whether permanent residency was the dominant pattern for the numerous small hunting and gathering groups who entered Spanish missions in South Texas.

We have pursued a preliminary assessment of this issue through stable isotope analysis on 19 human individuals and six faunal species from Mission San Juan de Capistrano, and two prehistoric human individuals from Bexar County, Texas. Stable isotope studies allow for dietary reconstruction. The ethnohistorical and archeological evidence indicates a mission resident diet comprised largely of maize and beef. If the majority of Native people entered and remained at the mission and consumed a diet dominated by maize and beef, their bone collagen would express a particular carbon and nitrogen isotope signal. On the other hand, a non-mission diet may be inferred by alternative isotope values, which would then imply a limited use of the mission by hunting and gathering groups.

HISTORICAL CONTEXT

The San Antonio missions were established in the early 18th century in present day Bexar County along the San Antonio River (Figure 1). San Antonio de Valero, better known as the Alamo, opened its doors in 1718, and it was soon followed by the founding of Mission San José y San Miguel de Aguayo in 1720. Mission Valero's promoter was Fray Antonio Olivares, who had first seen the San Antonio area in 1709. He felt the area was an ideal location for supplying the material needs of a mission, as well as serving as a half-way station between the Spanish settlements to the west and the presidios and missions in East Texas (Bannon 1979; see Carlson and Corbin, this volume). The settlement of San Antonio was important, therefore, in securing the entire frontier province of Texas. In 1731, 13 years after the establishment of San Antonio de Valero, three missions were moved from East Texas. These were Nuestra Señora de la Purisima Concepción de Acuna, San Juan de Capistrano, and San Francisco de la Espada, creating a chain of five missions on the San Antonio River (Habig 1968).

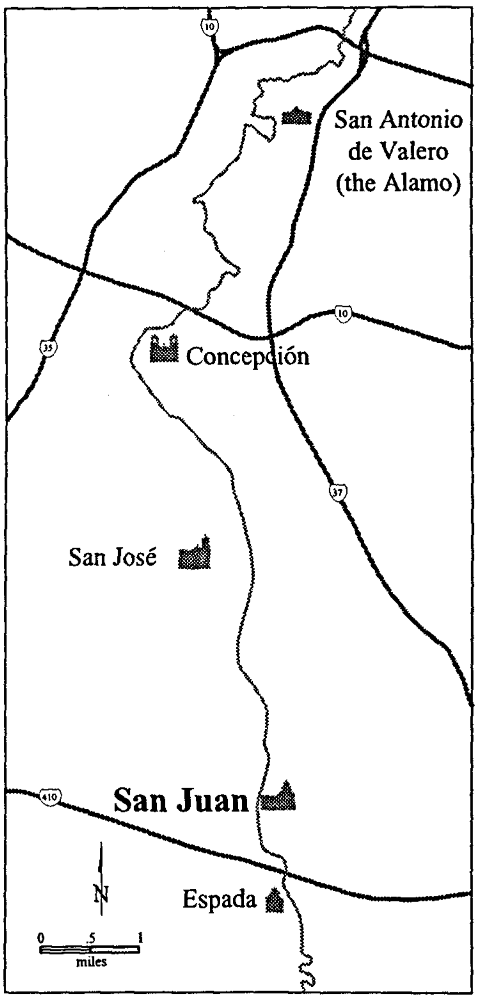

Figure 1. The San Antonio Missions.

Native groups who entered the San Antonio missions came from areas in Texas, Northeastern Mexico, and the Southern High Plains. The latter was home to the Apache, a few of whom entered Mission San Antonio de Valero (Schuetz 1980a). Due to incomplete records, the entirety of groups who entered these missions will probably never be known; however, it appears that indigenous people came from areas south of San Antonio, northeastern Mexico, and along the Rio Grande from its delta as far upstream as Laredo (Campbell and Campbell 1985).

Groups known to have been present at Mission San Juan have been compiled from mission registers and a variety of other sources (Campbell and Campbell 1985; Schuetz 1980a). In 1777, Father Morfi wrote that Mission San Juan de Capistrano was founded for the Orejones, Sayopines, Pamaques, and Piquiques (Schuetz 1968). The early 18th century mission foundation document states, however, that Mission San Juan was founded for the Tilijae (Tiloujaa) and the Venado groups (Campbell and Campbell 1985). Approximate pre-mission locations and mission entrance dates for known Native groups at Mission San Juan (Figure 2) are taken from Campbell and Campbell (1985), Salinas (1990), and Schuetz (1980a).

Prior to missionization, Native Americans in South Texas and northeastern Mexico practiced either an inland hunting and gathering subsistence strategy focused on the prairies and riparian zones, or a coastal adaptation focused primarily on the resources of the bays, estuaries, and barrier islands (Hester 1981). According to historical documents, once these hunters and gatherers became active participants in mission life, their diet was comprised largely of domesticated plants and animals, specifically maize and cattle (Leutenegger 1976; Leutenegger and Habig 1978; Schuetz 1968, 1980a). Maize and beef were significant dietary items in both attracting Native groups to the missions (Hinojosa 1991) and in providing the major components of the mission diet. Analyses of archeological faunal remains from neighboring Mission San José and Mission Valero demonstrate that cattle bone comprised a high percentage of the overall faunal assemblage (Hard et al. 1995; Meissner 1998; Tomka and Fox 1998). Furthermore, numerous references to maize and domesticated animals, as they

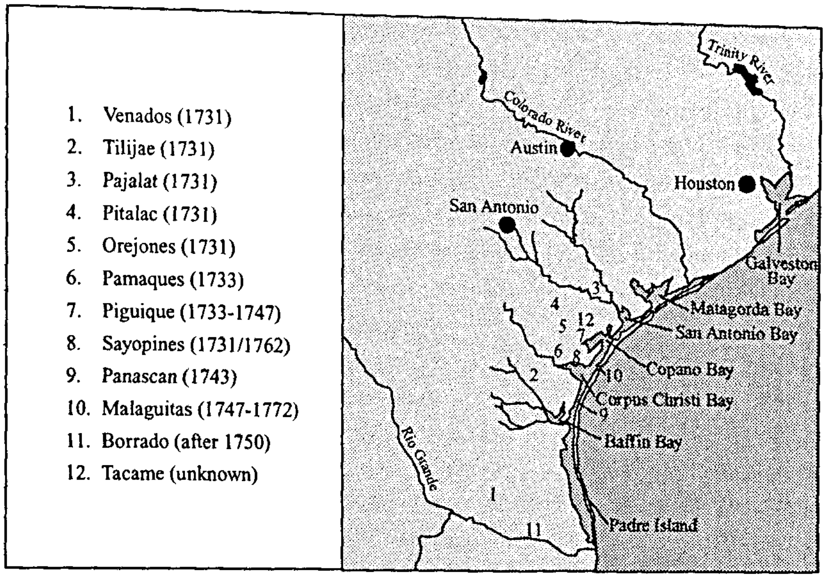

Figure 2. Approximate entrance dates and pre-mission locations for known Native groups at Mission San Juan de Capistrano.

pertain to both consumption and inventories, are found in historical documents of the San Antonio missions. For example, in 1762, Padre Dolores made an inspection of Mission San Juan and reported "...in the granary, that is a spacious room, they store about 1,000 fanegas of maize and beans necessary for the sustenance of the Indians, for which purpose they also keep one thousand head of large cattle, and 3500 small livestock" (Schuetz 1968:46).

PERMANENT OCCUPATION OF THE MISSIONS

The Spanish Crown and Religious Fathers viewed the mission as an institution for the permanent *reduccion* of Native peoples, and they tried to control the mobility of their residents. Apostates who fled the mission were often returned with the aid of presidial soldiers, thereby insuring that they remained under the supervision of the Padre (Habig 1968; Hinojosa 1991).

Permanent occupation of the missions by some Native groups is inferred from references to the requests and needs of indigenous people, to missionary reports, and to demographic analysis of mission populations. Apparently, some groups were ready to settle and requested missions be established for them. The Fathers found that these individuals were often familiar with many Hispanic skills such as planting and house construction (Hinojosa 1991). It may be that some of these individuals were apostates from missions on the Rio Grande. Others, probably in need of protection from warring groups, were also anxious to enter Spanish missions (Hinojosa 1991). The following passage written by a Texas missionary in 1740 demonstrates the frustration of missionizing Native groups, but alludes to the successful transition to mission life:

> The conversions are not difficult but are burdensome as it is necessary to work with them in the manner of a mother giving birth to an infant. It might take five, six, or seven years to bring them to be rational creatures, and it is a rarity to find one who didn't flee two or three times to the wilderness (Schuetz 1980a:233).

At Mission Valero, where almost complete mission registers exist, it is known that some individuals permanently resided there as they have been traced through birth, baptismal, marriage, and death registers (Schuetz 1980a). Although infant mortality was high at Valero (67 percent of 319 individuals who are recorded in both birth and death registers died before the age of three), there were 14 individuals who attained an age between 20-29 years, and eight who lived to between 30-45 years of age (Schuetz 1980a). This suggests that while life expectancy was low if born at the mission, there were individuals who remained there from birth through adulthood.

INTERMITTENT, OR SHORT-TERM OCCUPATION OF THE MISSIONS

While it is known that some Native American groups requested the establishment of a mission and appeared to be ready to adopt mission life or simply needed the protection the mission provided, others may have initially "entered" because of the availability of food without understanding in full the obligations inherent in mission life. Hinojosa

(1991) states, however, that most groups did not want to join the missions and many had to be coerced, threatened, or bribed. A passage by Fray Benito Fernandez de Santa Ana aptly explains the process: "There are Indians who are hungry, and they accept the faith through the enticement of food... and there are those who... require the weapons of your Majesty to bring them into civil society" (Hinojosa 1991:67).

Historical documents contain numerous references to Spanish recruiting efforts and Native desertions at Texas missions (Leutenegger 1976; Salinas 1990; Schuetz 1968, 1980a). The continuous recruitment of neophytes by the Spanish Fathers is cited by an anonymous missionary of Concepción in approximately 1760: "From time to time the missionary should journey to the coast and bring back the fugitives, who regularly leave the mission trying at the same time to gain some recruits, if possible, so that more conversions are realized and the mission does not come to an end because of the lack of natives" (Leutenegger 1976:47).

The demographic history of Mission San Juan is characterized by population fluctuations from its founding in 1731 through secularization in 1794 (Schuetz 1968). Declines in resident populations are associated with major desertions and epidemics; population increases resulted from the return of apostates and new recruits (Schuetz 1968, 1980b).

In 1762, the San Antonio missions were working to complete the reduction of Native groups from a broad geographical area ranging from the lower Rio Grande to the west side of present day Galveston Bay (Schuetz 1980a). From ca. 1760-1780, a number of documents referred to recruiting efforts as mission populations declined (Salinas 1990). All five of the San Antonio missions were officially secularized in 1794, and Mission San Juan transferred communal ownership of mission lands to 12 individual Native resident heads of household (Schuetz 1980b).

What is not yet understood is just how successful the missions were in retaining, hispanicizing, and subsequently integrating indigenous peoples into the larger Spanish community. Alternatively, how many of the hunting and gathering groups temporarily or intermittently occupied the missions, or deserted, never to return.

MATERIALS AND METHODS

Materials

Stable isotope analysis was conducted on 19 human individuals and six faunal species from Mission San Juan. The individuals were recovered from Mission San Juan's "old church" or Structure 26 (Figure 3). Based on historical records and recovered artifacts, the "old church," which was

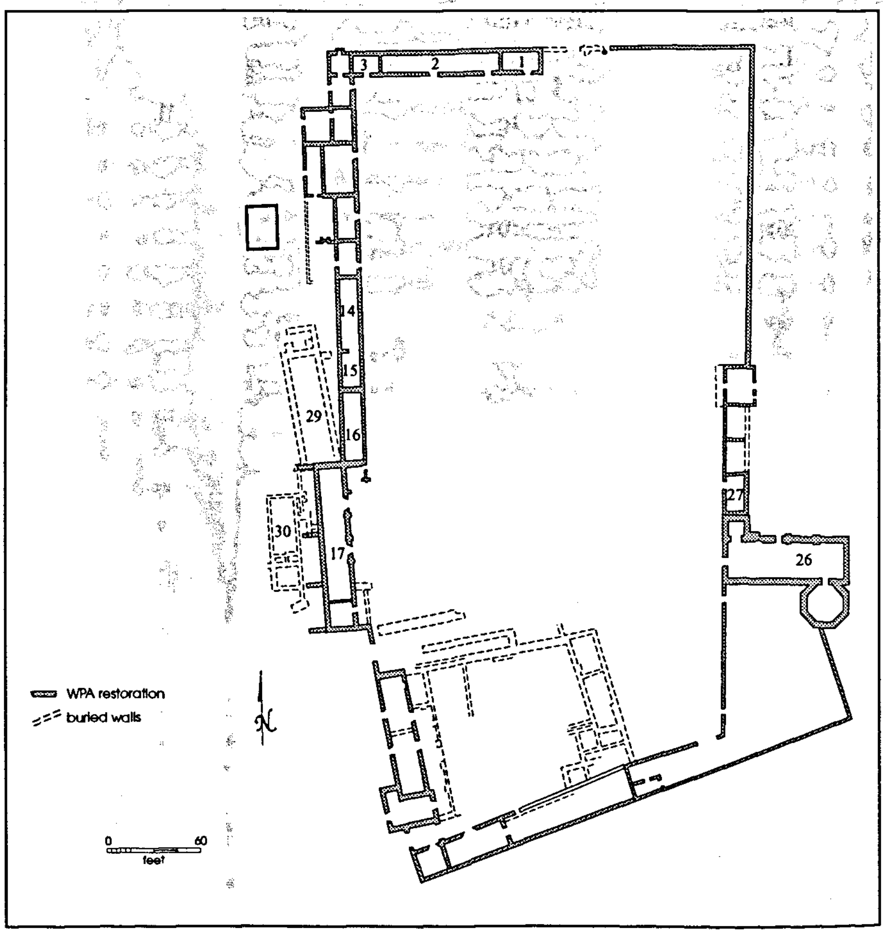

Figure 3. Mission San Juan de Capistrano.

never completed, dates from approximately 1763-1785 (Schuetz 1968). Recent osteological analysis conducted by Doug Owsley (1998 personal communication) from the Smithsonian Institution and a team of physical anthropologists demonstrates that the human skeletal assemblage is largely Native American, with perhaps a small number of individuals of Native American and European admixture. We used two criteria to select the human samples for stable isotope analysis. The first was that the individuals chosen be positively identified as male or female. This was done in order to evaluate potential dietary differences between the sexes. Based on Miller's (1989) analysis, 10 females and 9 males were selected. The second criteria was to include burials that represented only one individual. Comingled burials were not selected in order to avoid the possibility of analyzing multiple elements from the same individual. Human rib bones were chosen for analysis in 15 of the 19 samples; due to the lack of rib bones in four individuals, miscellaneous bone was used. We selected the faunal sample from Mission San Juan rooms containing unmixed colonial deposits. A variety of elements (e.g., turtle carapace and cow femur) were chosen from these collections.

For comparative purposes, we also conducted stable isotope analysis on two individuals from Bexar County. One individual from 41BX952 is dated by the association of an Edwards arrow point. The Edwards point dates from ca. A.D. 900-1040 (Turner and Hester 1993), and while not embedded in the bone, it was in direct association with the vertebrae (Meissner, 1999 personal communication). The other individual from 41BX677 produced an accelerator radiocarbon date of A.D. 1420-1650 (2 sigma, calibrated) from bone collagen (Tennis 1994). We selected miscellaneous bone from these two individuals for analysis. Harold Krueger from Geochron Laboratories (Cambridge, Massachusetts) performed the stable isotope analysis; Krueger and Sullivan (1984) and Cargill (1996) describe the analytical procedures.

Stable Isotope Analysis

Since their introduction 20 years ago, stable carbon and nitrogen isotope studies have become widely accepted analytical techniques for reconstructing some major dietary components such as the use of maize, aquatic, and terrestrial resources (e.g., Hutchinson et al. 1998; Pate 1994; Schoeninger and Moore 1992; Schwarcz and Schoeninger 1991; Vogel and van der Merwe 1977). Stable ^{13}C and ^{15}N in human bone collagen are measured with a mass spectrometer. The abundance of a stable isotope in a sample is measured as a ratio of the heavier to the lighter isotope, with reference to the ratio of a standard reference material (Ambrose 1993:65). The reference standards are: $^{13}C/^{12}C$ of Pee Dee Belemnite (PDB) and $^{15}N/^{14}N$ of atmospheric nitrogen known as the Ambient Inhalable Reservoir (AIR). Isotope ratios are expressed with the delta symbol (δ) in parts per thousand (‰ or per mil), using the following formula:

$$\delta(‰) = [(\text{Ratio of sample/Ratio standard})-1] \times 1000$$

Typically the resulting $\delta^{13}C$‰ values are negative and the $\delta^{15}N$‰ values are positive.

As these isotopes are introduced, metabolized, and incorporated into the cells of organisms and passed up through the food chain, the changes that occur in the isotope ratios are known as "fractionation." Because the degree of fractionation is predictable and largely known, an organism's isotopic values can indicate its dietary history. For archeological contexts bone collagen is the most frequently available tissue. When carbon is incorporated into bone collagen, there is a positive fractionation or enrichment of 3-5‰ between diet and collagen, and 5‰ is usually assumed for analytical purposes (Bender et al. 1981; DeNiro and Epstein 1978; Schwarcz and Schoeninger 1991; Vogel 1978). For example, an herbivore with a pure C_3 diet (-27.1‰) would have a bone collagen level of around -22.1‰ (Hard et al. 1996:265).

Since omnivores, including humans, consume plants and animals, the carbon chains utilized for collagen synthesis may not be produced in direct proportion to the occurrence of carbon molecules in the bulk diet. Although this has been the standard model (e.g., van der Merwe 1982; Spielmann et al. 1990), it now appears that the carbon molecules are not derived from the bulk diet, but may be derived largely from protein, rather than fats or carbohydrates (Ambrose and Norr 1993; Krueger and Sullivan 1984; Tieszen and Fagre 1993a, 1993b). Glycine is abundant in maize and makes up 33 percent of collagen's amino acids. If it provided the carbon molecules for collagen, it would account for the high carbon isotopic values seen in the human collagen of maize agriculturalists (Tieszen and Fagre 1993b:37). Although this research is in its early stages, it is now clear that collagen isotopic levels cannot be directly translated into the bulk dietary proportions of C_3 versus C_4 sources, although major dietary trends have been successfully detected. There is some indication that the isotopic values of bone apatite, rather than collagen, more precisely reflect bulk dietary proportions (Ambrose and Norr 1993; Tieszen and Fagre 1993a). While this is a promising alternative, insufficient comparative data are available to consider this approach here, although we also report the bone apatite values from the San Juan Capistrano population. In contrast to carbon, nitrogen is only found in proteins.

Our approach is to use bivariate plots of collagen $\delta^{13}C$ and $\delta^{15}N$ values compared with the collagen isotopic values of other archeological populations whose isotopic signatures and diet are understood. In addition, we consider the known isotopic levels of potential dietary components in order to make inferences regarding the dietary history of the San Juan Capistrano population.

The isotopic collagen signature should reflect the diet over the period of time in which bone collagen is fully replaced. Since the bone collagen turnover rate is 10 to 30 years, the stable isotope values should reflect an average of the dietary intake during this period (Stenhouse and Baxter 1979:339; Bumstead 1985:544; Krueger and Sullivan 1984:210). Thus, the isotopic signature of an individual who spent most of his life in one region, but lived at the mission for only a few years before expiring, will reflect his former rather than his later diet.

Terrestrial Carbon

Plants incorporate carbon from the atmosphere using one of three photosynthetic pathways, two of which result in distinct carbon stable isotope ratios ($^{13}C/^{12}C$) (Bender et al. 1973; Pate 1994; Smith 1971, 1972). These isotopic signatures are then incorporated into the tissue, including bone collagen, of humans and other animals that eat those plants. Most herbs and shrubs, all trees, and temperate cool-season grasses use the Calvin or C_3 pathway, named for a three-carbon molecule formed during CO_2 assimilation. These plants discriminate against the heavier ^{13}C isotope, producing more negative $\delta^{13}C$ values that range between -20 and -35‰, with a mean of about -27‰ (DeNiro 1987:183; Ehleringer 1989:41; O'Leary 1988:334). Although there is substantial variation in the isotopic signatures of C_3 plants, no overlap occurs between them and the other major photosynthetic pathway, the C_4 or Hatch/Slack pathway.

Plants such as amaranth, Portulaca, tropical and warm-season grasses, maize, millet, sugarcane, and some shrubs in the Euphorbiaceae and Chenopodiaceae families use the C_4 pathway (Pate 1994:172). C_4 plants produce a four-carbon molecule during CO_2 uptake and they do not discriminate against the ^{13}C isotope as much as C_3 plants do. Therefore, they have an isotopically heavier $\delta^{13}C$, with a mean of about -13‰ (O'Leary 1988:334; Stothers and Bechtel 1987:138) and a range of -7 to -16‰ (Ehleringer 1989:41; Hard et al. 1996:264: Pate 1994:173). These plants, with their more positive values, are said to be isotopically heavier or enriched in ^{13}C.

Arid land succulents, such as cacti, agave, and some euphorbs utilize a third photosynthetic pathway, crassulacean acid metabolism (CAM). Such taxa can vary their pathway depending upon if they uptake CO_2 diurnally or nocturnally (Ehleringer 1989:41; O'Leary 1981, 1988; Pate 1994:173). The day-growing group has values within the range of C_3 taxa and the night group's values are within those of C_4 plants.

Freshwater and Marine Carbon

The $\delta^{13}C$ value of freshwater fish and fauna are affected by the influences of both terrestrial C_3 and C_4 sources and have been demonstrated to range between -23.7‰ and -12.7‰ (Cargill 1996:103; Katzenberg 1989:323; Schoeninger and DeNiro 1984:629; Tuross et al. 1994:295). The marine $\delta^{13}C$ value of the dissolved inorganic carbon pool, from which oceanic life derives its carbon, is positively enriched about 7.0‰ relative to atmospheric carbon (Fry and Sherr 1984:17). Therefore, most marine plants have $\delta^{13}C$ values more positive than terrestrial C_3 plants (DeNiro 1987:187). However, substantial variability exists in the $\delta^{13}C$ values of marine organisms that is related to cold vs. warm water organisms as well as to particular coastal ecosystems such as seagrass meadows, coral reefs, algae blooms, and saltmarshes (Cargill 1996:105; Fry and Sherr 1984:19-20; Little and Schoeninger 1995:358; Schoeninger and DeNiro 1984:628). For example, the large seagrass meadows of *Syringodium filiformis* in the lower Laguna Madre of Texas exhibit a mean $\delta^{13}C$ value of -5.4‰ and *Halodule wrightii*, the dominant seagrass in the upper Laguna Madre, has a mean $\delta^{13}C$ value of -10‰ (Fry and Parker 1979:500-501). In fact, 85 percent of the animals analyzed from seagrass meadows from the Gulf of Mexico had $\delta^{13}C$ values between -8.3 and -14.5‰. In contrast, offshore animals had more negative values (between -15.0‰ and -19.0‰). In addition, there is some evidence that there are slight (<1‰) increases in tissue $\delta^{13}C$ values for each successive trophic level, although this may be related to the role of near shore taxa in the food chain (Fry and Sherr 1984:28, 30).

The $\delta^{13}C$ values of nearshore marine animals can mimic those of terrestrial C_4 plants; humans feeding on nearshore taxa may have a similar bone collagen signature as that of a maize-dependent population. Fortunately, stable nitrogen isotope analysis can assist with this discrimination (Hutchinson et al. 1998; Schoeninger and DeNiro 1983:1381; Walker and DeNiro 1986:56).

Terrestrial Nitrogen

Atmospheric nitrogen is 99.64 percent of the stable isotope ^{14}N, with the remainder ^{15}N. Plants uptake soil nitrogen isotopes and animals ingest plant and animal tissue containing nitrogen isotopes. As with carbon, nitrogen isotopes are then incorporated into amino acids in plant and animal tissues. Fractionation occurs at various points in the uptake and metabolic processes, resulting in variability in the $\delta^{15}N$ values that can be compared to known samples. Human bone collagen is typically used for archeological samples. Dietary inferences can be made through comparison with the values of known samples, and by taking into account the fractionation that may have occurred in the nitrogen uptake and tissue formation processes.

Nitrogen, an essential component of all protein, comprises 79 percent of the atmosphere as N_2. Paradoxically, N_2 cannot be directly used by most organisms, but first must be chemically transformed through bacterial N_2 fixation. Fixation occurs with bacteria living symbiotically with legumes and root-noduled, non-leguminous plants, free-living soil bacteria, and blue-green algae in soil (Smith 1990:258). Bacterial action fixes nitrogen in the soil by converting it to ammonia, a form that is plant usable. Fixation occurs in two additional ways: the breakdown of organic matter, and the combination of atmospheric N_2 with precipitation, also combined with high energy inputs from lightening to produce usable nitrates (Smith 1990:258). Fractionation can be affected by these fixation processes.

The stable isotope of ^{14}N, relative to ^{15}N, is lost more rapidly as soil organic matter decomposes, resulting in $\delta^{15}N$ values of -4.0 to +14. Nitrogen fixing plants have a typical range of -2.0 to +2.0‰ and non-fixing plants have mean values of about +3.0‰, but a range of 0 to +6.0‰ is reported (Pate 1994:180). Variation in plant $\delta^{15}N$ may be related to the degree of nitrogen fixation, climate, and micro-habitat (Ambrose 1993:96). The ^{15}N isotope value of the same plant species may vary depending on local ecological conditions.

The relationship between the $\delta^{15}N$ isotope values in animal tissue, such as bone collagen, and diet is dependent upon the degree that ^{14}N, relative to ^{15}N, is more rapidly gained during the metabolic and cell formation processes. The $\delta^{15}N$ values increase 3-4‰ from that of the ingested plants, for each successive step up the trophic ladder (Ambrose 1993:97; Pate 1994:180). However, these values are means from global surveys and there is significant variation among different ecological settings. For example, herbivores from hot, dry environments tend to have higher $\delta^{15}N$ values than those from cool, moist environments. This variability is related to variation in fractionation levels and $\delta^{15}N$ dietary plant values (Ambrose 1993:97). Therefore, comparisons should be made within, not across, ecosystems. Ideally, samples from all components of the ecosystem under study should be analyzed in order to reconstruct diet from bone collagen. Fortunately, however, there appears to be no significant difference in $\delta^{15}N$ values among tissues of the same animal (Ambrose 1991:297).

Freshwater and Marine Nitrogen Isotope Variation

Stable nitrogen isotope values can potentially be used to discriminate between terrestrial and marine diets because marine ecosystems tend to have higher values than most terrestrial systems. Dissolved atmospheric N_2 in seawater is +1.0‰. In addition, much more of the usable nitrogen in marine and freshwater systems is produced by bacterial breakdown of organic material into ^{15}N-enriched nitrates than in terrestrial systems (Schoeninger and Moore 1992:256). As a result, aquatic plants at the base of the trophic scale have $\delta^{15}N$ values of about +7‰, 4‰ higher than most terrestrial plants (Ambrose 1993:94; Schoeninger and Moore 1992:Figure 1). Marine nitrogen-fixing plants, such as blue green algae, seagrasses, and saltmarsh grasses such as those found in reef, mangrove, and saltmarsh ecosystems, may have $\delta^{15}N$ values similar to those of terrestrial ecosystems. Blue green algae and saltmarsh grasses have measured $\delta^{15}N$ values of about +1.0‰ (Little and Schoeninger 1995:358; Minagwa and Wada 1984:1135). Therefore, the distinction between diets derived from marine ecosystems such as those with depleted $\delta^{15}N$ values and terrestrial ones is difficult using stable nitrogen or carbon isotopes (Ambrose 1993:94).

As with terrestrial systems, there is about a 3‰ enrichment of $\delta^{15}N$ values at each successive trophic level. However, because of variation among marine ecosystems, trophic level determinations should only be made within, not between, ecosystems. For example, from the Usujiri tidal zone of Japan, primary producers such as seaweed and phytoplankton have $\delta^{15}N$ value of +6.8‰; primary consumers (mussels, shore crabs, sea anemones, and starfish) are +8.5 to +9.5‰; secondary consumers (including fish and octopuses) are +10.6 to +12.7‰; and tertiary feeders such as seagulls are +15.6 to +16.8‰ (Minagawa and Wada 1984:1137). In contrast, lower $\delta^{15}N$ values are found in nitrogen-fixing seagrass food webs. Juvenile shrimp from seagrass meadows along the South Texas coast have $\delta^{15}N$ values between +6.0 to +8.0‰ (Fry 1983:789), and pinfish from seagrasses in San Antonio Bay have an average $\delta^{15}N$ value of +10.2‰ (Huebner 1994). Offshore non-migratory shrimp are +11.8‰ (Fry 1983:794) and offshore pinfish are 13.6‰ (Huebner 1994). Fish bone collagen from the Mitchell Ridge site (41GV66) in Galveston County had $\delta^{15}N$ values of +9.9‰ for drum and +6.6‰ for gar (Huebner 1994). By examining the stable carbon and nitrogen isotope results from Mission San Juan de Capistrano with the ecological factors affecting isotope values, it is possible to make inferences regarding the dietary history of individuals.

RESULTS OF THE STABLE ISOTOPE ANALYSES

Delta ^{13}C values for bone apatite and collagen, and $\delta^{15}N$ values for bone collagen, for the 19 mission individuals, six faunal species, and two archeological comparative samples are provided in Table 1. The carbon apatite values are discussed in Cargill (1996). Individuals from the San Juan de Capistrano mission exhibit collagen $\delta^{13}C$ values that range between -11.8 and -7.9‰, with a mean of -9.5‰ and a standard deviation of ± 0.9‰. There is a 3.9‰ difference between the most enriched and the most depleted $\delta^{13}C$ value in the mission sample. Experimental laboratory studies indicate that animals raised on a monotonous diet should yield $\delta^{13}C$ values within 1‰ of one another; this holds true for $\delta^{15}N$ values as well (DeNiro and Schoeninger 1985). The $\delta^{13}C$ values of mission residents, therefore, indicate some variation in food consumption; however, the range of values reflects the consumption of C_4 plants and animals reliant upon C_4 plants.

The $\delta^{15}N$ values are more tightly clustered and differ by less than 2‰, indicating less variability in the consumption of dietary protein. The values range from +11.0 to +12.8‰ (see Table 1) with a mean of +11.9‰ and a standard deviation of ± 0.5‰. These values are indicative of a diet that includes freshwater or marine resources. When $\delta^{13}C$ and $\delta^{15}N$ values for females and males are compared, it is apparent that the sexes share similar isotopic signatures.

The faunal samples exhibit a wide range of carbon and nitrogen values. For example, catfish has a $\delta^{13}C$ value of -20.9‰ and a $\delta^{15}N$ value of +10.6‰, while the values for cow are -15.0‰ ($\delta^{13}C$), with a $\delta^{15}N$ value of +5.7‰. Overall, the animals that graze or browse have $\delta^{13}C$ values indicative of a diet based on both C_3 and C_4 plants. In South Texas, the presence of C_4 grasses is often reflected in the $\delta^{13}C$ values of herbivorous animals. The most negative $\delta^{13}C$ values are associated with freshwater catfish and turtle, showing a C_3-like source of freshwater carbon. The $\delta^{15}N$ values indicate that catfish has the most positive value (+10.6), while terrestrial herbivores, as expected, exhibit

Table 1. δ¹³C and δ¹⁵N values for Mission San Juan Individuals and Fauna

Individual/Sex	δ¹³C Apatite	δ¹³C Collagen	δ¹⁵N Collagen
26 B 12B/Female	-5.7	-9.9	+11.5
26 B 13A/Male	-4.9	-9.6	+11.6
26 B 13C/Male	-4.4	-8.9	+11.9
26 B 16B/Male	-4.7	-8.5	+12.1
26 B 16C/Male	-6.3	-11.8	+12.3
26 B 17B/Female	-5.5	-10.1	+12.8
26 B 18A/Male	-5.6	-9.9	+11.3
26 B 18B/Female	-4.6	-9.4	+11.9
26 B 18C/Male	-6.3	-11.5	+12.8
26 B 1/Male	-6.0	-9.8	+11.9
26 B 7D/Male	-4.3	-9.6	+12.4
26 B 8B/Female	-3.8	-7.9	+11.5
26 B 9/Male	-5.0	-10.2	+12.2
26 B 10/Female	-4.7	-9.7	+11.8
26 B 11A/Female	-4.1	-9.0	+12.2
26 B 11C/Female	-5.1	-9.8	+12.0
26 B 11E/Female	-4.5	-9.0	+11.3
26 B 11F/Female	-4.8	-8.7	+12.2
26 B 11G/Female	-5.3	-9.0	+11.0
Mean	n/a	-9.5	+11.9
S.D.	n/a	0.93	0.49
41BX952	-11.9	-17.7	+7.9
41BX677	-5.3	-10.0	+10.7
Fauna	**δ¹³C Apatite**	**δ¹³C Collagen**	**δ¹⁵N Collagen**
Cow	-6.1	-15.0	+5.7
Javelina	-8.5	-15.8	+7.3
Pond Turtle	-6.7	-19.2	+5.0
Flathead Catfish	-6.3	-20.9	+10.6
Turkey	-9.0	-16.0	+6.1
Sheep or Goat	-8.3	-17.3	+6.5

relatively low δ¹⁵N values of +5.7 and +6.5‰. The two non-mission individuals from Bexar County exhibit isotope values very different from one another. The individual from 41BX952 (associated with an Edwards point) produced a δ¹³C value of -17.7‰ and a δ¹⁵N of +7.9‰. The Late Prehistoric/Protohistoric individual from 41BX677 has a δ¹³C value of -10.0‰ and a δ¹⁵N of +10.7‰.

INTERPRETATION AND DISCUSSION

A bivariate plot showing δ¹³C values along the X axis and δ¹⁵N values along the Y axis is used to compare the Mission San Juan sample to populations with a diversity of subsistence regimes (Figure 4 and Table 2). When the δ¹³C values of Mission San Juan de Capistrano residents are examined, they most closely resemble those δ¹³C values observed in maize-dependent groups. Interestingly however, the δ¹⁵N values of San Juan residents do not resemble δ¹⁵N values commonly found in maize agriculturalists, but rather, reflect those δ¹⁵N values associated with populations who exploit freshwater or marine resources.

δ¹³C AND δ¹⁵N VALUES OF MAIZE AGRICULTURALISTS

While maize agriculturalists exhibit mean δ¹³C values ranging from -12.4‰ (Spielmann et al. 1990) to -7.2‰ (Hutchinson et al. 1998) that reflect the consumption of a C_4 plant, their mean δ¹⁵N values typically fall between +8.0 or +9.0‰ (Schoeninger and DeNiro 1983); this is similar to the mean δ¹⁵N value of +8.0‰ reported for terrestrial carnivores (Schoeninger and DeNiro 1984). A mean δ¹⁵N value of +9.0‰ is reported for both prehistoric maize agriculturalists from the Tehuacan Valley in Mexico (Schoeninger and DeNiro 1983) and Pecos Pueblo (Spielmann et al. 1990). Historic Southwestern Pueblo Hawikuh maize agriculturalists have a mean δ¹⁵N value of +8.0‰ (Schoeninger and DeNiro 1983). Even inland and coastal maize agriculturalists located at Spanish missions in Florida

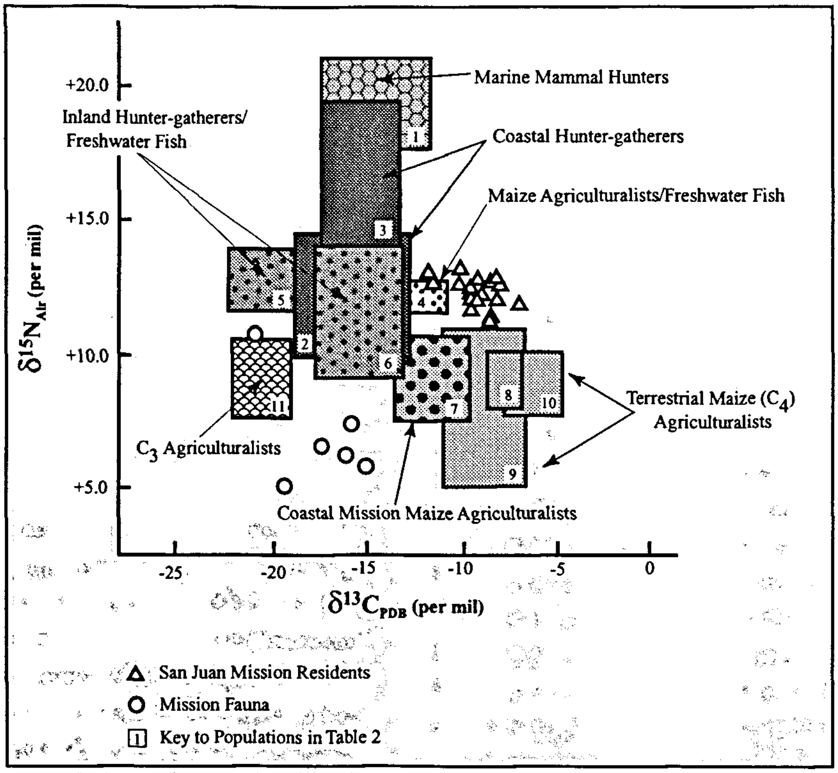

Figure 4. Isotopic signatures from Mission San Juan de Capistrano and historic and prehistoric populations.

and Georgia exhibit mean $\delta^{15}N$ values of +8.6, +9.4, and +10.2‰ (Hutchinson et al. 1998).

The stable isotope data from the Old Socorro Mission in the El Paso, Texas area is anomalous. The mean $\delta^{13}C$ value for the Old Socorro residents (-11.0‰) is similar to populations dependent on maize; however, the mean $\delta^{15}N$ value (+10.8‰) is higher than usual for agriculturists. Consequently, the enriched values at Old Socorro are not well understood as associated fauna have not been isotopically analyzed and substantial temporal variability exists within the sample.

The $\delta^{13}C$ value of maize is well documented (Bender 1968; DeNiro and Hastorf 1985; Schwarcz et al. 1985; Tieszen and Fagre 1993b); however, available $\delta^{15}N$ values for maize are limited. Reported $\delta^{15}N$ values include: +2.2‰ for archeological maize (Schoeninger et al. 1990), +6.4 to +7.8‰ for archeological carbonized maize (DeNiro and Hastorf 1985), and +7.6‰ for modern maize (Spielmann et al. 1990). This wide variation in $\delta^{15}N$ values demonstrates the need for additional stable nitrogen isotope analysis on maize in order to provide a more reliable data set for future dietary reconstruction. Clearly, the Mission San Juan population—with a mean $\delta^{15}N$ value of +11.9‰—has $\delta^{15}N$ values associated with protein sources other than maize and terrestrial herbivores.

Enriched $\delta^{15}N$ values have been documented in plants and animals from arid environments (Ambrose 1991), and in terrestrial plants located near saline or coastal shores (Heaton 1987). In order to assess whether environmental conditions are responsible for the relatively high $\delta^{15}N$ values observed in the mission resident sample, six faunal species from the colonial deposits were analyzed (see Table 1). Although the faunal sample is small, the nitrogen values of the herbivores and omnivores do not suggest either an elevated source of nitrogen at the base of the local food web or that herbivores exhibit high nitrogen values associated with drought-tolerant animals. That the mission residents' isotope signature reflects the consumption of domesticated animals, particularly cattle, is not supported by the $\delta^{15}N$ values of these animals. The fauna have relatively low $\delta^{15}N$ values as expected of herbivores. Applying a +3.0‰ trophic level increase to the $\delta^{15}N$ value of cow and goat/sheep, results in consumer $\delta^{15}N$ values between +8.7 and +9.5‰, respectively, values well below that of mission residents. From the fauna analyzed, catfish has a sufficient $\delta^{15}N$ value (+10.6‰) to account for the elevated $\delta^{15}N$ values observed in mission residents.

$\delta^{13}C$ AND $\delta^{15}N$ VALUES OF POPULATIONS DEPENDENT ON FRESHWATER FAUNA

It may be the case that the enriched $\delta^{13}C$ values and the elevated $\delta^{15}N$ values observed in the Mission San Juan residents are due to the consumption of maize and freshwater fauna (see Figure 4). Prehistoric maize agriculturalists from Southern Ontario whose diets consisted of approximately 50 percent maize and freshwater fauna from the Great

Table 2. Key to Populations Shown in Figures 4 and 5

Number	Location of Population and Subsistence Strategy	Reference
1	Alaska, Marine Mammal Hunters	Schoeninger and DeNiro 1983
2	Georgia, Coastal Hunters-Gatherers	Hutchinson et al. 1998
3	California, Coastal Fisher-Gatherers	Schoeninger and DeNiro 1983
4	Southern Ontario, Maize Agriculturalists and Freshwater Fauna	Schwarcz et al. 1985
5	Southern Ontario, Hunters and Gatherers Freshwater Fauna	Schwarcz et al. 1985
6	Florida, Hunters-Gatherers and Freshwater Fauna	Tuross et al. 1994
7	Georgia, Coastal Mission, Maize Agriculturalists	Hutchinson et al. 1998
8	New Mexico, Pecos Pueblo, Maize Agriculturalists	Spielmann et al. 1990
9	New Mexico, Hawikuh, Maize Agriculturalists	Schoeninger and DeNiro 1983
10	Mexico, Tehuacan Valley, Maize Agriculturalists	DeNiro and Epstein 1981; Schoeninger and DeNiro 1983
11	Europe Agriculturalists	Schoeninger and DeNiro 1983
12	Texas, Hunters-Gatherers and Freshwater Fauna, Blue Bayou Site	Huebner and Comuzzie 1992
13	Texas, Broad-based Economy, Bison and Maize, Antelope Creek phase	Habicht-Mauche et al. 1994
14	Texas, Coastal Hunters-Gatherers, Corpus Christi	Huebner 1994
15	Texas, Coastal Hunters-Gatherers, Mitchell Ridge Site	Huebner 1994
16	Texas, Maize Agriculturalists, Old Socorro Mission	Evans 1989
17	Texas, Inland Hunters-Gatherers, Loeve-Fox Site	Huebner, 1995 personal communication
18	Texas, Inland Hunters-Gatherers, Olmos	Huebner, 1995 personal communication
19	Texas, Inland Hunter-Gatherer, 41WY113	Bousman et al. 1990
20	Texas, Inland Hunter-Gatherer, 41BX952	Cargill 1996
21	Texas, Inland Hunter-Gatherer, 41BX677	Cargill 1996
22	Texas, Coastal Hunter-Gatherer, 41WY50	Bousman et al. 1990

Lakes, have a mean $\delta^{13}C$ value of -12.6‰ and a mean $\delta^{15}N$ value of +12.4‰ (Katzenberg 1989). Since $\delta^{15}N$ values observed in freshwater fauna often match or exceed those values found in terrestrial carnivores, a higher $\delta^{15}N$ value exists in freshwater consumers.

Mean $\delta^{15}N$ values similar to Mission San Juan residents are also observed in the Archaic Florida Windover population (+11.8‰), and the Protohistoric Tatham Mound Florida population (+11.5‰). The elevated $\delta^{15}N$ values in the Windover population are attributed to the exploitation of riverine resources (Tuross et al. 1994), and the enriched $\delta^{15}N$ values in the Tatham Mound population are associated with the consumption of riverine and lacustrine fauna (Hutchinson et al. 1998). Similarly, in Texas, Huebner and Commuzie (1992) conclude that the presence of elevated $\delta^{15}N$ values in the Blue Bayou population (mean of +10.5‰) probably resulted from the exploitation of riverine fauna (Figure 5). The $\delta^{13}C$ values of the populations discussed above

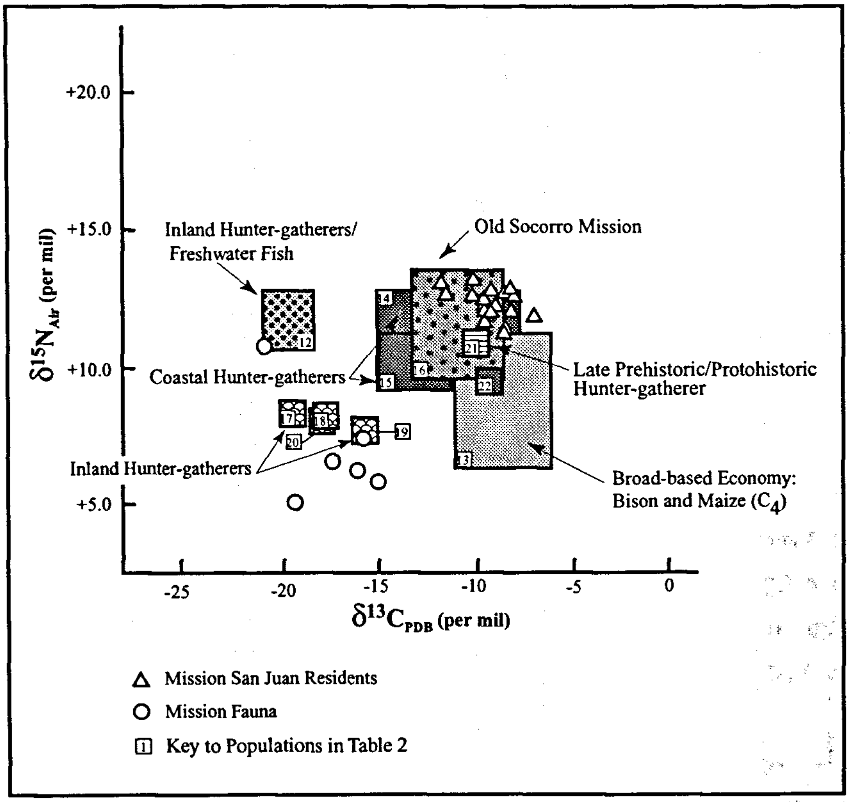

Figure 5. Isotopic signatures from Mission San Juan de Capistrano and historic and prehistoric populations in Texas.

range between -20.3 and -10.0‰, reflecting the availability and exploitation of C_3, C_4, or a combination of C_3 and C_4 resources.

$\delta^{13}C$ AND $\delta^{15}N$ VALUES OF POPULATIONS DEPENDENT ON MARINE RESOURCES

Populations dependent on marine resources exhibit a wide range of $\delta^{15}N$ and $\delta^{13}C$ values (see Figures 4 and 5). The enriched $\delta^{15}N$ values observed in Mission San Juan residents are also observed in coastal populations dependent on nearshore marine resources (see Figures 4 and 5). Delta ^{15}N values reported for Georgia coastal hunters and gatherers range between +10.6 and +14.4‰, with a mean $\delta^{15}N$ value of +12.8‰ (Hutchinson et al. 1998). The mean $\delta^{15}N$ value from Georgia, therefore, is only 1‰ more enriched than the mean $\delta^{15}N$ value of the Mission San Juan residents. However, Georgia coastal hunters and gatherers exhibit more depleted $\delta^{13}C$ values (ranging between -18.6 and -13.4‰, with a mean $\delta^{13}C$ of -15.1‰), indicating the consumption of a more C_3-like source of terrestrial and/or marine carbon.

In Texas, both the enriched $\delta^{13}C$ and $\delta^{15}N$ values for the Mission San Juan residents occur together in coastal hunters and gatherers (see Figure 5 and Table 2). The enrichment of both carbon and nitrogen stable isotope ratios in coastal populations is probably a result of the exploitation of marine fauna that inhabit the unique ecosystem of extensive seagrass meadows located along the Texas coast. The prehistoric populations of the Mitchell Ridge site, the Corpus Christi area, and 41WY50 (one individual), exhibit values ranging between -14.7 and -7.7‰, with a mean $\delta^{13}C$ value of -11.9‰ reported for Mitchell Ridge and -13.0‰ for the Corpus Christi area (Huebner 1994). The $\delta^{13}C$ value for 41WY50 is -9.7‰ (Bousman et al. 1990). Delta^{15}N values range between +9.2 and +12.8‰, with a mean of +10.4‰ reported for both the Mitchell Ridge site and the Corpus Christi area (Huebner 1994). The $\delta^{15}N$ value reported for 41WY50 is +9.6‰ (Bousman et al. 1990). In comparison, Mission San Juan residents have mean $\delta^{13}C$ and $\delta^{15}N$ values of -9.5 and +11.9‰, respectively, demonstrating that both carbon and nitrogen stable isotope ratios are within the range expected for a Texas coastal diet.

TEXAS INLAND HUNTERS AND GATHERERS, INCLUDING COMPARATIVE SAMPLES FROM 41BX677 AND 41BX952

Comparative sample 41BX677 is dated to the 15th-17th century A.D. The $\delta^{13}C$ value of -10.0‰ and the $\delta^{15}N$ value of +10.7‰ may reflect an inland hunting and gathering adaptation immediately preceding Spanish contact in the area. While a single sample is certainly not conclusive, and radiocarbon dating of bone is known to be problematic, the $\delta^{13}C$ and $\delta^{15}N$ value of this individual may be explained by the consumption of freshwater fauna, as well as C_4 and/or CAM plants and animals dependent upon those plants, including bison. Late Prehistoric bison in Texas have carbon isotopic values ranging from -13.7 to -8.5‰, and nitrogen isotopic values from +3.2 to +7.6‰ (Huebner and Boutton 1996). On the other hand, the isotopic signatures may reflect a marine adaptation, as the $\delta^{13}C$ and $\delta^{15}N$ values of the individual from 41BX677 are similar to those observed in Texas' coastal groups and to predicted values for a subsistence based on nearshore marine resources.

Inland hunters and gatherers dating from the Middle Archaic through the Austin phase of the Late Prehistoric period have $\delta^{13}C$ and $\delta^{15}N$ values quite unlike those observed among the Mission San Juan de Capistrano residents. Both $\delta^{13}C$ and $\delta^{15}N$ values are more depleted, suggesting the exploitation of a very different resource base. The mean $\delta^{13}C$ values associated with the Loeve-Fox and Olmos samples are -19.4 and -17.7‰, respectively (Huebner, 1995 personal communication). The $\delta^{13}C$ values reported for single individuals at 41WY113 and 41BX952 are -15.7 and -17.7‰, respectively. Compared to Mission San Juan residents, the $\delta^{13}C$ values from these samples suggest less C_4 influence in the diets of inland hunters and gatherers. The mean $\delta^{15}N$ values reported for both Loeve-Fox and Olmos are +8.0‰. The $\delta^{15}N$ values for the individuals at 41WY113 and 41BX952 are +7.6‰ and +7.9‰, respectively. The $\delta^{13}C$ and $\delta^{15}N$ values indicate that inland hunters and gatherers exploited primarily C_3 plants and terrestrial herbivores dependent upon those plants.

CONCLUSIONS

The $\delta^{13}C$ values of human individuals at Mission San Juan de Capistrano closely resemble those of maize-dependent populations. However, maize-dependent populations do not exhibit the consistently high $\delta^{15}N$ values observed in San Juan residents, unless freshwater fauna contributed significantly to the diet.

That the Mission San Juan residents regularly consumed cattle for the decade or more required for the bone collagen turnover rate, is not supported by the isotope analysis conducted on herbivores from the colonial archeological deposits. The cow and goat/sheep fauna have low $\delta^{15}N$ values, and populations consuming these terrestrial herbivores would exhibit relatively low $\delta^{15}N$ values as well; this contrasts sharply with the elevated $\delta^{15}N$ values (+11.0 to +12.8‰) observed in mission individuals. Therefore, the elevated $\delta^{15}N$ values in Mission San Juan residents are not consistent with the archeological faunal record that indicates that cow was a major resource. Neither are the elevated $\delta^{15}N$ values of Mission San Juan residents consistent with historic mission records indicating that maize was an important dietary component for mission residents (Hard et al. 1995; Leutenegger 1976; Schuetz 1968; Wade 1993).

Enriched $\delta^{13}C$ and elevated $\delta^{15}N$ values similar to those expressed by San Juan residents are observed in Texas hunting and gathering groups who exploited marine resources. In fact, given (a) similar $\delta^{13}C$ and $\delta^{15}N$ values observed in prehistoric humans buried near the coast, (b) the historical literature that discusses the recruitment of neophytes and the recovery of apostates from the coast, and (c) the fact that many of the known groups who entered Mission San Juan had pre-mission locations near the coast (see Figure 2), we believe that the stable isotope values of the Mission San Juan residents represent a coastal hunting and gathering adaptation. Furthermore, we believe that the dominant Native population at Mission San Juan was originally from the coastal area of Texas and lived on a mission diet either intermittently or for a relatively short time.

Based on bone collagen turnover rates, a mission dietary signature should be acquired if an individual remained at the mission for at least 10+ years consuming a diet comprised primarily of maize and beef. Schuetz's (1980a) demographic work at Mission Valero demonstrates that 22 individuals actually occupied the mission from birth through adulthood (20 through 45 years of age). Therefore, if stable isotope analysis was conducted on a complete burial population, at least some individuals should have carbon and nitrogen values reflecting a mission diet. If the human remains analyzed from the "Old Church" at Mission San Juan are representative of the majority of Native Americans who entered the San Antonio missions, the stable isotope values suggest that neophytes did not remain at the mission long enough (10+ years) to have their isotope values affected by a mission diet. In addition, the demographic profile of Native American residents at Mission Valero is characterized by high infant mortality, disease, and desertions. This, combined with mission documents that refer to the continual recruitment of neophytes to replace declining populations, supports the conclusion that the major pattern of mission residency was of short duration. Furthermore, a coastal dietary signature does not run counter to the historical and archeological evidence that indicates that maize and beef were main staples of the mission diet in Texas.

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REFERENCES CITED

Ambrose, S. H.
1991 Effects of Diet, Climate and Physiology on Nitrogen Isotope Abundances in Terrestrial Foodwebs. *Journal of Archaeological Science* 18:293-317.
1993 Isotopic Analysis of Paleodiets: Methodological and Interpretive Considerations. In *Investigations of Ancient Human Tissue*, edited by M. K. Sandford, pp. 59-130. Gordon and Breach Science Publishers.

Ambrose, S. H. and L. Norr
1993 Environmental Evidence for the Relationship of the Carbon Isotope Ratios of Whole Diet and Dietary Protein to Those of Bone Collagen and Carbonate. In *Molecular Archaeology of Prehistoric Human Bone*, edited by J. B. Lambert and G. Grupe, pp. 1-37. Springer-Verlag, Berlin.

Bannon, J. F.
1979 *The Spanish Borderlands Frontier 1513-1821.* University of New Mexico Press, Albuquerque.

Bender, M. M.
1968 Mass Spectrometric Studies of Carbon-13 Variations in Corn and other Grasses. *Radiocarbon* 10:468-472.

Bender, M. M., D. A. Baerreis, and R. A. Steventon
1981 Further Light on Carbon Isotopes and Hopewell Agriculture. *American Antiquity* 46:346-353.

Bender, M. M., I. Rouhani, H. M. Vines, and C. C. Black
1973 $^{13}C/^{12}C$ Ratio Changes in Crassulacean Acid Metabolism Plants. *Plant Physiology* 52:427-430.

Bousman, C. B., S. A. Tomka, and G. L. Bailey
1990 *Prehistoric Archeology and Paleoenvironments in Hidalgo and Willacy Counties, South Texas: Results of the Phase II Test Excavations.* Reports of Investigations No. 76. Prewitt and Associates, Inc., Austin.

Bumstead, M. P.
1985 Past Human Behavior from Bone Chemical Analysis-Respects and Prospects. *Journal of Human Evolution* 14:539-551.

Campbell, T. N. and T. J. Campbell
1985 *Indian Groups Associated with Spanish Missions of the San Antonio Missions National Historical Park.* Special Report 16. Center for Archaeological Research, The University of Texas at San Antonio.

Cargill, D. A.
1996 Stable Isotope Analysis at Mission San Juan de Capistrano, San Antonio, Texas. Master's Thesis, Anthropology Program, University of Texas at San Antonio.

DeNiro, M. J.
1987 Stable Isotopy and Archaeology. *American Scientist* 75:182-191.

DeNiro, M. J. and S. Epstein
1978 Influence of Diet on the Distribution of Carbon Isotopes in Animals. *Geochimica et Cosmochimica Acta* 42:495-506.
1981 Influence of Diet on the Distribution of Nitrogen Isotopes in Animals. *Geochimica et Cosmochimica Acta* 45:341-351.

DeNiro, M. J. and C. A. Hastorf
1985 Alteration of $^{15}N/^{14}N$ and $^{13}C/^{12}C$ Ratios of Plant Matter During the Initial Stages of Diagenesis: Studies Utilizing Archaeological Specimens from Peru. *Geochimica et Cosmochimica Acta* 49:97-115.

DeNiro, M. J. and M. J. Schoeninger
1985 Stable Carbon and Nitrogen Isotope Ratios of Bone Collagen: Variation Within Individuals, Between Sexes, and Within Populations Raised on Monotonous Diets. *Journal of Archaeological Science* 10:199-203.

Ehleringer, J. R.
1989 Carbon Isotope Ratios and Physiological Processes in Arid Land Plants. In *Stable Isotopes in Ecological Research*, edited by P. W. Rundel, J. R. Ehleringer, and K. A. Nagy, pp. 41-54. Springer Verlag, New York.

Evans, C. T.
1989 An Analysis of Burials from the Old Socorro Mission, Socorro, Texas. *The Artifact* 27:1-50.

Fry, B.
1983 Fish and Shrimp Migrations in the Northern Gulf of Mexico Analyzed Using Stable C, N, and S Isotope Ratios. *Fishery Bulletin U.S.* 81:499-509.

Fry, B. and P. L. Parker
1979 Animal Diet in Texas Seagrass Meadows: $\delta^{13}C$ Evidence for the Importance of Benthic Plants. *Estuarine and Coastal Marine Science* 8:499-509.

Fry, B. and E. B. Sherr
1984 $\delta^{13}C$ Measurements as Indicators of Carbon Flow in Marine and Freshwater Ecosystems. *Contributions in Marine Science* 27:13-47.

Habicht-Mauche J., A. A. Levendosky, and M. J. Schoeninger
1994 Antelope Creek Phase Subsistence: The Bone Chemistry Evidence. In *Skeletal Biology in the Great Plains: Migration, Warfare, Health, and Subsistence*, edited by D. W. Owsley and R. L. Jantz, pp. 291-304. Smithsonian Institution Press, Washington, D.C.

Habig, M. A.
1968 *The Alamo Chain of Missions*. Franciscan Herald Press, Chicago.

Hard, R. J., R. P. Mauldin, and G. R. Raymond
1996 Mano Size, Stable Carbon Isotope Ratios, and Macrobotanical Remains as Multiple Lines of Evidence of Maize Dependence in the American Southwest. *Journal of Archaeological Method and Theory* 3(4):253-318.

Hard, R. J., A. A. Fox, I. W. Cox, K. J. Gross, B. A. Meissner, G. I. Mendez, C. L. Tennis, and J. E. Zapata
1995 *Excavations at Mission San Jose y San Miguel de Aguayo, San Antonio, Texas.* Archaeological Survey Report No. 218. Center for Archaeological Research, The University of Texas at San Antonio.

Heaton, T. H. C.
1987 The $^{15}N/^{14}N$ Ratios of Plants in South Africa and Namibia: Relationship to Climate and Coastal/Saline Environments. *Oecologia* 74:236-246.

Hester, T. R.
1981 Tradition and Diversity Among the Prehistoric Hunters and Gatherers of Southern Texas. *Plains Anthropologist* 26(92):119-128

Hinojosa, G. M.
1991 The Religious-Indian Communities: The Goals of the Friars. In *Tejano Origins in Eighteenth-Century San Antonio*, edited by G. E. Poyo and G. M. Hinojosa, pp. 61-83. University of Texas Press, Austin.

Huebner, J. A.
1994 Stable Carbon and Nitrogen Isotope Analysis of Human Diets at the Mitchell Ridge Site (41GV66), Galveston County, Texas. MS in authors' possession.

Huebner, J. A. and T. W. Boutton
1996 The Isotopic Ecology of Bison in Late Prehistoric Texas. MS in possession of authors.

Huebner, J. A. and A. G. Comuzzie
1992 *The Archeology and Bioarcheology of Blue Bayou: A Late Archaic and Late Prehistoric Mortuary Locality in Victoria County, Texas.* Studies in Archeology 9. Texas Archeological Research Laboratory, The University of Texas at Austin.

Hutchinson, D. L., C. S. Larsen, M. J. Schoeninger, and L. Norr
1998 Regional Variation in the Pattern of Maize Adoption and Use in Florida and Georgia. *American Antiquity* 63(3):397-416.

John, E. A. H.
1991 Independent Indians and the San Antonio Community. In *Tejano Origins in Eighteenth-Century San Antonio*, edited by G. E. Poyo and G. M. Hinojosa, pp. 123-135. University of Texas Press, Austin.

Katzenberg, A. M.
1989 Stable Isotope Analysis of Archaeological Faunal Remains from Southern Ontario. *Journal of Archaeological Science* 16:319-329.

Krueger, H. W. and C. H. Sullivan
1984 Models for Carbon Isotope Fractionation Between Diet and Bone. In *Stable Isotopes in Nutrition*, edited by J. R. Turnlund and P. E. Johnson, pp. 205–220. U.S. Department of Agriculture, ACS Symposium Series 258. American Chemical Society, Washington, D.C.

Larsen, C. S., M. A. Schoeninger, N. J. van der Merwe, K. M. Moore, and J. A. Lee-Thorp
1992 Carbon and Nitrogen Stable Isotopic Signatures of Human Dietary Change in the Georgia Bight. *American Journal of Physical Anthropology* 89:197-214.

Leutenegger, Fr. B.
1976 *Guidelines for a Texas Mission: Instructions for the Missionary of Mission Concepción in San Antonio.* Old Spanish Missions Historical Research Library at San Jose Mission, San Antonio.

Leutenegger, Fr. B. (translator) and Fr. M. A. Habig (compiler and annotator)
1978 *The San José Papers: The Primary Sources for the History of Mission San José y San Miguel de Aguayo from Its Founding in 1720 to the Present, Part I: 1719-1791.* Old Spanish Missions Historical Research Library at San Jose Mission, San Antonio.

Little, E. A. and M. J. Schoeninger
1995 The Late Woodland Diet on Nantucket Island and the Problem of Maize in Coastal New England. *American Antiquity* 60(2):351-368.

Meissner, B. A.
1998 Analysis of Vertebrate Faunal Remains from a Spanish Colonial Mission, San Antonio de Valero (the Alamo), Bexar County. Master's Thesis, Anthropology Program, University of Texas at San Antonio.

Miller, E. A.
1989 The Effect of European Contact on the Health of Indigenous Populations in Texas. Master's Thesis, Department of Anthropology, Texas A&M University, College Station.

Minagawa, M. and E. Wada
1984 Stepwise Enrichment of 15N along Food chains: Further Evidence and the Relation Between $\delta^{15}N$ and Animal Age. *Geochimica et Cosmochimica Acta* 48:1135-1140.

O'Leary, M. H.
1981 Carbon Isotope Fractionation in Plants. *Phytochemistry* 20(4):553-567.
1988 Carbon Isotopes in Photosynthesis: Fractionation Techniques May Reveal New Aspects of Carbon Dynamics in Plants. *Bioscience* 38(5):328-336.

Pate, F. D.
1994 Bone Chemistry and Paleodiet. *Journal of Archaeological Method and Theory* 1(2):161-205.

Ricklis, R. A.
1996 *The Karankawa Indians of Texas: An Ecological Study of Cultural Tradition and Change.* University of Texas Press, Austin.

Salinas, M.
1990 *Indians of the Rio Grande Delta.* University of Texas Press, Austin.

Schoeninger, M. J. and M. J. DeNiro
1983 Stable Nitrogen Isotope Ratios of Bone Collagen Reflect Marine and Terrestrial Components of Prehistoric Human Diet. *Science* 220:1381-1383.
1984 Nitrogen and Carbon Isotopic Composition of Bone Collagen from Marine and Terrestrial Animals. *Geochimica et Cosmochimica Acta* 48:625-639.

Schoeninger, M. J. and K. Moore
1992 Bone Stable Isotope Studies in Archaeology. *Journal of World Prehistory* 6:247-296.

Schoeninger, M. J., N. J. van der Merwe, K. Moore, J. Lee-Thorpe, and C. S. Larsen
1990 Decrease in Diet Quality Between the Prehistoric and Contact Periods. In *The Archaeology of Mission Santa Catalina De Guale, Part 2, Biocultural Interpretations of a Population in Transition,* edited by C.S. Larsen, pp. 78-93. Anthropological Papers No. 68. American Museum of Natural History, New York.

Schuetz, M. K.
1968 *The History and Archeology of Mission San Juan Capistrano, San Antonio, Texas. Volume 1, Historical Documentation and Description of the Structures.* Archeological Program Report 10. Texas State Building Commission, Austin.
1980a The Indians of the San Antonio Missions 1718-1821. Ph.D. dissertation, Department of Anthropology, University of Texas at Austin.
1980b Historical Outline of Mission San Juan de Capistrano. *La Tierra* 7:3-15.

Schwarcz, H. P., J. Melbye, A.M. Katzenberg, and M. Knyf
1985 Stable Isotopes in Human Skeletons of Southern Ontario: Reconstructing Palaeodiet. *Journal of Archaeological Science* 12:187-206.

Schwarcz, H. P. and M. J. Schoeninger
1991 Stable Isotope Analysis in Human Nutritional Ecology. *Yearbook of Physical Anthropology* 34:283-321.

Smith, B. D.
1971 Carbon Isotope Ratios of Respired CO_2 from Castor Bean, Corn, Peanut, Pea, Radish, Squash, Sunflower, and Wheat Seedlings. *Plant and Cell Physiology* 12:451-455.
1972 Natural Abundance of the Stable Isotopes of Carbon in Biological Systems. *Bioscience* 22:226-231.

Smith, R. L.
1990 *Ecology and Field Biology.* Harper and Row Publishers, New York.

Spielmann, K. A., M. J. Schoeninger, and K. Moore
1990 Plains-Pueblo Interdependence and Human Diet at Pecos Pueblo, New Mexico. *American Antiquity* 55(4):745-765.

Stenhouse, M. J. and M. S. Baxter
1979 The Uptake of Bomb ^{14}C in Humans. In *Radiocarbon Dating*, edited by R. Berger and H. E. Suess, pp. 324-341. University of California Press, Berkeley.

Stothers, D. M. and S. K. Bechtel
1987 Stable Carbon Isotope Analysis: An Inter-Regional Perspective. *Archaeology of Eastern North America* 15:137-154.

Tennis, C. L.
1994 *Evaluation of Archaeological Material from the Little Church of La Villita Property, San Antonio, Texas.* Archaeological Survey Report No. 228. Center for Archaeological Research, The University of Texas at San Antonio.

Tieszen, L. L. and T. Fagre
1993a Effect of Diet Quality and Composition on the Isotopic Composition of Respiratory CO_2, Bone Collagen, Bioapatite, and Soft Tissues. In *Prehistoric Human Bone: Archaeology at the Molecular Level*, edited by J. B. Lambert and G. Grupe, pp. 121-155. Springer Verlag, Berlin.
1993b Carbon Isotopic Variability in Modern and Archaeological Maize. *Journal of Archeological Science* 20:25-40.

Tomka, S. A. and A. A. Fox
1998 *Mission San Jose Indian Quarters Wall Base Project, Bexar County, Texas.* Archaeological Survey Report No. 278. Center for Archaeological Research, The University of Texas at San Antonio.

Turner, E. S and T. R. Hester
1993 *A Field Guide to Stone Artifacts of Texas Indians.* 2nd Edition. Gulf Publishing Company, Houston.

Tuross, N., M. L. Fogel, L. Newsom, and G. H. Doran
1994 Subsistence in the Florida Archaic: The Stable Isotope and Archaeobotanical Evidence From the Windover Site. *American Antiquity* 59(2):288-303.

van der Merwe, N. J.
1982 Carbon Isotopes, Photosynthesis, and Archaeology. *American Scientist* 70:596-606.

Vogel, J. C.
1978 Isotopic Assessment of the Dietary Habits of Ungulates. *South African Journal of Science* 74:298-301.

Vogel, J. C. and N. J. van der Merwe
1977 Isotopic Evidence for Early Maize Cultivation in New York State. *American Antiquity* 42:238-242.

Wade, M. F.
1993 Our Daily Bread: The Role of Grinding Technology in the Socio-Economics of South Texas During the 18th Century. Master's Thesis, Department of Anthropology, The University of Texas at Austin.

Walker, P. L. and M. J. DeNiro
1986 Stable Nitrogen and Carbon Ratios in Bone Collagen as Indices of Prehistoric Dietary Dependence on Marine and Terrestrial Resources in Southern California. *American Journal of Physical Anthropology* 71:51-61.