

CLIMATE AND DIET IN FREMONT PREHISTORY:
ECONOMIC VARIABILITY AND ABANDONMENT OF MAIZE AGRICULTURE
IN THE GREAT SALT LAKE BASIN

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English Abstract. Research reported here is based on the stable isotope (^{13}C , ^{15}N) and radiocarbon chemistry of Fremont burials from wetlands lining the eastern shores of the Great Salt Lake (GSL). Bone collagen stable isotope signatures covary with reliance on maize and intake of animal protein, facilitating useful reconstructions of past diet. Among the GSL Fremont, economic strategies vary over time with an initial increase in reliance on maize (A.D. 400-850) followed by a period of marked economic diversity (A.D. 850-1150) then a return to reliance on wild foods (after A.D. 1150). During the period of greatest economic diversity, male and female diets vary significantly and male diets are correlated with status differences evidenced by grave goods. There is also a clear temporal correlation between the rapid abandonment of maize agriculture and significant moisture anomalies in regional tree ring chronologies and pollen profiles. These results are discussed in the context of recent arguments regarding economic diversity, social complexity and the demise of the Fremont.

Spanish Abstract. Los estudios que estan registrados aqui estan formulados de los isótopos stables (^{13}C , ^{15}N) y radiocarbono química de los entierros de los pantano del orilla este del Lago Salado. El proteina de los huesos de los isótopos estables cambia de acuerdo con la cantidad de maize y proteina animala que estaba disponible, haciendo posible averiguar los dietos del pasado. Entre los Fremont de Lago Salado las estrategias economicas cambian con tiempo dependiente en la aumetación de maize (A.D. 400-850) y despues una diversidad econmica (A.D. 850-1150) y de allí un regreso a las comidas silvestres (despues de A.D. 1150). Durante el periodo de la mayor diversidad, las comidas de los hombres y de las mujeres varian mucho y lo que comieron los hombres tiene mucho que ver con su estado social mostrado con lo que se encuentra en las tumbas. Tambien hay una correlación temporal entre el abandonamiento del sembrar maize y el registro de los anillos de los arboles yel perfil polen. Se habla de estos resultados en un contexto respecto a la diversidad economica, complejidad social, y el fin de los Fremont.

On September 18, 1776, the Domínguez-Escalante expedition crossed the northern Colorado Plateau at the foot of the Uinta Mountains in northeastern Utah. Father Escalante made the following entry in his journal: "We continued upstream along the (Río de San Cosme [Duchesne River]), and after going west one league we saw ruins near it of a very ancient pueblo where there were fragments of stones for grinding maize, of jars, and pots of clay. The pueblo's shape was circular, as indicated by the ruins now almost completely in mounds" (Warner 1976:47). Father Escalante had come upon a Fremont residential site.

The Fremont cultivated maize in the eastern Great Basin and on the northern Colorado Plateau between ca. A.D. 400-1350 (Jennings 1978) practicing subsistence strategies difficult to characterize with a uniform set of traits (see Janetski 1998; Madsen 1989; Madsen and Simms 1998; Marwitt 1980; Spangler 1995). Fifty years after Morss (1931) recorded the first Fremont site, Marwitt (1980:9, 12) wrote:

It is a striking but sad fact that the many man-years that we and others have spent in the field and the laboratory, and the hundreds of thousands of dollars of other peoples' money expended by archeologists in studying the Fremont have so far produced very little in the way of agreement on the nature of the prehistoric phenomena we have been dealing with... We cannot agree on cultural origins, chronology, the kind and amount of internal cultural variation, subsistence and land-use patterns, external cultural relations, or the ultimate fate of the human societies we are studying. Nor do we even have a standard terminology for the cultural complex we are investigating. These are all fundamental requirements for coherent archeological reconstruction.

Two decades have brought significant progress. In particular Simms has argued for economic or "adaptive" diversity (Simms 1986, 1990; Simms and Bright 1997); work in Clear Creek Canyon has drawn attention to Fremont social complexity (Janetski 1998; Janetski and Talbot 1995:363-382) and the demise of Fremont farming has been extensively debated (Bettinger 1994; Bettinger and Baumhoff 1982; Madsen and Rhode 1994; Simms 1983,

1990, 1994; Young and Bettinger 1992). Nonetheless, the issues Marwitt raised are not resolved, those surrounding the abandonment of farming in particular; and work cited above raises an additional set of questions regarding the relationship between economic diversity and social complexity. Here we use the isotope signatures of dated burials from the Great Salt Lake (GSL) wetlands to explore the temporal relationship between reliance on maize, gender and socio-economic status. The GSL mortuary assemblage is well-suited for this purpose since it spans the transition from maize farming to foraging and represents a local Fremont population with unexpectedly high levels of social and economic complexity.

The Fremont Archaeological Complex

The Fremont complex is commonly distinguished from preceding Archaic and subsequent Late Prehistoric foragers by material culture, settlement pattern and site structure. Stone balls and bone and stone gaming pieces, deer-hock moccasins (Aikens 1970:103-109) and unfired trapezoidal figurines (Jennings 1978) are unique to the Fremont. Ceramics are primarily plain grayware but may include painted black-on-gray and occasional red varieties as well as corrugated and incised styles (Jennings 1978). One-rod-and-bundle basketry is typical (Adovasio 1980). Ground stone is pervasive and the bow and arrow was in use from the beginning of the Fremont era (see Madsen and Simms 1998 for a review). Fremont residential sites cluster at 1500-1800 m on alluvial fans and stream terraces along the eastern Great Basin/northern Colorado Plateau rim (Figure 1). They are commonly located in sage/pinyon-juniper transition zones, on deep alluvial soils, where valleys grade into upland foraging areas and the frost-free season approximates 120

days (Lindsay 1986:Figure 3; Talbot 1995). The Fremont also farmed above wetlands north and east of the GSL (Aikens 1966, 1967; Fawcett and Simms 1993; Fry and Dalley 1979; Shields and Dalley 1968; Simms et al. 1991), at Baker and Garrison, two well-watered drainages along the central Utah/Nevada border (Taylor 1954; Wilde and Soper 1999), in the Uinta Basin (Ambler 1966a, b; Spangler 1995), on the Tavaputs Plateau (Spangler 1995) and along Green and Colorado River drainages (see Spangler 1995; Talbot 1995 for reviews).

Limited aerial exposure and early emphasis on artifact collection led to the inference that Fremont farming bases were typically small, politically isolated communities of fewer than six co-occupied pit houses and less than 25-30 residents (Jenning 1978; Sammons-Lohse 1981; see also Gilman 1987).

There is very little evidence that the basic unit of labor and subsistence activity superseded the household itself or that political, religious or social functions integrated these households consistently... [T]he recurring Fremont community pattern was the small, self-sufficient household unit consisting of one to three dwelling structures, and associated storage facilities, hearths, pits, and outdoor work areas (Sammons-Lohse 1981:135).

Larger, more complex sites were thought to be rare, often attributed to reoccupation of the same location by one or two households (e.g., Madsen 1989:31; Sammons-Lohse 1981:134). Sammons-Lohse nicely summarizes conventional views on Fremont social complexity; however, recent work in Clear Creek Canyon (Figure 1) suggests that these views are an oversimplification (Janetski and Talbot 1995:363-382; Talbot 1995:295-330). After ca. A.D. 900 in well-watered locations along the Basin/Plateau rim, dispersed households appear allied with larger population centers some with ceremonial structures and communal storage (Talbot 1995). Five Finger Ridge in Clear Creek Canyon meets the

criteria for a population center with a jacal "integrative" structure, spatially aligned, above-ground storage features and 37 pit houses, half of which were occupied between A.D. 1250-1300 (Janetski 1998:42-43; Talbot 1995:295-330; Talbot et al. 1995, Vol. 4). Janetski and Talbot (1995:365) conclude that during the main occupation "several groupings of closely affiliated households...are apparent" and suggest "these supra-household groups were united as a community under some form of controlling sociopolitical organization." Nawthis Village (Metcalf 1984:30) appears to meet these criteria as well with more than 50 structures grouped to suggest "intra-site spatial organization may be much more complex than the simple spatial isolation of household units" (Jones and Metcalfe 1981:25). In 1872 a member of the U.S. Geographical Survey sighted 400-500 mounds in the Parowan Valley, most plowed over by the turn of the century (Judd 1926). Brigham Young's (1851) estimated of 120 mounds is more conservative (cited in Talbot 1995:313); yet either report calls into question the argument that individual Fremont households functioned as autonomous political units. Surface adobe structures also appear late in the Fremont sequence, some with multi-room floorplans reminiscent of Anasazi room blocks (Nawthis Village [Metcalf 1984]; Baker [Wilde 1992; Wilde and Soper 1999]; Garrison [Taylor 1954]; Round Spring at Hogan Pass [Metcalf et al. 1993]; see also Wormington 1955).

Fremont Subsistence Strategies

In 1924 Kidder labeled Utah the "Northern Periphery" (Kidder 1927:489). By implication the Fremont derived from a Southwest culture base but exhibited less social complexity and relied more on wild foods than the Anasazi. After World War II, Fremont archaeology became

distinct from work in the Southwest resulting in development of a local paradigm that considered the Fremont an indigenous development and divided the study area into five regional variants based primarily on material culture (Ambler 1966b; Marwitt 1970). Maize agriculture was a defining element of all but the GSL variant (Marwitt 1970:147). This view persisted until the mid-1970s when flotation and palynology techniques were introduced. As researchers began to recover diverse assemblages of wild plant and pollen taxa from residential bases (e.g., Metcalfe 1984), they questioned the importance of maize. In particular at Backhoe Village on the Sevier River, pollen profiles rich in cattail (*Typha latifolia*) and sparse in maize led to the conclusion that wetlands resources supported riparian village settlements in the eastern Great Basin (Madsen 1979, 1982; Madsen and Lindsay 1977). More recently, Simms (1986; Simms and Bright 1997) has made a compelling argument for adaptive diversity contending that Fremont groups practiced fluid subsistence strategies contingent upon local conditions. Some relied heavily on maize while others were less invested in farming and some lived on wild foods. A recent stable isotope study with burials from residential sites outside the GSL Basin, herein designated the "village" study, shows that sampled Fremont relied as heavily on maize as aboriginal farmers at Mesa Verde, CO, Pecos Pueblo, NM, or Grasshopper Pueblo, AZ (Table 1), (Coltrain 1993, 1997; Coltrain and Stafford 1999). However, the Fremont "village" sample is small (n=13), comprised of individuals from residential sites or salvage sites with residential midden, and may not represent the full range of Fremont economic activities south of the GSL Basin.

Demise of the Fremont

An equally long-standing debate focuses on the wide-spread abandonment of Fremont farming sites between A.D. 1150-1350. Some argue that Numic-speaking foragers from Death Valley expanded north and east across the Great Basin after A.D. 1000 (see Madsen and Rhode 1994 for reviews). Allegedly practicing more efficient foraging strategies and equipped with seed-beaters which increased yields, the Numa were thought to have out-competed the Fremont, replacing or absorbing them (Bettinger 1994; Bettinger and Baumhoff 1982; Young and Bettinger 1992). The Numic expansion hypothesis derives from linguistic evidence for the relatively recent arrival of Numic-speaking people in the study area (Fowler and Fowler 1972; Lamb 1958; Miller 1966; Miller et al. 1971; but see Goss 1977; Shaul 1986) and is supported by arguments regarding the economics of food acquisition and mechanics of population replacement as noted above. Yet, temporal estimates of linguistic divergence are not well-substantiated (Lamb 1958; see also Grayson 1994; Simm 1983; Thomas 1994); Numic speakers may have been present in the western Great Basin as early as 5000 B.P. Correlations between material culture and linguistic affiliation are also unclear (Grayson 1994; Simms 1994; but see Adovasio and Pedler 1994; Reed 1994) and the archaeological record mitigates against the notion that Fremont economic strategies were uniform across the region and thus would have been uniformly impacted by Numic expansion (Simms 1990).

An alternative hypothesis for the abandonment of farming appeals to deteriorating climate and was proposed as early as the 1950s (Hunt 1953; Rudy 1953; Wormington 1955). Thirty years later, Lindsay (1986) showed that Fremont farming bases were located at a relatively uniform elevation and argued that the Fremont were balancing available moisture

against an adequate frost-free season. Given this pattern, he reasoned that reduced summer moisture and a shortened growing season forced the Fremont to abandon agriculture. Although Lindsay's argument was flawed by circularity, it has been supported by two more recent palynological studies (Newman 1988, 1996). These indicate Fremont maize agriculture coincided with a relatively brief period of elevated temperature and increased growing-season moisture resulting from the intrusion of summer monsoons northwest of their historic boundary, coincident with the Medieval Warm Period (Broecker 2001; Stine 1994; Whitlock and Bartlein 1993). Janetski (1994) presents a lucid discussion of these issues, arguing that a mosaic of economic strategies existed along the eastern Great Basin rim north of Utah Lake. Each would have been affected differently by decreasing summer moisture at the end of the Medieval Warm Period, presenting a varied set of opportunities for foragers on the periphery to occupy Fremont farming sites.

In sum, although the Fremont have been recognized as an archaeological complex for more than half a century, researchers do not fully understand the nature or extent of Fremont social or economic complexity nor are they in agreement regarding the abandonment of farming. The Fremont complex engaged in a lengthy but ultimately unsuccessful experiment with aboriginal maize farming at its elevational and drought-tolerance limits leaving what has proven to be a confusing material record.

The Great Salt Wetlands Mortuary Assemblage

Prior to European contact, extensive wetlands lined the eastern margins of the GSL from Salt Lake City north to Brigham City. Hundreds of archaeological sites have been recorded in the wetlands. The GSL

burial assemblage contains 86 individuals recovered in the early 1990s from state lands immediately south of Willard Bay (Figure 3). Excavation and osteological analyses of the collection are reported in detail elsewhere (Fawcett and Simms 1993; Owsley et al. 1996; Simms 1993; Simms et al. 1991). Fifty burials were accelerator radiocarbon dated and analyzed for stable carbon and nitrogen isotopes (Coltrain 1997, 2001; Coltrain and Stafford 1999). The remaining 36 were either too fragmentary or degraded for analysis. The study also includes four burials from Willard (42B030) and Warren Mounds (42B076) immediately east of the wetlands and three individuals from a salvage site in the Jordan River delta (42SL197) (Figure 2). Here we briefly review wetlands skeletal pathologies; similar data on Warren, Willard and 42SL197 burials are not available. This is followed by a very brief description of Willard Mounds and 42SL197, a more detailed account of wetlands site structure and a review of other Fremont sites in the GSL wetlands. Warren Mound was never formally excavated.

Wetlands Skeletal Pathologies

Skeletal pathologies were evident in 40 of 86 individuals recovered from the wetlands (Table 3; Bright and Loveland 1999; Fawcett and Simms 1993; Owsley et al. 1996; Simms et al. 1991). Degenerative joint disease was common in adults over 30 and extreme dental wear was observed in adults over 40 and a subset of younger individuals. Mastoid infections were prevalent and evidence of nutritional stress was common. Transverse lines were evident on the long bones of 23 individuals; three subadults exhibited cribra orbitalia and enamel hypoplasia was present in four cases. Altogether 33 percent of the skeletal population exhibited one or more symptoms of nutritional stress. (Note also, the

latter two conditions are likely underrepresented since less than half the collection was recovered with crania.) Eight individuals suffered stress related or traumatic injuries.

Wetlands Site Structure

Early in the last century Judd (1917:119) wrote, "The mounds still visible at Willard have been much plowed over... Of the dozen or more mounds noted twenty years ago...only one remained in the spring of 1915 in a comparatively undisturbed condition." He exposed a circular pit structure with wooden support members and interior hearth, faunal bone, plain and corrugated ceramics, Utah metates and lithics "common to nearly all prehistoric sites in the Southwest" (Judd 1917:119-120). Twenty-five years earlier MaGuire had collected "considerable quantities" of maize from the site for the Columbian Exposition (Judd 1926:5). 42SL197 burials were recovered from backhoe fill at a construction site along a relic channel in the Jordan River delta. Fill associated with the remains contained ceramic sherds, a mano and metate, worked bone and bison (*Bison bison*), deer (*Odocoileus hemionus*), muskrat (*Ondatra zibethicus*), waterfowl, and fish remains (Schmitt et al. 1994).

The GSL mortuary collection was excavated during the spring and summer of 1990, fall of 1992 and early summer of 1993, after the lake receded to 4203 feet from a record high-stand of 4212 feet reached in 1987 (Figure 2). Receding floodwaters stripped vegetation and eroded soils along the lake's shallow eastern shoreline creating a desiccated mud flat scattered with artifacts and human remains exposed to weathering and vandalism. Sites were visible as dense, raised aggregates of organic waste and site density approached 30 per square mile (Simms et al. 1991:26). Repeated episodes of erosion made analysis

of burial contexts difficult. With one notable exception discussed below (42WB324), individuals appear to have been interred singly in shallow pits with few if any grave goods.¹ Most burials were associated with temporary campsites identified by storage or refuse pits, blackened, shallow activity areas, ash stains, postholes, extramural hearths and midden. Artifact assemblages were primarily surface finds, charred and uncharred shell and faunal bone, projectile points from both the Fremont and Late Prehistoric periods and large assemblages of lithic debris, ground stone, worked bone, ceramic sherds and camp rock transported from higher elevations.

In striking contrast to ephemeral campsites, 42WB324 (Figure 3) contained 11 individuals resting on or immediately above an ashy lens of burned bulrush 4.5 m in diameter. The effects of erosion made it difficult to reconstruct burial events; however the earliest dates to A.D. 668, the most recent to A.D. 1127, and early and late burials do not overlap at 2 sigma (Table 2). Equally striking are numerous grave goods recovered from the lower stratum of the site, one complete and one fragmentary projectile point, bifaces, scrapers, lithic debitage, ground stone, bison horn, and worked bone: awls, fish hooks and gaming pieces (Simms et al. 1991:44-52). Excavators found no evidence for structures, hearths or storage facilities (Simms et al. 1991:44-50).

An additional 11 burials were recovered from three sites with structural components. The southeast corner of 42WB32 (Figure 3), the most thoroughly investigated of the three, contained a shallow pit house with interior, adobe-rimmed hearth and evidence for a surface structure with wattle-and-daub foundation (Simms et al. 1991; Fawcett and Simms 1993). This section of the site lines the eastern bank of relic Injun

Creek and is slightly higher in elevation than use areas lying to the west closer to the lake (Fawcett and Simms 1993:Figure 22). A large faunal collection was dominated by muskrat, large mammals, fish and medium-sized waterfowl. Most were neither burned nor displayed cut marks; but numerous muskrat and bird long-bone shafts had been broken for marrow (Fawcett and Simms 1993:209). Pit structures in outline were visible at 42WB48 (Simms et al. 1991:29); and 42WB185 has evidence for a substantial structure in the form of adobe blocks embossed with log impressions 10 cm in diameter (Simms et al. 1991:33).

In the mid-1960s Aikens (1966) excavated a cluster of 17 low mounds approximately 1.3 km south of 42WB32, also along the eastern bank of Injun Creek. He identified several storage/refuse pits and extramural hearths, three "pole and mud" structures (Aikens 1966:15) and a rectangular, surface adobe storage unit. Aikens (1966:14) argued that Injun Creek was occupied year-round by Fremont "horticulturist-hunters" who subsisted on maize, wetlands plants and small and large mammals. Although no plant materials were recovered, given the prevalence of ground stone he concluded that maize had been grown on or near the site. Six relatively undisturbed burials, four with grave goods (sherds, bone beads, and ground stone) were also recovered.

Bear River 1 and 2 (Aikens 1966, 1967), the Knoll site and the Levee site's early component (A.D. 400-1000) (Fry and Dalley 1979) are similar to Injun Creek (Figure 2). The late component at Levee contains three rectangular, adobe-walled pit houses, hearths and subfloor storage. At Bear River 3, maize and six pit houses with interior hearths were identified (Shields and Dalley 1978). Muskrat, microtine

rodents, waterfowl, fish and bison (*Bison bison*) dominated faunal assemblages (Harper 1967; Lupo and Schmitt 1997:Table 3).

Methods

The bone collagen stable isotope techniques described below monitor variation in reliance on maize and intake of animal protein among the 57 individuals whose diverse burial contexts have been reviewed. In addition to AMS dating, the collection has been aged and slightly over half are sexed providing a temporally diagnostic record of differences in diet and their relationship to age-at-death, status and gender.

Stable Carbon Isotope Analysis

Stable carbon isotope analysis of skeletal remains monitors the relative abundance of carbon-13 to carbon-12 ($^{13}\text{C}/^{12}\text{C}$) in bone collagen or the hydroxyapatite of bone or tooth enamel (see Pate 1994 for a review). The ratio of $^{13}\text{C}/^{12}\text{C}$ is expressed in delta (^{13}C) notation as parts "per mil" (‰), or parts per thousand difference from PDB, an internationally recognized standard², and covaries with maize intake in New World terrestrial economies (e.g., Decker and Tieszen 1989; Spielmann et al. 1990; Vogel and van der Merwe 1977). Maize is a warm-season grass that uses a C_4 (Slack-Hatch) photosynthetic pathway to metabolize atmospheric CO_2 (Peisker and Henderson 1992). C_4 photosynthesis evolved early in the Miocene as an adaptation to reduced atmospheric CO_2 concentrations and is found primarily in tropical and subtropical grasses where daytime growing-season temperature exceeds 22°C and precipitation exceeds 25 mm (Ehleringer et al. 1997). Cool-season grasses and greater than 99 percent of the dicots, including virtually all trees and most shrubs and herbaceous plants, employ a C_3

(Calvin) pathway discriminating heavily against ^{13}C during photosynthesis (O'Leary et al. 1992). Structural and enzymatic properties of the C_4 pathway result in less discrimination, increasing the ratio of $^{13}\text{C}/^{12}\text{C}$ in C_4 plant tissues. Because discrimination is tightly correlated with plant type (Smith and Epstein 1971), C_3 and C_4 plants have discrete ^{13}C means and ranges as follows:³ C_3 plants, -26.7 ± 2.7 per mil (n=370); C_4 grasses, -12.5 ± 1.1 per mil (n=455) (Cerling et al. 1998:Figure 3).⁴ These values are passed up the food chain leaving a diagnostic signature in the tissues of consumers and do not covary with the skeletal element analyzed or sex of the sample, independent of differences in feeding ecology (Hobson and Schwarcz 1986; Lovell et al. 1986).

^{13}C is measured on a light isotope ratio mass spectrometer and computed as follows.

Equation 1:

$$^{13}\text{C} = \frac{R_{\text{sample}} - R_{\text{standard}}}{R_{\text{standard}}} \times 1000 \text{ ‰}$$

where $R = ^{13}\text{C}/^{12}\text{C}$

Recent Interpretive Issues

In the past, researchers assumed that bone collagen ^{13}C values were an unbiased indicator of C_4 intake, recording the percent of C_4 foods in sampled diets with a standard fractionation offset of +5 per mil (but see Krueger and Sullivan 1984). However, research in the early 1990s with rodents fed controlled diets indicated that bone collagen ^{13}C was biased by the isotope signature of dietary protein and the carbonates in bone apatite were a better predictor of overall diet (Ambrose and Norr 1993; Tieszen and Fagre 1993a). In archaeological assemblages, bone apatite is readily contaminated; but carbonates in the

apatite of tooth enamel retain their diet signal (Cerling and Harris 1999; Cerling et al. 1997a, b; MacFadden et al. 1996; Wang and Cerling 1994).

When the GSL wetlands collection was sampled, we were unaware of the possible advantages of analyzing carbonates in tooth enamel. Since then the collection has been re-interred. However, there is good reason to believe that collagen ^{13}C values are also diagnostic of maize consumption among prehistoric farmers with low-to-moderate levels of animal protein intake (Schwarcz 2001). Non-essential amino acids (neAAs) occupy two of three positions in collagen amino acids chains; and collagen ^{13}C is relatively tightly correlated with the isotope signature of carbon used in their synthesis. If intake of animal protein is adequate to supply all essential and neAAs amino acids used in collagen synthesis, the carbon isotope ratio of bone collagen will reflect that of dietary protein (Schwarcz 2001). However if protein intake is not adequate, as among maize farmers with skeletal evidence for nutritional stress, the energy component of the diet will supply carbon for amino acid synthesis and bone collagen will more closely reflect the isotope signature of total diet. In these cases, collagen ^{13}C values should provide an integrated record of adult diet over three decades. Bone collagen turns over slowly requiring ca. 30 years to replace existing carbon with an equivalent amount of carbon (Stenhouse and Baxter 1977, 1979:333; see also Harkness and Walton 1972, and Libby et al. 1964).

Nitrogen Isotope Analysis

Stable nitrogen isotope analysis follows from the understanding that $^{15}\text{N}/^{14}\text{N}$ increases by approximately 3 per mil each step up the food chain. Since heavy urea is discriminated against at renal membrane boundaries, ^{14}N is excreted and ^{15}N retained for protein synthesis

(Ambrose and DeNiro 1986). Most terrestrial plant taxa obtain nitrogen from soil ammonium (NH_4^+) or nitrate (NO_3^-) and have mean ^{15}N values of ca. 3-6 per mil with a 0-9 per mil range contingent upon temperature and aridity (Pate 1994). Herbivores in temperate climates typically exhibit ^{15}N values of 6-9 per mil, while arid-land species and non-obligate drinkers, those that recycle urea, reflect their water-conservation strategies in more positive ^{15}N values (Ambrose 1991). Rodents practicing coprophagy may also exhibit elevated ^{15}N values. Conversely, nitrogen fixing plants like legumes, and plant taxa in association with mycorrhizae, nitrogen-fixing fungi in the biological crust of arid soils, have mean ^{15}N values of 1 per mil, with a -2 to 2 per mil range (Evans and Ehleringer 1994; Pate 1994).

The ratio of $^{15}\text{N}/^{14}\text{N}$ is expressed in delta notation, computed as shown in equation 2 and is typically a positive value since atmospheric nitrogen is the standard at 0 per mil.

Equation 2:

$$^{15}\text{N} = \frac{R_{\text{sample}} - R_{\text{standard}}}{R_{\text{standard}}} \times 1000 \text{ ‰}$$

where $R = ^{15}\text{N}/^{14}\text{N}$

Procedures

Laboratory procedures are reported in Coltrain (1993; 1997) and Coltrain and Stafford (1999). Briefly, wetlands samples were demineralized in 0.6N HCl, base extracted with 5 percent KOH, lyophilized to obtain collagen yields then gelatinized and filtered. The water-soluble filtrate was again lyophilized then combusted. CO_2 and N_2 were collected off-line by cryogenic distillation and analyzed for stable isotopes against the appropriate reference gas on a Finnigan Delta S mass spectrometer at the Stable Isotope Research Facility for Environmental Research at the University of Utah. A second aliquot of

CO₂ was graphitized and graphite forwarded to Lawrence Livermore National Laboratory for accelerator radiocarbon measurements. Similar procedures were followed with faunal material; however, protein was combusted on a Carlo Erba EA1108 CHN elemental analyzer and analyzed for stable isotopes on a Finnigan MAT 252 Conflow mass spectrometer.

Results

Radiocarbon dates and stable isotope values for wetlands burials (n=57) are shown in Table 2 and Figure 4. Protein preservation was evaluated by whole-bone percent nitrogen, atomic carbon to nitrogen ratios and collagen yields (Table 2). All whole-bone samples contained or exceeded .4 percent nitrogen by weight (Petchey and Higham 2000; Stafford et al. 1990). Atomic C/N ratios for all samples for which we have data fell within the 2.9 to 3.6 range indicative of adequately preserved bone collagen (Ambrose 1990) and all but one sample, Burial 37⁵, produced collagen yields of 4.5 percent or greater. Analytical precision is ± .2 per mil in ¹³C and ± .3 per mil in ¹⁵N. Paired ¹³C measurements on six randomly chosen samples produced a mean sigma of ± .17 per mil. Paired ¹⁵N measurements (n=37) produced a mean sigma of ± .20 per mil.

Isotopic and Temporal Variation in Diet

Wetlands carbon and nitrogen isotope ratios are inversely correlated and covary with five monitored variables: radiocarbon age, sex, age-at-death, skeletal robusticity and skeletal pathology. The relationship between C₄ intake and radiocarbon age and C₄ intake and protein consumption, sex and age-at-death are summarized here (see also Coltrain and Stafford 1999) and elaborated upon in the discussion section. Remaining variables are treated solely in the discussion section. Burials from 42SL197 and Warren and Willard Mounds are dated

but not sexed or aged reliably and are included in the analysis of temporal variation in diet only.

The GSL wetlands collection dates from cal A.D. 423-1410 with a calibrated 2 sigma range of A.D. 252-1442. Before ca. A.D. 1150, individuals exhibit a wide range of stable carbon isotope values (-19.8 to -10.0 per mil). After A. D. 1150, ^{13}C is uniformly depleted in ^{13}C (< -17.2 per mil) (Table 2, Figure 4). Burials from Warren and Willard Mounds that date before A.D. 1150 (n=3) have ^{13}C values at the upper end of the wetlands range (i.e., > -14.0 per mil). The remaining Willard burial (Fs 1/108) dates to A.D. 1295 \pm 60 and has a ^{13}C value of -18.0 per mil, consistent with depleted ^{13}C in individuals dating late in the sequence. Calibrated intercept dates plotted without sigmas segregate ^{13}C values into three distributions (Figure 4 and Table 4). Accordingly, we have divided the temporal span of the study into three periods to illustrate general trends and transitions in GSL Fremont diet.

During Period I, ca. A.D. 400-850, diets become increasing enriched in ^{13}C indicating growing reliance on C_4 foods (Figure 5). Although sample size is small, the relationship between radiocarbon age and ^{13}C is significant at $p=.0412$ ($F=5.484$; $df=11$). In Period II, A.D. 850-1150, both the range of isotope values and variability within that range increase. However, all high C_4 diets terminate at or before A.D. 1168; whereas the upper 2 sigma range of one mixed (Burial 16) and several low C_4 diets are younger in age (Table 2, Figure 5). During Period III, after A.D. 1150, ^{13}C values are uniformly depleted in ^{13}C . Slight deviation from the mean (Table 4) indicates sampled individuals ate isotopically similar diets, significantly different from mean diets in preceding periods (Period I: $t=5.339$, $df=11$, $p=.0002$; Period II: $t=3.655$, $df=12$, $p=.0033$).

Nitrogen isotope ratios range from 4.3 to 15.4 per mil with a mean of 12.0 ± 1.8 per mil. Period means approach or are within analytical precision of each other (Table 4). Individuals with ^{15}N values above 15 per mil are nursing infants between the ages of 6 months and 3.5 years (Burials 35, 36, 69). The collection also contains one weaned infant 1.5-2.5 years in age (Burial 11). Dating to A.D. 1263 with $^{15}\text{N}=11.9$ per mil and $^{13}\text{C}=-17.2$ per mil, the child appears to have been nursed briefly and weaned early onto a diet of wild foods. A young adult male (Burial 49) and one unsexed adult (Burial 73), both dating to Period II, have extremely low ^{15}N values, 4.4 per mil and 4.3 per mil respectively. Depleted ^{13}C (-19.2 per mil, -19.8 per mil) indicates they ate little if any maize and are unlikely to have had long-term access to legumes, nitrogen fixing cultigens with ^{15}N values near 0 per mil. Their unusually low nitrogen isotope ratios indicate they were not indigenous to the GSL Basin but foraged in a more arid region where pinyon (*Pinus monophyla*) or acorn (*Quercus* sp.) and perhaps tubers, in association with mycorrhizae, made up a significant component of their diets.⁶ ^{15}N values for remaining individuals fall between 10.5 and 14.4 per mil and are inversely correlated with ^{13}C . Whether nursing infants are included or excluded the relationship is significant at $p=.0170$ ($F=6.079$; $df=53$) and $p=.0243$ ($F=5.403$; $df=50$) respectively (Figure 6).

Sexual Variation in Diet

Twenty-six individuals from the GSL wetlands collection are sexed⁷ (Table 2; Fawcett and Simms 1993; Owsley et al. 1996; Simms et al. 1991). Within this subset (Table 6, Figure 7), mean male ^{13}C is -14.4 ± 3.5 per mil ($n=14$), significantly more positive than the female mean, -17.6 ± 1.1 per mil ($n=12$), ($t=-2.667$; $df=11$; $p=.0219$). The standard deviation for males is more than three times that of females and the range more than double. However, mean male and female nitrogen

isotope ratios are within analytical precision at $12.3 \pm .6$ and $12.4 \pm .8$ per mil respectively.

Diet and Age-at-Death

Forty-nine individuals are assigned an age category (see Table 2; Fawcett and Simms 1993; Owsley et al. 1996; Simms et al. 1991), and mean intake of C₄ foods appears to correlate roughly with age (Table 7, Figure 8). Infants (0-5 years) have the most negative ¹³C readings; adults over 45 exhibit the opposite trend. However, goodness of fit is low ($r^2=.425$) and the relationship between age at death and diet is not significant ($F=2.96$; $df=5$; $p=.1605$). Error bars illustrate marked deviation from the mean for all but the youngest age category. When individual data points are plotted, r^2 drops to .022. However, pair-wise comparisons in ¹³C indicate that diets in Categories 2 versus 3, 2 versus 5 and 3 versus 5 are statistically similar at $p<0.1$ (*Dunnett* $t=.046$, $.039$, $.077$ respectively). We do not calculate mean ¹⁵N values by age category given the lack of significant differences in ¹³C by age category and the absence of variation in ¹⁵N by temporal period (Table 4) and sex (Table 6).

Plant and Faunal Stable Isotope Ratios

Forty-nine plant specimens were analyzed for stable isotopes (Table 5). Kernels from six varieties of modern, commercially-grown aboriginal maize have mean carbon and nitrogen isotope values of -11.0 ± 1.0 and 3.1 ± 2.0 per mil respectively (Table 8) and are slightly depleted in ¹³C relative to archaeological samples due burning of fossil fuels. Mean values for charred archaeological maize from Fremont sites in the eastern Great Basin and uncharred archaeological maize from sites in southeastern Utah are listed in Table 8. Elevated ¹⁵N in maize from southeastern Utah suggests crops were fertilized with human or turkey manure. Modern, wild C₄ plants have a mean ¹³C of -12.1 ± 1.2 per mil

and ^{15}N of 7.0 ± 4.2 per mil. Extremely high ^{15}N values for barnyard grass probably result from the use of fertilizers. Modern C_3 plants have a mean ^{13}C of -25.6 ± 2.1 per mil and ^{15}N of 4.7 ± 2.5 per mil. Here variability in ^{15}N is a function of soil ^{15}N and, in *Quercus*, the presence of mycorrhizae. Four modern tubers expressed even more negative mean ^{13}C values (-26.8 ± 1.5 per mil) and ^{15}N readings ($-.5 \pm 2.9$ per mil), again indicating the presence of mycorrhizae.

Twenty-three faunal specimens from Injun Creek (42WB34) were analyzed for stable isotopes (Table 5). Large mammals excluding bison exhibit mean carbon and nitrogen isotope values of $-19.9 \pm .5$ and 7.2 ± 1.2 per mil respectively (Table 8) showing a virtual absence of C_4 forage. (Prehistoric C_3 plant ^{13}C averages -24.5 per mil; fractionation between herbivore forage and bone collagen ^{13}C is ca. $+5$ per mil.) Sixteen bison from five Fremont sites in and adjacent to the GSL wetlands have mean carbon and nitrogen isotope values of $-19.0 \pm .8$ per mil and $7.3 \pm .5$ per mil (Table 9) indicating a near-absence of C_4 grasses in bison diets as well. Enrichment of less than 1 per mil in bison relative to other large mammals indicates C_4 grasses made up less than 10 percent of bison forage. Large mammal ^{15}N values place grass and browse ^{15}N at approximately 4 per mil.

Small mammals have mean carbon and nitrogen isotope ratios of -20.3 ± 1.6 and 8.5 ± 2.8 per mil, again showing an absence of C_4 forage. Depleted ^{13}C and elevated ^{15}N in *Lutra canadensis* reflects a diet of fish and amphibians (Zaveloff & Collett 1988) and elevated rodent ^{15}N indicates coprophagy. *Microtus montanus* has a slightly elevated ^{13}C reading suggesting occasional access to maize stores. Waterfowl averaged -18.6 ± 2.8 and 10.3 ± 4.0 per mil. One *Branta* specimen and both *Anas* exhibit C_3 diets, while the remaining *Branta* may have intermittently gleaned in maize fields. Both genera are shallow

water foragers common to the Great Basin and occasionally graze terrestrially (Ryser 1985). *Pelecanus* ^{13}C (-17.1 per mil) provides a slightly enriched estimate (~1 per mil) of *Gila atraria*, Utah chub, the only shallow-water fish native to the GSL basin (Sigler and Sigler 1996) and probably an important source of protein, unlike the pelican itself. *Pelecanus* breed in large colonies on Gunnison Island in the GSL taking fish available within a meter of the surface (Ryser 1985). Catostomidae are bottom feeders as adults subsisting primarily on algae (Sigler and Sigler 1996) and show depleted ^{13}C and ^{15}N characteristic of C_3 aquatic plant diets. Finally, enriched isotope values in *Larus* sp. indicate the gull was an adept scavenger occasionally taking maize or insects, crickets, etc., feeding on maize.

Discussion

Variability in GSL wetlands diets is not in keeping with high maize diets at "village" sites outside the GSL Basin (Table 10) but accords well with Marwitt's (1970) early views on GSL Fremont subsistence, Simms' (1986) more recent argument for adaptive diversity and the presence of temporary campsites and residential bases in the wetlands. GSL burials fall into three categories representing real but not strictly categorical differences in diets: 1) individuals who consumed diets relatively high in C_4 foods (>-14 per mil, 2) those subsisting on mixed diets (-14 to -17 per mil and 3) those who subsisted on diets high in C_3 foods (<-17 per mil). Mean wetlands ^{13}C values (Table 11) are significantly different from each other and Fremont "village" diets at $p < .0001$ (Table 12). ^{15}N in each category is also significantly different from Fremont "village" diets; however there are no significant differences in ^{15}N between wetlands categories at $p < .05$ (Table 13). The lack of significance is somewhat surprising given the significant inverse correlation between wetlands ^{13}C and ^{15}N and is

likely influenced by sample size. Stable isotope readings for plants, fauna from Fremont assemblages and wetlands burials by category are graphed in Figure 9.

High C₄ Diets and Sex-based Variation

Individuals with ¹³C readings as or more positive than -14.0 per mil subsisted on diets relatively high in C₄ foods. Maize intake is the most parsimonious explanation for elevated ¹³C values given the near absence of wild C₄ plants (Table 14) in faunal and post-AD 1150 Fremont diets. Three additional lines of evidence support this argument.

- Burials with high ¹³C values were recovered from sites with evidence for maize cultivation. Willard burials dating before A.D. 1150 exhibit high ¹³C values consistent with early reports that Willard was a farming base (Judd 1917). Jordan River Burial 2 approximates a high C₄ diet but cannot be evaluated relative to its residential context. High C₄ diets were also associated with 42WB32 (n=1), 42WB48 (n=1), 42WB185 (n=1) and 42WB324 (n=5). With the exception of 42WB324, pit structures and other features indicative of residential bases are present at each of these sites, reviewed in an earlier section. The unique burial context and dietary patterning at 42WB324 are discussed below and are also indicative of farming.
- Evidence for nutritional stress is more common among individuals with high C₄ diets. Six of eight individuals with enriched ¹³C show signs of nutritional stress; whereas nutritional stress was evident in 45 percent of the remaining study population (see Table 3; Fawcett and Simms 1991; Owsley et al. 1996; Simms et al. 1991).⁸ The relationship between high C₄ diets and nutritional stress is consistent with the general expectation that New World maize

agriculturalists consumed less complete protein, suffering higher incidences of nutritional stress, than populations subsisting on wild resources.

- A negative correlation exists between three measures of long bone robusticity, bending, twisting and end-on rigidity, and high C₄ diets (Ruff 1999). In general, mobile lifestyles common to foragers increase mechanical loading on upper and lower limbs resulting in greater long bone robusticity in males in particular. More sedentary strategies common to agriculturalists result in less robust femora and humeri (see Ruff 1987, 1992, 1994; Ruff and Hayes 1983; Ruff et al. 1984). Among wetlands burials, high C₄ diets "...are associated with *decreasing* femoral and humeral robusticity, at least in males" (Ruff 1999:311, emphasis original). "A similar decline in relative mechanical loading of the limbs with the adoption of agriculture was found in Georgia coast samples [Ruff and Larsen 1990; Ruff et al. 1984]" (Ruff 1999:318). GSL burials with high maize diets are also significantly taller (Ruff 1999). Since six of eight individuals with high C₄ intake are male, the remainder unsexed, height differences may be a function of mild sexual dimorphism; whereas, diminished robusticity suggests reduced mechanical loading consistent with maize agriculture. Males with high C₄ diets may have foraged less frequently, transversed a flatter elevational gradient, or traveled shorter distances, foraging less intensively than individuals with mixed and C₃ diets.

Maize intake is the most parsimonious explanation for high C₄ male diets but adopting this position raises a number of issues. Sex-based differences of the magnitude exhibited by the GSL collection are unknown

in North American Formative populations although the scarcity of published studies that segregate diets by sex makes comparisons difficult. Ezzo (1993:Table 5.2) reports a significant difference, ignoring outliers, between males (-8.86 ± 0.76 per mil [n=19]) and females (-9.53 ± 1.25 per mil [n=18]) at Grasshopper Pueblo, AZ (A.D. 1275-1330), but the difference is less than 1 per mil. In contrast, forty Middle Mississippian burials showed no significant difference between male and female diets (Schurr 1992). Among the GSL collection, sex-based variation in diet is largely but not entirely driven by males from 42WB324. When 42WB324 burials are excluded from analysis, mean male ^{13}C (-15.9 ± 2.9 per mil) is similar to Period I and II population means (Table 15); yet the difference in male versus female diets remains significant ($t=-2.642$; $df=7$; $p=.0333$).

42WB324 males represent a special case distinguished by the co-occurrence of high C_4 intake, increased nutritional stress, reduced skeletal robusticity and a relatively elaborate burial context. The first three factors paired with elaborate interments indicate males with high maize diets may also have been high-status individuals, adding to a gradually accumulating body of mortuary data (e.g., Davis 1956; Dodd 1982; Madsen and Lindsey 1977) that "argues for the differential status of some adult males in Fremont communities" (Janetski and Talbot 1995:375). However, it is difficult to argue that high-status males simply ate more maize than females. Coltrain (2002) has suggested they consumed maize both as a dietary staple and ritual food in the form of maize beer, elevating their ^{13}C signatures accordingly. Pre-Inkan Peruvian burials analyzed for stable isotopes illustrate similar sex-based differences in maize intake attributed to consumption of beer

(Hastorf 1991; Hastorf and Johannessen 1993). The ethnographic and iconographic records indicate maize beer was an important ritual food in pre-Inkan society, and while women fermented beer, they seldom if ever engaged in feasting associated with its consumption (Hastorf 1991; Hastorf and Johannessen 1993; Moore 1989). Also note, if maize had both a ritual and dietary function, it would have had a corresponding social as well as economic currency enhancing its value relative to wild resources, bestowing prestige on males who dispensed it in exchange for labor, animal protein or political support.

High-status males do not exhibit low animal protein intake common to individuals relying heavily on maize as a dietary staple. They consumed significantly more animal protein than individuals in the "village" Fremont data set (Table 13) and their mean ^{15}N value is within .1 per mil of wetlands mixed diets and less than 1 per mil depleted relative to wetlands C_3 diets (Table 11). These comparisons suggest that ^{13}C readings of -15.0 to -16.0 per mil (see Table 4, 11) represent average reliance on maize and more enriched carbon isotope values are a function of additional consumption in the form of maize beer. Mean female ^{13}C (-17.6 \pm 1.0 per mil) remains depleted relative to average reliance on maize but may be in part influenced by slow turnover rates characteristic of adult bone collagen. If a subset of young females raised as hunter-gatherers joined farming households but died before their subadult carbon isotope signatures were fully replaced, their diets would appear mixed. Two females (Burial 3, 76) younger than age 40 were recovered from residential bases with a high C_4 burial and evidence for maize cultivation. Females may also have spent

more time collecting wild resources than males, consuming wild foods while foraging.

The approximate 3 per mil difference between male and female diets may also be influenced by sample bias. Although 52 percent of the study population is sexed, sexed individuals are not evenly distributed across the temporal span of the study. Three of four sexed burials dating to Period III are female. Were it possible to sex the entire Period III assemblage, a larger subset should be male and mean male ^{13}C values would decrease accordingly, narrowing the distance between male and female diets. This does not negate the presence of high-status males with high C_4 diets, but again suggests that sex-based differences in reliance on maize as a dietary staple may not be as great as statistical means indicate.⁹

Nitrogen isotope ratios among individuals with high C_4 diets average 11.8 per mil, approximately 4 per mil more enriched than mammals and 1.5 per mil more enriched than waterfowl suggesting that large and small mammals made up a slightly greater component of animal protein intake than waterfowl.

Mixed Diets

Individuals with ^{13}C readings between -17.0 and -14.0 per mil could have grown maize intermittently, taken waterfowl with occasional access to maize or traded animal protein or labor for maize to overwinter on. Maize and/or C_4 enriched animal protein probably made up between 25-50 percent of their diets. Their animal protein intake appears less than that of individuals subsisting on C_3 diets but greater than "village" Fremont and their ^{15}N values again indicate greater emphasis on large and small mammals than waterfowl.

High C₃ Diets

Individuals with ¹³C readings more negative than -17.0 per mil subsisted on diets high in C₃ plant and animal protein. Prior to A.D. 1150, these diets may have included small amounts of maize or waterfowl with access to maize. While not significant at p<.05, mean ¹⁵N is enriched relative to wetlands mixed and high C₄ diets reflecting higher protein consumption. Ruff's (1999) study and the general health of the skeletal population indicate that individuals with low C₄ diets engaged in more rigorous activities, likely spent more time foraging, and suffered less nutritional stress than those with high or moderate C₄ intake.

Diet and Age-at-Death

Children, subadults and adults between the ages of 25-45 consumed statistically indistinguishable, mixed diets. Infants, adults between 17-24 and those over 45 consumed diets significantly different from the preceding three age categories and significantly different from each other. Infant diets appear extremely low in C₄ foods; within group variation is minimal and negative ¹³C values are in accord with reliance on nursing females whose diets also appear low in C₄ intake. However, breast milk is high in lipids and lipids are depleted in ¹³C relative to other macronutrients (Tieszen and Fagre 1993b; see also Wright and Schwarcz 1998); thus infant isotope signatures may be biased by the high lipid content of breast milk (Oftedal 1984). Young adults and those over 45 consumed a higher percentage of C₄ foods than other age groups. In the 17-24 age category, this is driven by young males from 42WB324. In the >45 age group, older males have the highest ¹³C readings; although only one was recovered at 42WB324. The consumption

of maize beer may be making a contribution to elevated diets in these age categories.

Geographic Variation

Economic diversity in a geographic area as constrained as the GSL wetlands raises questions regarding the social mechanisms that maintained long-term differences in diet. High-status, high C₄ males may have exercised control over access to arable land and/or maize surpluses and maize beer, maintaining their economic and social standing through trade, ritual events or intimidation. Here the Fremont "village" data set provides an interesting counterpoint. Among "village" burials, all from residential sites outside the GSL Basin, grave goods are rare and diets are uniformly high in maize (Table 10). However, one adult male interred below the floor of an Evans Mound pit structure (Table 10:Fs1276.83) was buried with a great horned owl (*Bubo virginianus*), several magpies (*Pica pica*) and assorted lithic, bone and ceramic artifacts (Pecotte 1982). This unusually rich collection of grave goods suggests that status distinctions existed among Fremont males in village populations and that, unlike the wetlands, these distinctions were not necessarily maintained by differential access to maize. All "village" Fremont exhibit high maize diets.

Alternatively, economic diversity in the GSL wetlands, at the northwestern limits of Fremont agriculture, may have been maintained by the cost/benefit structure of foraging versus maize farming. Either wetlands foraging return rates (kcal/hr) were commensurate with farming or maize yields were less predictable than in areas south of the GSL Basin, deterring wholesale investment in agriculture. Again, the "village" data set provides a useful comparison. Smoking Pipe (Forsyth

1984) and Backhoe Village (Madsen and Lindsay 1977) are adjacent to wetlands lining the Provo and Sevier rivers respectively and burials from both sites exhibit high maize diets similar to the remainder of the "village" population. If farming in locations further south routinely yielded higher average caloric returns than foraging and invested farmers with status, maize cultivation would have been favored despite the proximity of riparian or lacustrine resource patches. Moreover, their proximity may have encouraged farming by dampening risk associated with crop failure.

Temporal Variation

The growing importance of maize during Period I coincides with a marked increase in the number of Fremont residential sites and a ten-fold increase in the frequency of Fremont radiocarbon dates across the eastern Great Basin (Talbot and Wilde 1989:Figure 2). Period II, coincident with the Medieval Warm Period, also coincides with the height of Fremont expansion south of the GLS Basin (Massimino and Metcalfe 1999; Talbot and Wilde 1989:Figures 2-4). Sites are larger and more numerous than any other time in Fremont history. Over half the GSL wetlands collection dates to this period and population growth is accompanied by increasing economic and social complexity. After A.D. 1150, farming ceases in and around the wetlands. The interior hearths of three pit houses at the Levee site (Fry and Dalley 1979) are last fired at ca. A.D. 1150 (Shuey 1979:106). Note also, the upper 2 sigma range of high C₄ burials terminates at A.D. 1168 (Figure 5). At approximately the same time, an equally striking reduction takes place in the frequency of radiocarbon dates from residential sites south of the GSL Basin (Talbot and Wilde 1989:Figures 2, 5).

The abandonment of farming among the GSL Fremont, coincident with wide spread abandonment of Fremont settlements elsewhere is commonly attributed to either Numic expansion or climatic deterioration. We favor the latter explanation for the following reasons: 1) Post-A.D. 1150 Fremont foragers exhibit diets common to the GSL wetlands unlike burials 49 and 73 whose diets are high in pinyon, acorn or tubers grown on arid soils. This suggests that the post-A.D. 1150 study population does not represent an influx of foragers from the western Great Basin or elsewhere in the arid west. 2) Climatic deterioration is evident in pollen and tree-ring chronologies discussed below and indicates the onset of drought or a shift from summer to winter dominated rainfall, perhaps preventing farming in some locations and curtailing it in others.

Climatic Deterioration

In the Southwest, maize cultivation is accompanied by rapid population growth and followed by deforestation, soil depletion and erosion leading to economic collapse (Redman 1999). By way of explanation, Redman cites Kohler (1992) who argues that after centuries of extracting nutrients, fuel and building materials from a fragile environment, Southwest economies were in precarious balance with their ecosystems and even moderate climatic perturbation resulted in abandonment of agricultural sites. In the GSL Basin, the transition from maize cultivation to a foraging economy is correlated with a negative moisture anomaly in tree-ring records from both the eastern and western rims of the Great Basin (Figure 10). Figure 11a shows wetlands radiocarbon dates at 2 sigma graphed against ^{13}C , clearly indicating the shift from maize to a diet of wild foods at ca. AD 1150. Figure 11b is

a ^{13}C pentad chronology from White Mountain bristlecone at 2880 m on the California/Nevada border, at the western rim of the Great Basin ($37^{\circ}23'\text{N}$, $118^{\circ}09'\text{W}$) (Leavitt 1994). The most positive ^{13}C value occurs at A. D. 1150 signaling the most arid period in the chronology, following a brief period of below average moisture.¹⁰ Figure 11c is a tree-ring width chronology from Wildhorse Ridge bristlecone pine at 2805 m on the Wasatch Plateau ($39^{\circ}25'\text{N}$, $111^{\circ}04'\text{W}$) (Graybill 1986). The narrowest ring in this sequence also occurs at ca. A.D. 1150 following approximately 25 years of below average moisture.

Western climate studies indicate the White Mountain and Wildhorse Ridge tree-ring records are correlated. Mitchell (1976) and Fritts (1991) place both sites in the same climatic region based on equivalent potential temperature and tree-ring width chronologies respectively. Other studies place both sites outside the modern monsoon boundary but within the summer precipitation limit (Davis 1994; Petersen 1994). Davis (1994) specifically argues for a northern summer precipitation boundary originating between the Cascade and Sierra Nevada mountains, stretching east across northern Nevada and the Great Salt Lake Basin, terminating in southwestern Wyoming.

Reconstructed drought maps from pinyon ^{13}C DEL indices¹¹ provide further support for the correlation between eastern and western Great Basin climate (Leavitt 1993). Drought contours were developed using a network of 14 pinyon sites with orthogonal cores from four trees per site (Leavitt and Long 1989a). Drought contours for the pentad 1930-1934 extend from east-central California to the eastern Great Basin rim with negative departures in moisture increasing in severity from southeast to northwest (Figure 12). Palmer Hydrological Drought Indices

mapped for the same period show a similar pattern of negative departures. Tree-ring ^{13}C drought contours for pentads 1950-1954 and 1900-1904 exhibit a like geographic pattern (Leavitt and Long 1989b). A statistical comparison of isotope drought indices over 81 pentads (1580-1980) for White Mountain, CA, bristlecone versus Gate Canyon, UT, pinyon ($39^{\circ}52'\text{N}$, $110^{\circ}13'\text{W}$) (Figure 10) shows a positive correlation at $r=.671$, significant at $p<.001$.

The Beef Pasture pollen record (Davis 1994), (Figure 11d) is additional evidence for widespread climatic deterioration. Beef Pasture is a grass and sedge meadow at 3060 m on the west slope of the La Plata Mountains in southwest Colorado. The abundance of pinyon pollen, as an index of summer moisture, decreases markedly at A.D. 1150. This coincides with fluctuations in crop yields reconstructed from tree-ring widths that indicate persistent shortfalls between A.D. 1146-1193, one of three periods of extensive famine during the southwestern Colorado Formative (Burns 1983:233-234; see also Billman et al. 2000). These and other studies (e.g., Hughes and Funkhouser 1998) indicate that the negative moisture anomaly exhibited by White Mountain and Wildhorse Ridge bristlecone at A.D. 1150 is not a micro-climatic episode but represents region-wide climatic deterioration.

The strong temporal association between climate and diet does not indicate a causal relationship *a priori*; nonetheless, it strongly suggests that prehistoric farming east of the GSL wetlands was abandoned due to a decrease in growing season moisture. Either the seasonality of precipitation changed or drought occurred. The White Mountain and Wildhorse Ridge tree-ring records show a significant moisture anomaly at A.D. 1150 preceded by several decades of below-average moisture. The

Beef Pasture pollen profile indicates a significant, long-term reduction in growing-season moisture. Either condition alone or, more feasibly, in conjunction with local environmental degradation may have eliminated maize cultivation as a viable economic strategy. In addition, drought conditions would have lowered the GSL, extending river deltas with an accompanying expansion of shoreline wetlands, increasing their attractiveness as a foraging environment, perhaps altering economic payoffs sufficient to result in final abandonment of maize agriculture. Finally, social distinctions maintained by feasting or trading in maize or maize beer would have been severely threatened by agricultural shortfalls, perhaps increasing social tensions to the extent that maize surpluses could not be defended. The abandonment of Fremont residential sites is less dramatically recorded in the archaeological record than the collapse of the Anasazi. Residential population densities were lower and eastern Great Basin wetlands may have somewhat mitigated crop failure; yet, the effects of climatic deterioration were apparently as far reaching. After centuries of maize cultivation, Fremont in the GSL Basin abandoned agriculture likely in response to a cascading suite of social and economic deterrents triggered by a decline in growing season moisture.

Summary

We have presented results of stable isotope and radiocarbon analysis of skeletal populations from the eastern shores of the Great Salt Lake and discussed them in light of current views on Fremont economic and social complexity and the abandonment of farming. Reported diets varied within a single time period, over time and by sex. The implications of economic diversity are particularly striking given the

constrained geographic range of the study, suggesting that between A.D. 400-1150, populations in the Great Salt Lake Basin were faced with a fluid subsistence cost/benefit structure, consistent with the intrusion of summer moisture into an extensive wetlands bordered by grasslands suitable for farming. Evidence for differential status among a subset of males indicates that a social hierarchy may also have been present, maintained by the ability to produce a surplus of maize and trade maize or maize beer for animal protein, labor or political support. At A.D. 1150, the onset of drought or a shift in the seasonality of moisture either eliminated farming altogether or adversely affected crop yields disrupting social networks to the extent that farming was abandoned. Economic diversity was replaced by uniform reliance on wild foods and evidence for male status distinctions is no longer present.

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Notes

1. Two adult females (Burial 3 & 32) were recovered with a mano and bivalve (*Anodonta californiensis*) and stone pestle respectively. A tubular bone bead and small pendant accompanied a child's burial (Burial 70 (Simms et al. 1991:25)).
2. PDB is a Cretaceous cephalopod (*Belemnitella*) recovered from the Pee Dee Formation, related to modern squid and octopus. PDB has by definition a value of 0 per mil (Craig 1957) and is enriched in ^{13}C . Thus ^{13}C values on Holocene organics are typically negative.
3. A third pathway (Crassulacean acid metabolism [CAM]) is restricted primarily to succulents and can replicate C_4 plant isotope signatures (Griffith 1992).
4. The average ^{13}C reading for maize grown before the extensive burning of fossil fuels is -10.5 per mil (Tieszen and Fagre 1993b).
5. Burial 37 was charred and a hole had been bored through the left proximal ulna at the olecranon (Simms et al. 1991:Table 7). Despite low collagen yields, it produced an atomic C/N ratio of 3.2, well within the 2.9-3.6 range indicative of adequately preserved bone collagen.
6. ^{15}N =1.0 per mil in pinyon from a upland Nevada site and .3 per mil in acorn from a northern Arizona grove (Table 5). Extremely low ^{15}N values indicate the presence of nitrogen-fixing mycorrhizae in the biological soil crust of both arid woodland species (Evans and Ehleringer 1994). Three of four tubers in Table 5 produced similar ^{15}N values.
7. Sex and age categories were initially assigned by Loveland in Simms et al. 1991, and Fawcett and Simms 1993. Thirty of the most complete individuals in the collection were reanalyzed by Owsley et al. (1996);

tables and figures reflect their revisions with the exception of probable assignments of sex to subadults 22 and 52.

8. One of three individuals with enamel hypoplasia (Burial 17) and five of 23 with transverse lines (Burials 47, 53, 55, 56, 58) consumed high C₄ diets.

9. Owsley et al. (1996) sexed Burial 52, a 12-13 year old from 42WB324 with ¹³C of -14.8 per mil, as a probable female. While the sexing of subadults is problematic, the possible presence of a female with a moderately high C₄ diet also suggests that the current sample of sexed burials is not representative.

10. Tree ring widths vary with the effects of moisture and temperature on food stores during the current and previous annual cycle (Fritts 1976; Rose et al. 1981), while tree-ring ¹³C is particularly responsive to growing-season moisture. During moisture stress, stomatal closure reduces transpiration limiting intercellular CO₂ concentrations. This reduces discrimination against ¹³CO₂ during photosynthesis resulting in elevated ¹³C (Bert et al. 1997; Francey and Farquhar 1982; Leavitt and Long 1988).

11. DEL Indices are the ratio of measured tree ring ¹³C to the corresponding value on a spline curve fitted to each chronology and are calculated as follows:

$$\text{DEL Index} = ({}^{13}\text{C}_{\text{DEL}} - 1) \times 1000$$

where ${}^{13}\text{C}_{\text{DEL}} = {}^{13}\text{C}_{\text{measured}} / {}^{13}\text{C}_{\text{spline curve}}$. They filter long term responses to changing CO_{2air} concentrations and absolute differences in ¹³C between sites (Leavitt 1993; Leavitt and Long 1989a). Expressed as ratios, DEL Indices lack units of measure. As they become more positive

effective moisture is increasing. Conversely, as indices become more negative, trees are experiencing increased water stress.

Figure 1

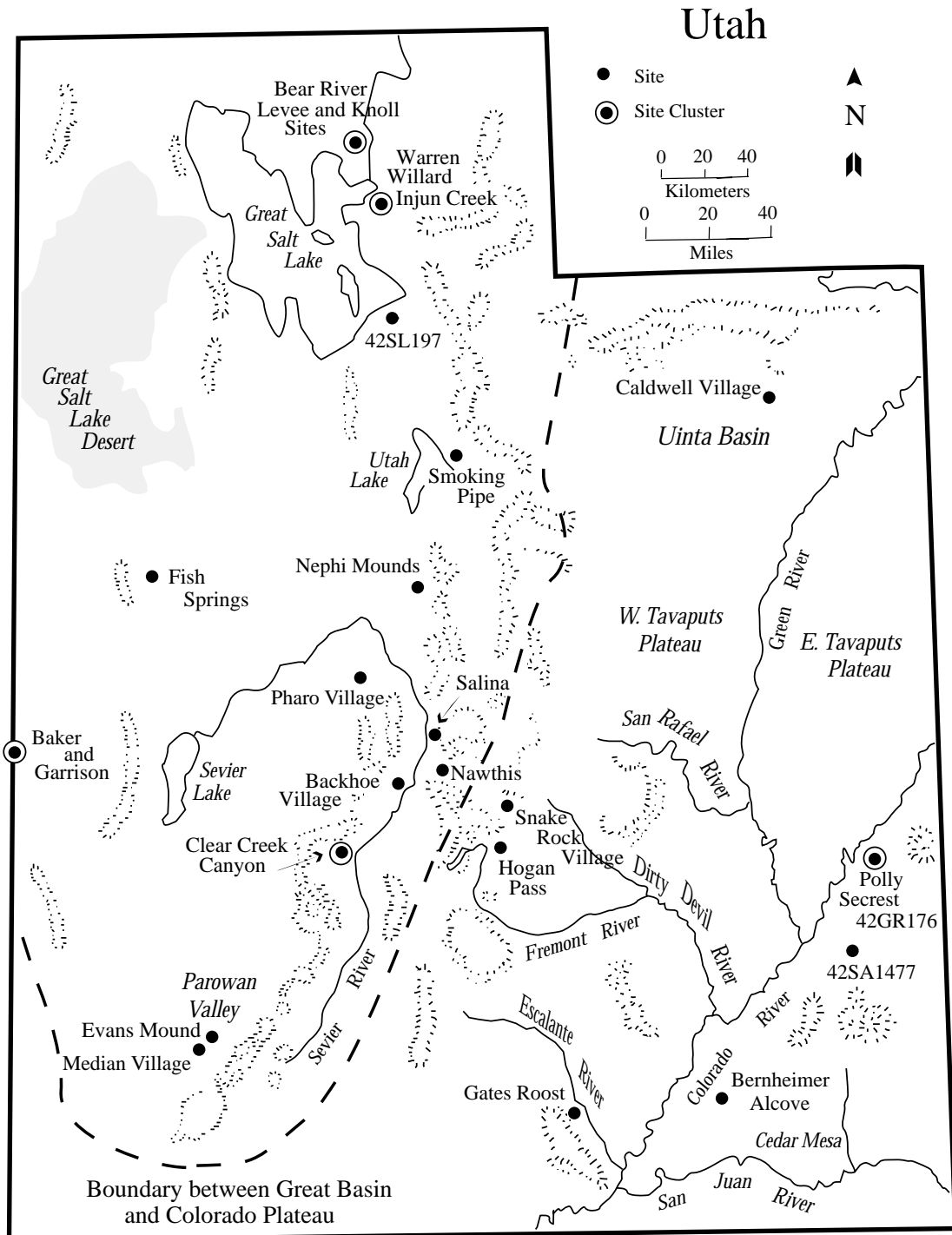


Figure 2

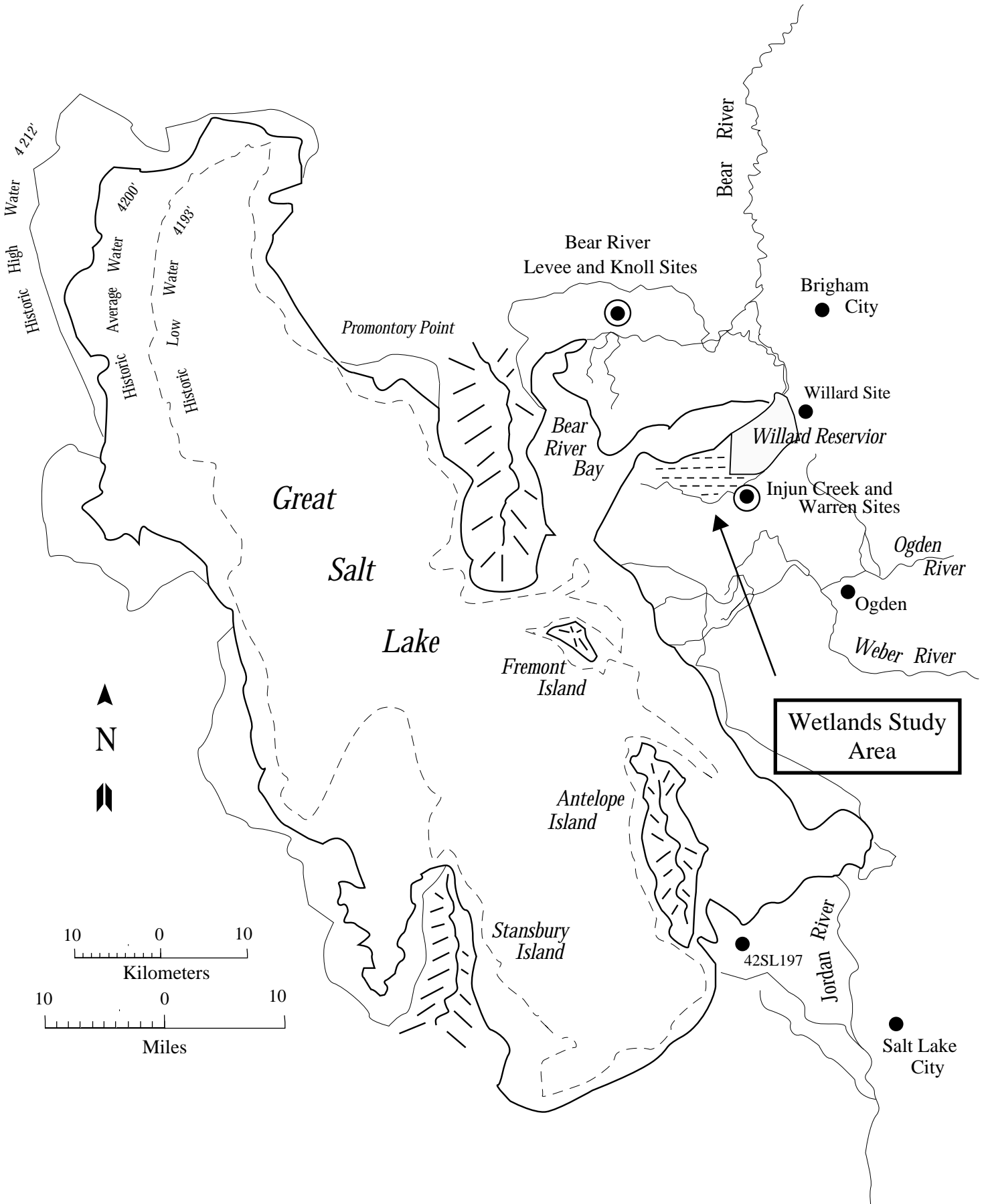


Figure 3

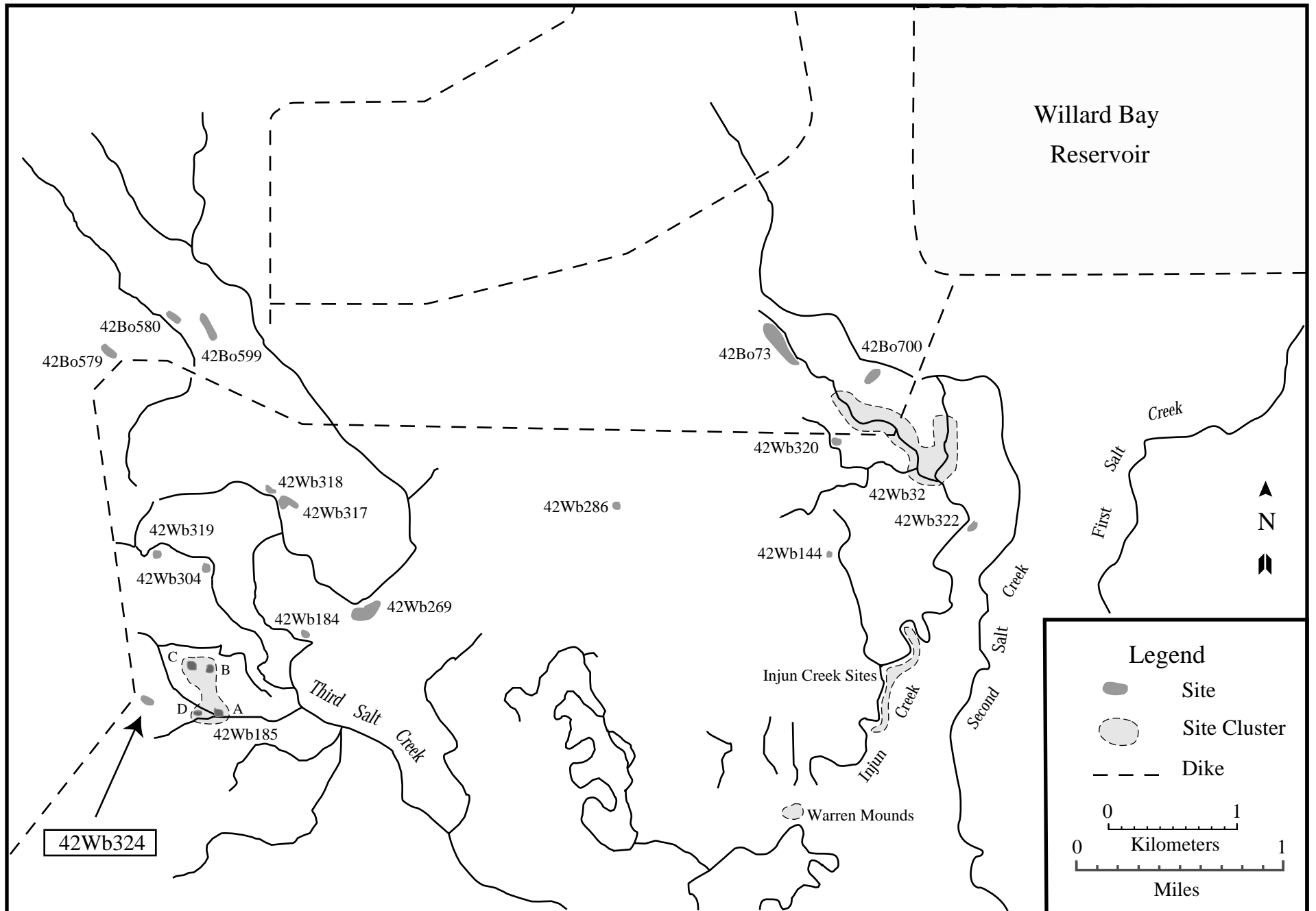


Figure 4

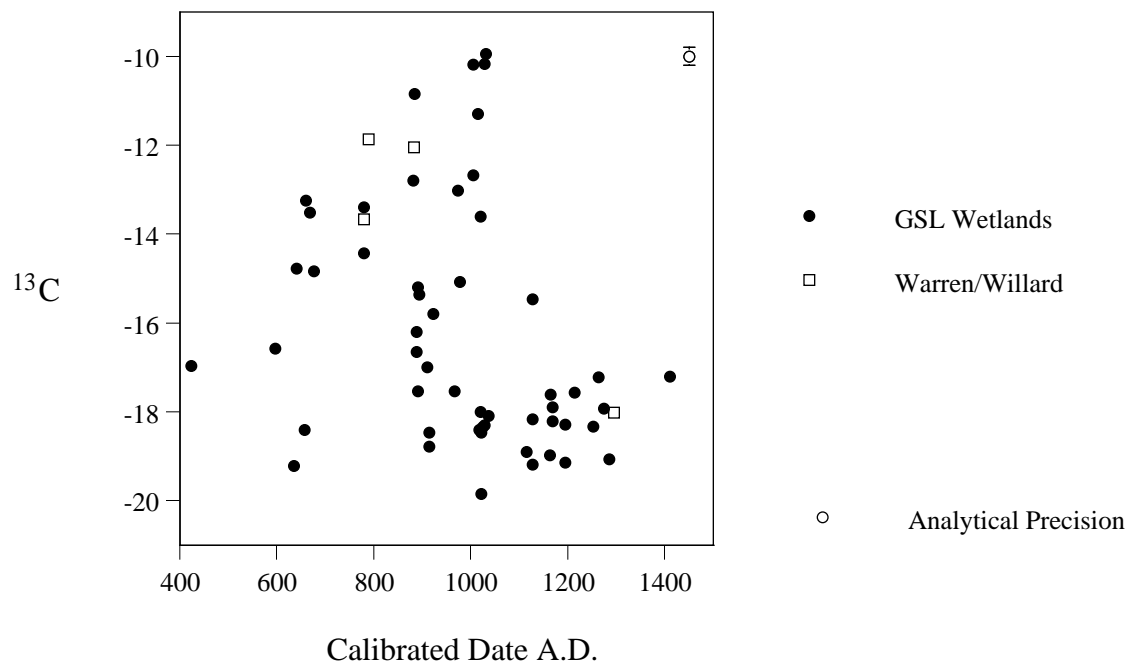


Figure 5

Calibrated Date A.D.

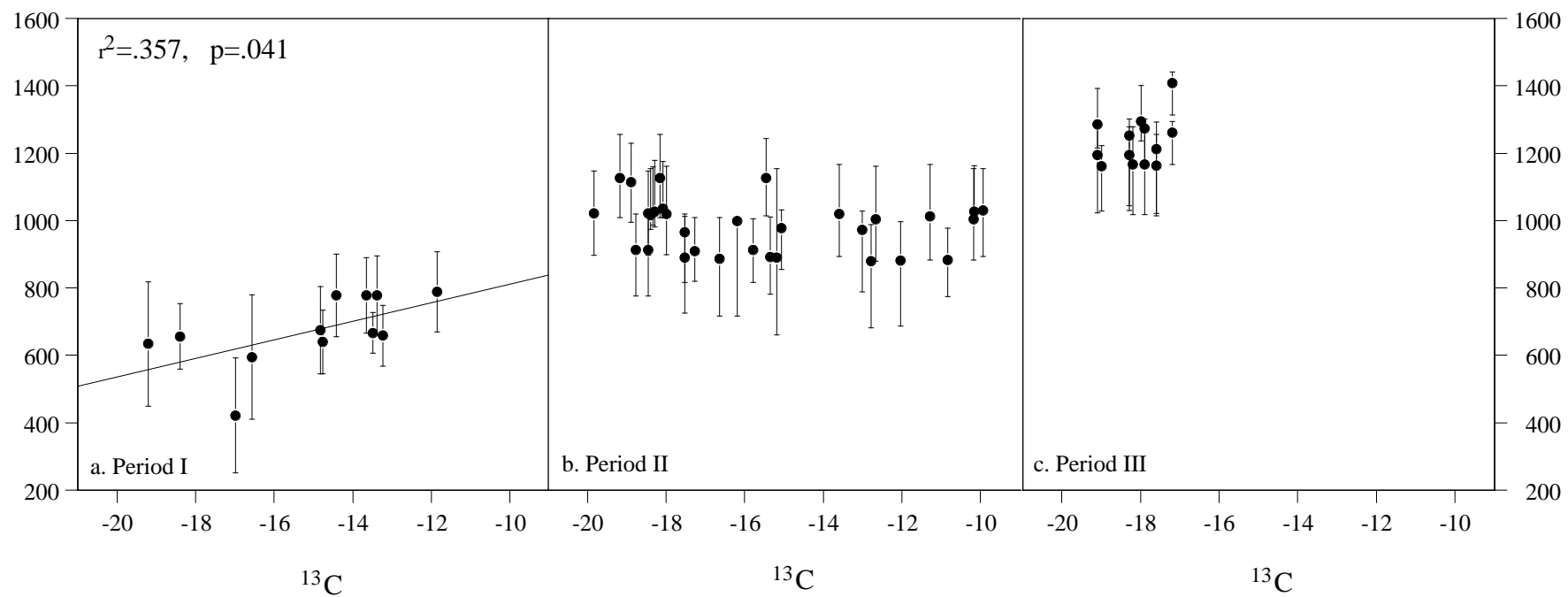


Figure 6

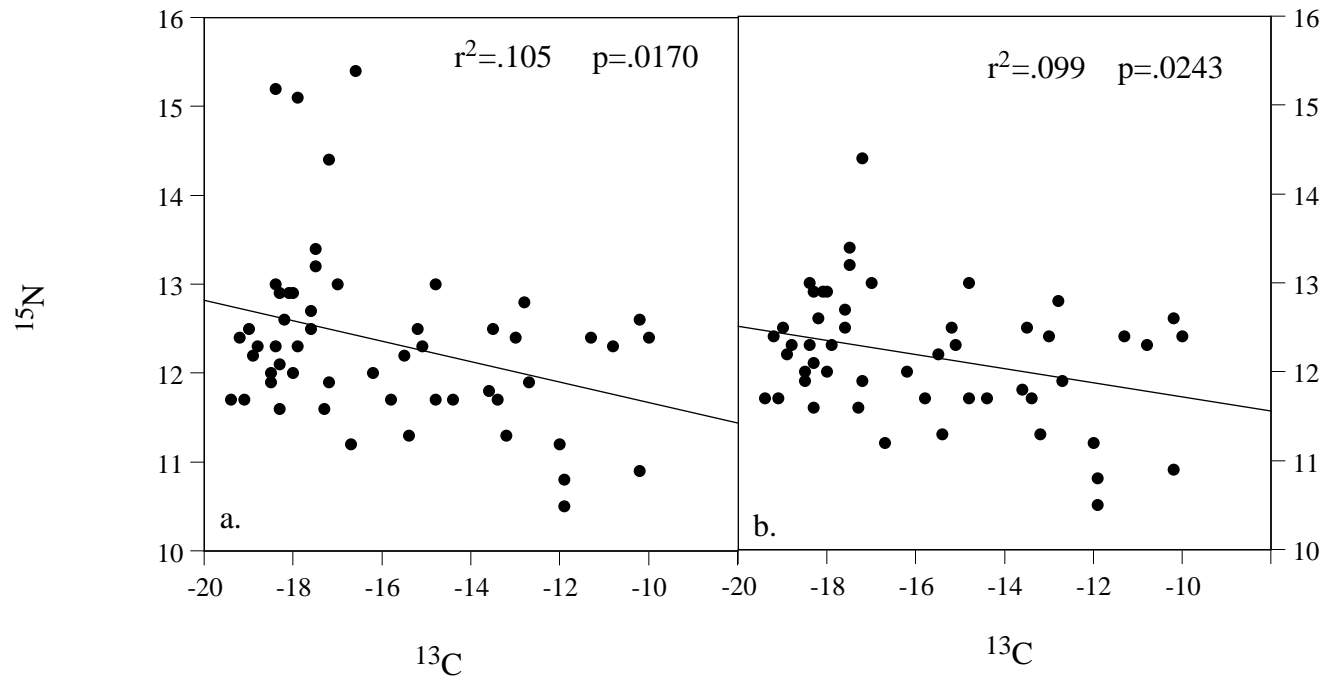


Figure 7

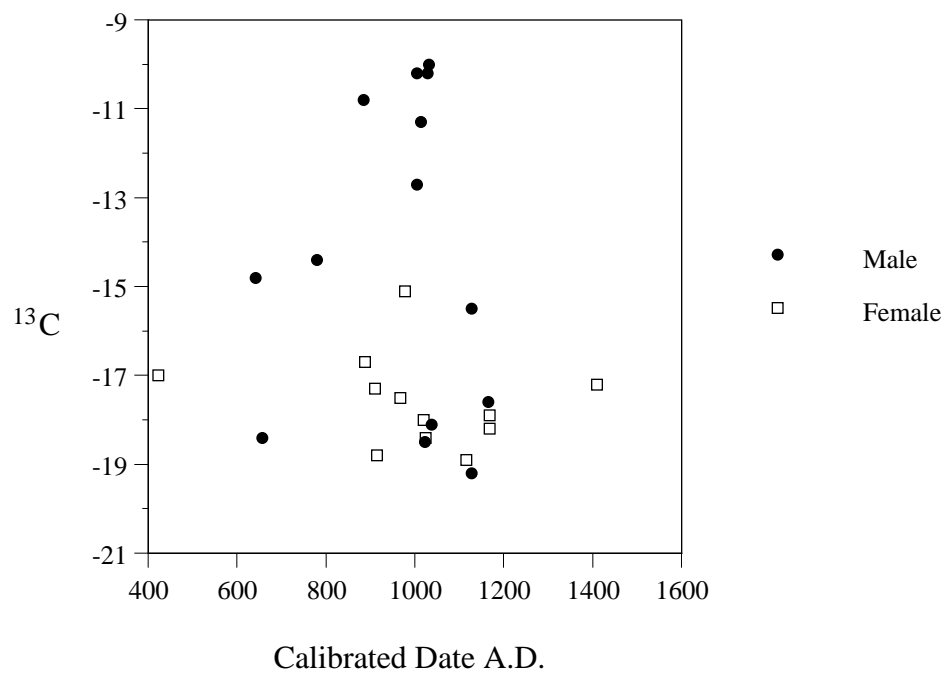


Figure 8

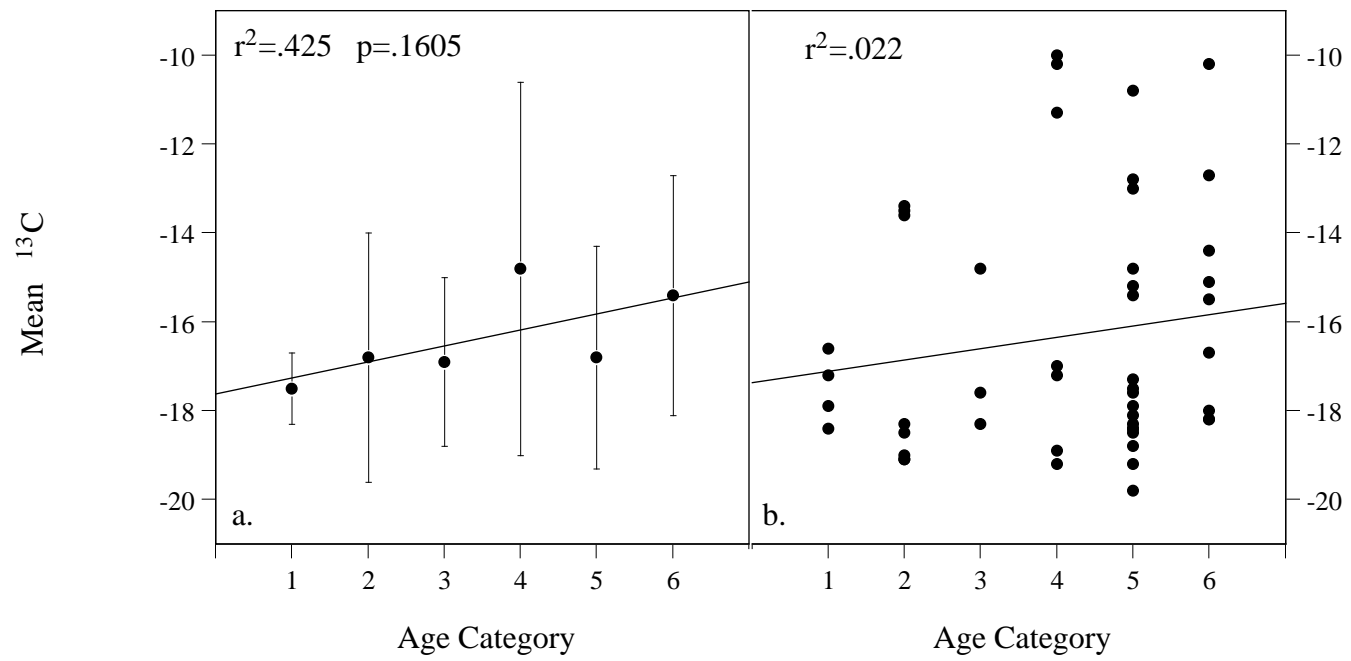


Figure 9

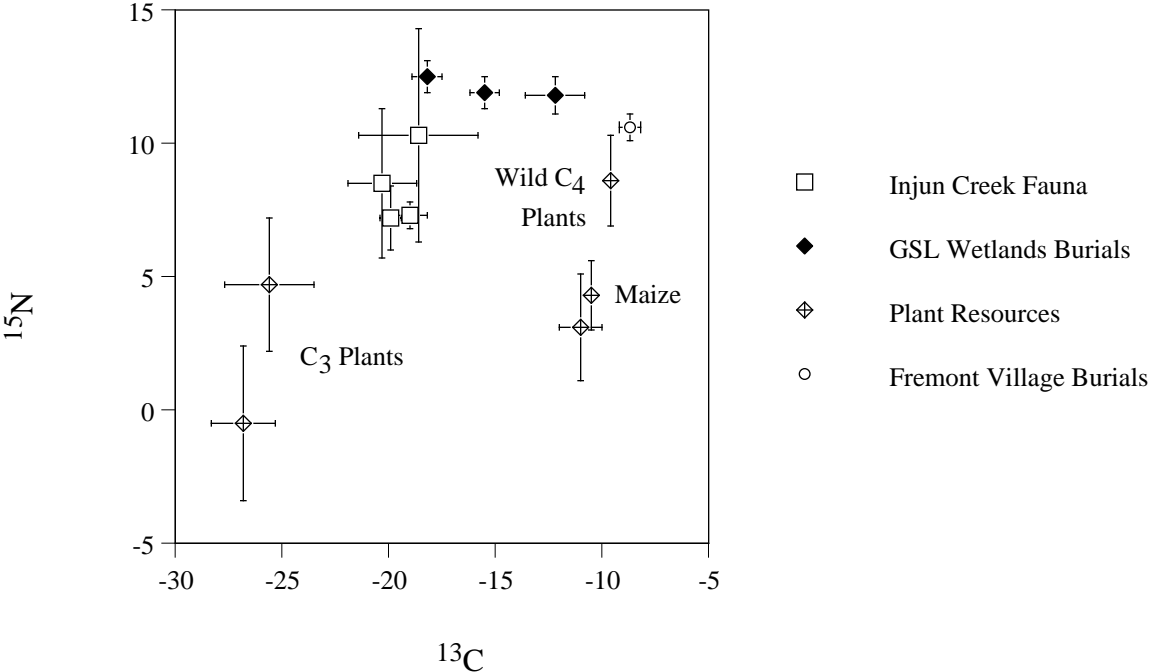


Figure 10

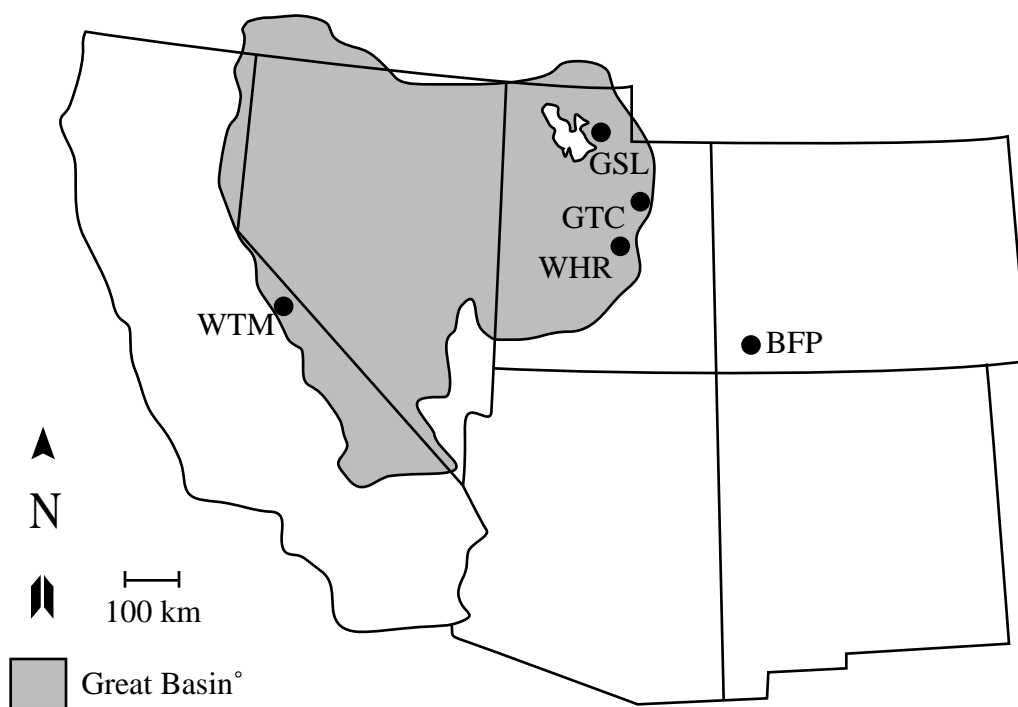


Figure 11

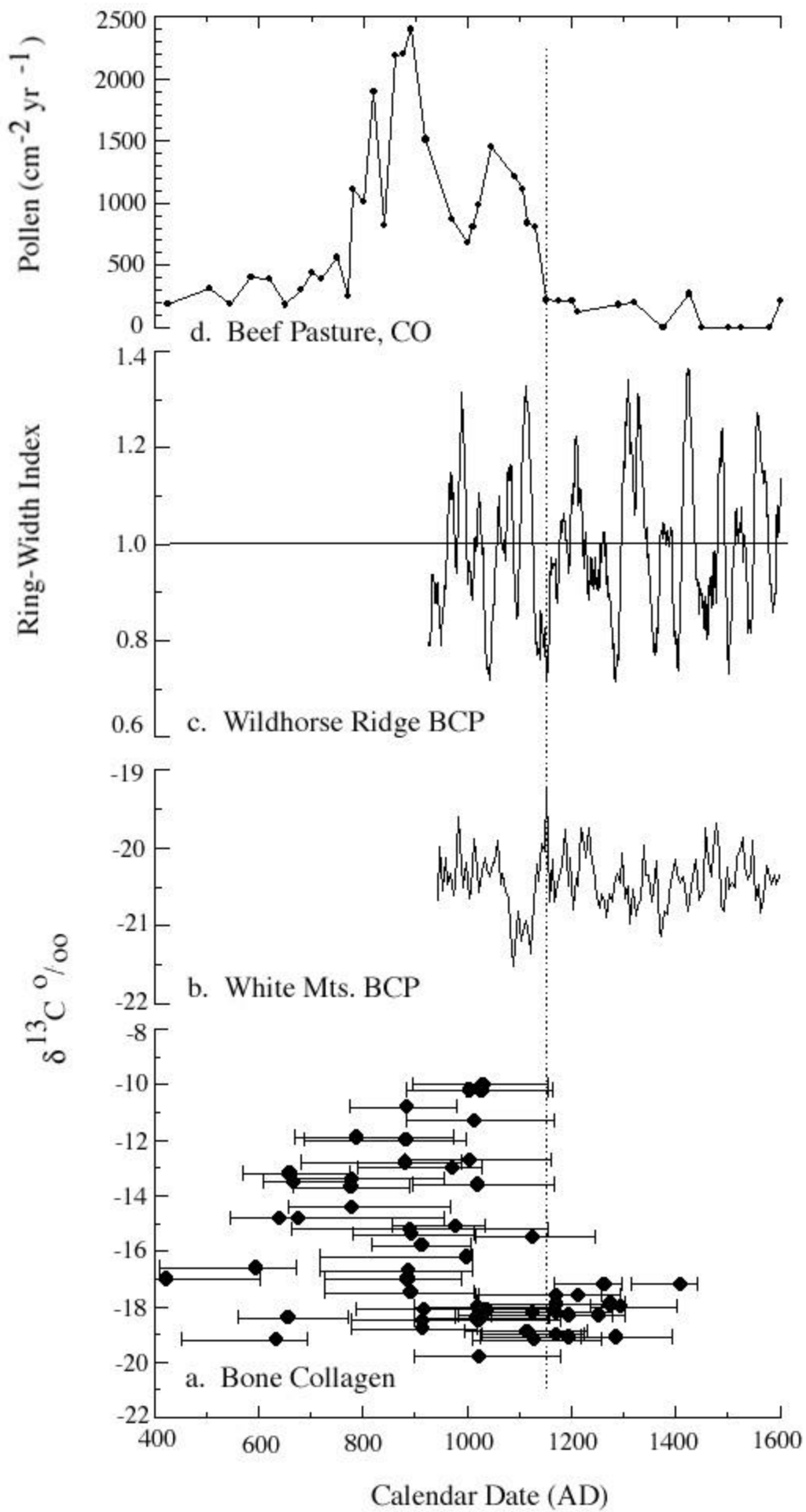


Figure 12

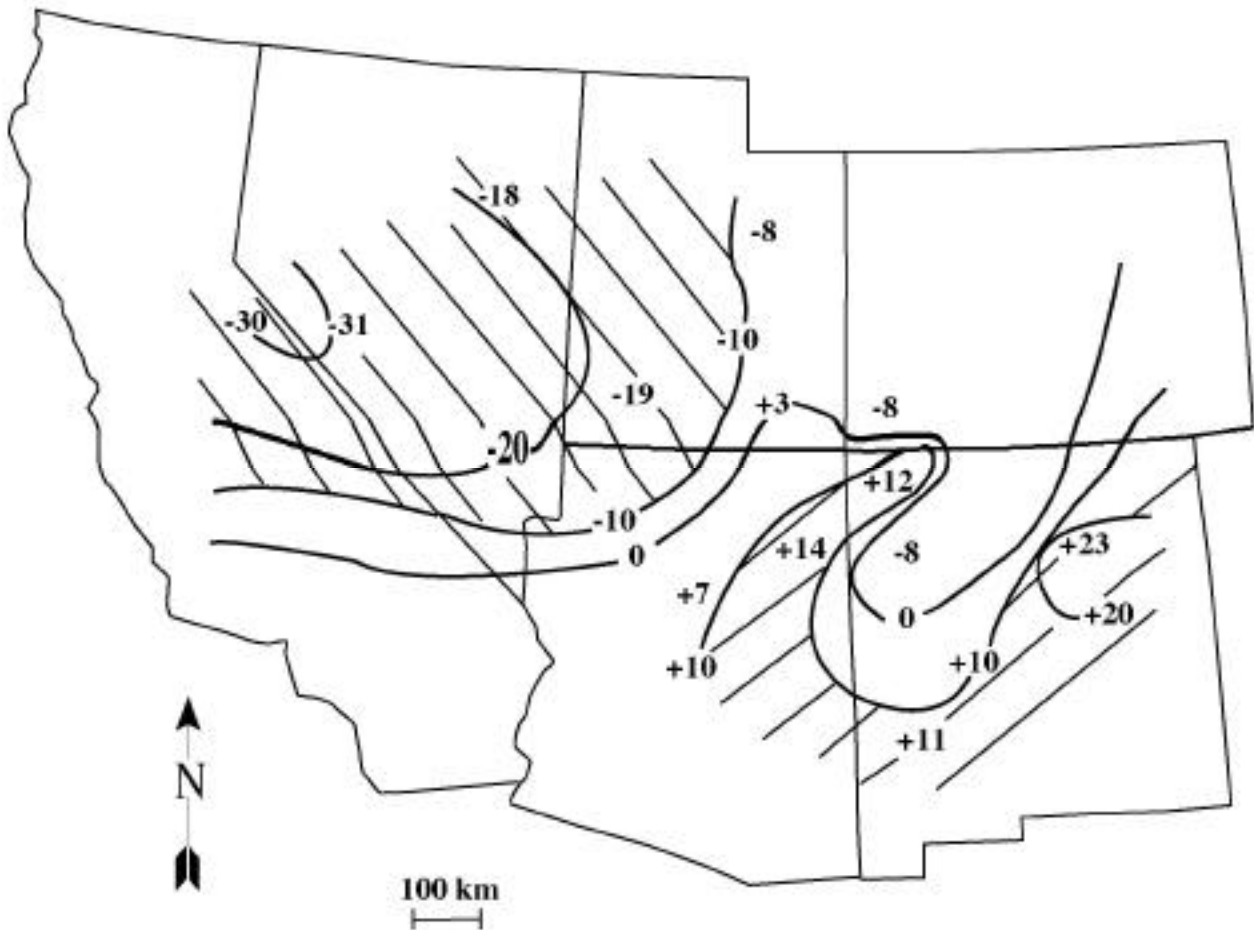


Figure Captions

1. Fremont archaeological sites in text and tables.
2. The Great Salt Lake wetlands study area, Fremont sites and historic shorelines.
3. Site map of the Great Salt Lake wetlands study area after Simms et al. 1991.
4. Bone collagen ^{13}C values for Great Salt Lake wetlands, Warren and Willard Mound burials graphed against calibrated radiocarbon intercept dates.
- 5a, b, c. Bone collagen ^{13}C values for Period I, II and III Great Salt Lake wetlands, Warren and Willard Mound burials graphed against calibrated radiocarbon intercept dates with 2 confidence intervals.
- 6a, b. Bone collagen ^{13}C values for Great Salt Lake wetlands, Warren and Willard Mound burials graphed against ^{15}N values with and without nursing infants. Burials 49 and 73 not shown.
7. Bone collagen ^{13}C values for Great Salt Lake wetlands sexed burials graphed against calibrated radiocarbon intercept dates.
- 8a, b. Mean and individual bone collagen ^{13}C values for Great Salt Lake wetlands burials regressed against age category.
9. Mean ^{13}C and ^{15}N values for modern and archaeological maize, modern C_3 plants, Injun Creek archaeological fauna excluding fish, GSL wetlands burials and Fremont village burials.
10. The hydrological Great Basin: (GSL) Great Salt Lake wetlands yielding Fremont burials sampled for ^{13}C and radiocarbon dates plotted in Figure 11a; (WTM) White Mountain bristlecone Methuselah B site sampled for historic drought indices (A.D. 1580-1980) and tree-ring ^{13}C values in Figure 11b; (WHR) Wildhorse Ridge bristlecone pine site

sampled for the tree-ring width chronology in Figure 11c; (BFP) Beef Pasture sampled for pinyon pollen plotted in Figure 11d; (GTC) Gate Canyon pinyon site sampled for historic ^{13}C drought indices (A.D. 1580-1980).

11. A comparison of subsistence patterns in the GSL wetlands with Great Basin tree-ring records and a pollen sequence from southwestern Colorado: (a) Wetlands radiocarbon dates at 2 graphed against ^{13}C showing the shift from maize to a diet of wild foods at ca. AD 1150; (b) tree-ring stable carbon isotope index from White Mountain Methuselah B bristlecone at 2880 m on the California/Nevada border; (c) Tree-ring width index from Wildhorse Ridge bristlecone pine at 2805 m on the Wasatch Plateau in central Utah; (d) pollen/cm²yr⁻¹ from Beef Pasture sediments at 3060 m on the west slope of the La Plata Mountains, southwestern Colorado.

12. Drought contours for the pentad 1930-1934 constructed from pinyon ^{13}C indices. Positive values indicate adequate moisture; negative values indicate increasing water stress.

Table 1. ^{13}C Values from Formative Sites in Utah and the Southwest.

Site/Location	n	Cultural Affiliation ^a	Date ^b	^{13}C ‰	Reference ^c	
42SV1060 ^d	UT	1	Fremont	-9.5	1	
Smoking Pipe	UT	1	Fremont	A.D. 778-1020 ^e	-9.2	2
Grasshopper Pueblo	AZ	37		A.D. 1275-1330	-9.2 ^f	4
Caldwell Village	UT	4	Fremont		-9.1	1
Badger House MV ^g	CO	6	PI		-8.9	3
Evans Mound	UT	3	Fremont		-8.8	1
Site 820 MV	CO	5	PII/III		-8.7	3
Grasshopper Pueblo	AZ	17		A.D. 1330-1400	-8.6	4
Two Raven House	CO	9	PII		-8.6	3
Pecos Pueblo	NM	8	Period VI	Post A.D. 1675	-8.5	6
Marcos Canyon	CO	4	PIII	A.D. 1450-1550	-8.3	3
Unprovenienced	CO	1	Bskt Mkr III		-8.3	3
Badger House MV	CO	10	PII/III		-8.3	3
Salina Sisters	UT	2	Fremont	A.D. 869-1162 ^e	-8.2	2
Pecos Pueblo	NM	9	Period IV	A.D. 1550-1650	-7.8	6
Pecos Pueblo	NM	10	Period III	A.D. 1450-1550	-7.7	6
Pecos Pueblo	NM	8	Period I	A.D. 1300-1400	-7.7	6
Polly Secrest	UT	2	Fremont	A.D. 1300	-7.7	7
Cedar Mesa	UT	4	Bskt Mkr II		-7.7	5
Pecos Pueblo	NM	11	Period V	A.D. 1600-1675	-7.6	6
Backhoe Village	UT	2	Fremont		-7.5	1
Pecos Pueblo	NM	7	Period II	A.D. 1400-1450	-7.5	6
Pecos Pueblo	NM	8	Black-on-white	A.D. 1200-1300	-7.5	6
San Antonio Pueblo	NM	3	Late Anasazi	A.D. 1300-1400	-7.4	7
Cedar Mesa	UT	3	PII/III		-7.3	5
Tijeras Pueblo	NM	5	Late Anasazi	A.D. 1300-1400	-7.0	7

^aListed as indicated by author(s)

^bListed if cited by author(s)

^c(1. Coltrain 1993), (2. Coltrain 1997), (3. Decker and Tieszen 1989), (4. Ezzo 1993), (5. Matson and Chishom 1991), (6. Spielmann et al. 1990), (7. Wolley 1988)

^dBurial mound in Gooseberry Valley adjacent to Nawthis Village (Figure 1)

^eCalibrated 2 range

^fReported value averages male and female ^{13}C

^gMV=Mesa Verde

Table 2. $\delta^{13}\text{C}$, $\delta^{15}\text{N}$, Calibrated Dates and Preservation for Great Salt Lake Wetlands Burials.										
Burial	Site	Age	Sex	$\delta^{13}\text{C}$ ‰	$\delta^{15}\text{N}$ ‰	Calibrated Date	Calibrated 2 σ Range	Atomic C/N	Bone %N ^a	Collagen Yield ^b
3 ^c	42WB48	33-37	F	-18.4	12.3	A.D.1024	A.D. 898-1160	3.4	3.9	21.1
6	"	adult		-13	12.4	A.D. 973	A.D. 789-1029	3.2	2.3	25.5
8	"	subadult		-17.6	12.7	A.D.1214	A.D.1016-1293		0.5	9.9
11	42WB184	1.5-2.5		-17.2	11.9	A.D.1263	A.D.1167-1296	3.1	3.5	23.2
14	42WB185 ^a	40-44	M	-14.8	13	A.D. 641	A.D. 547- 678	3.3	2	16.9
15	"	40-45	M	-18.4	13	A.D. 657	A.D. 560- 773		1.1	10.7
16	42WB185 ^c	60+	M	-15.5	12.2	A.D.1127	A.D.1016-1245	3.2	3.6	22.5
17	"	25-30		-12.8	12.8	A.D. 881	A.D. 683- 990		2.1	14
20	42WB269	30-34	M	-17.6	12.5	A.D.1165	A.D.1022-1257	3	2.5	18.2
21	"	25-29	F	-18.8	12.3	A.D. 914	A.D. 778-1020	3.1	0.9	11.8
22	"	10.5-11.5		-19	12.5	A.D.1163	A.D.1029-1224	3.2	1.8	10.1
23	"	20-30	M	-18.1	12.9	A.D.1037	A.D.1011-1177	3.4	3.2	17.8
26	"	7-8		-19.1	11.7	A.D.1286	A.D.1217-1393	3.1	2.7	16.9
27	"	17-25	F	-18.9	12.2	A.D.1115	A.D. 996-1230	3.2	2	18.7
28	"	44-49	F	-18.2	12.4	A.D.1168	A.D.1019-1279	3.2	3.7	19.2
29	"	6-7		-19.1	11.7	A.D.1195	A.D.1025-1283	3.4	3.4	12.3
32	42WB286	25-34	F	-17.9	12.3	A.D.1168	A.D.1019-1279	3.1	3.5	19.8
33	42WB304	Adult	M	-18.5	11.9	A.D.1022	A.D. 898-1179		2.9	16.9
35	42WB317	2.5-3.5		-18.4	15.2	A.D.1018	A.D. 976-1155	3.4	1	6.6
36	42WB318	2.5-3.5		-16.6	15.4	A.D. 596	A.D. 411- 672	3.1	1	6.6
37	"	30-44	F	-17.5	13.2	A.D. 967	A.D. 818-1020	3.2	0.8	3.3
40	42WB319	9.5-10.5		-18.3	12.1	A.D.1195	A.D.1031-1279	3.2	2	20
41	"	30-35		-18.3	11.6	A.D.1253	A.D.1046-1303	3.2	2.3	20.5
43	42WB320	16-20	F	-17.2	14.4	A.D.1410	A.D.1314-1442	3.2	3.4	22.4
45	42WB322	adult		-15.2	12.5	A.D. 891	A.D. 662-1156	3.2	3.4	19.5
47	42WB324	45-49	M	-12.7	11.9	A.D.1005	A.D. 880-1162	3.2	3.3	19.2
48	"	10-12.5		-13.6	11.8	A.D.1020	A.D. 895-1168	3.4	2.8	19
49	"	20-24	M	-19.2	4.4	A.D.1127	A.D.1010-1257	3.4	2	16.3
51	"	9-10		-13.4	11.7	A.D. 779	A.D. 662- 956	3.2	2.1	16.3
52	"	12.5-13.5		-14.8	11.7	A.D. 676	A.D. 547- 956		2.2	17.3
53	"	37-43	M	-10.8	12.3	A.D. 884	A.D. 775- 979	3.3	4	21.7
55	"	18-22	M	-10	12.4	A.D.1031	A.D. 895-1156	3.5	3.7	20.8
56	"	18-20	M	-11.3	12.4	A.D.1014	A.D. 885-1168	3.4	3.6	21.9
57	"	6.5-7.5		-13.5	12.5	A.D. 668	A.D. 608- 786	3.4	3.3	17.5
58	"	20-24	M	-10.2	12.6	A.D.1028	A.D. 997-1165	3.4	3.8	19.2
61	42B073	50-60	F	-15.1	12.3	A.D. 978	A.D. 857-1033	3.1	2.1	18.8
62	"	Unk		-17.5	13.4	A.D. 891	A.D. 727-1014	3.2	3.1	18.1
64	42B0579	18-23	F	-17	13	A.D. 423	A.D. 252- 602	3.1	0.4	5.9
65	42B0580	45+		-18.2	12.6	A.D.1127	A.D.1010-1257	3.3	0.8	14.4
66	"	subadult		-18.3	12.9	A.D.1028	A.D. 983-1180	3.2	1.7	17.3
68	42B0599	50-59	F	-18	12	A.D.1020	A.D. 900-1162	3.3	3.4	19.2
69	"	6mo./1.5		-17.9	15.1	A.D.1275	A.D.1165-1303	3.4	1	12
70	"	6.5-7.5		-18.5	12	A.D. 914	A.D. 778-1020	3.4	2.5	14.9
73	42WB144	adult		-19.8	4.3	A.D.1022	A.D. 898-1179	3.3	2.4	19.2
76	42WB185 ^c	25-29	F	-17.3	11.6	A.D. 910	A.D. 822-1011	3.2	3	21.3
77	42B0700	50+	M	-14.4	11.7	A.D. 779	A.D. 656- 968	3.2	2.4	18.6
78	42WB32	adult		-19.2	12.4	A.D. 635	A.D. 451- 694	3.1	1	14.5
79	"	adult		-15.4	11.3	A.D. 893	A.D. 782-1012	3.1	1.7	13.1
83	"	45+	M	-10.2	10.9	A.D.1005	A.D. 885-1156	3.1	2.9	19
84	"	50+	F	-16.7	11.2	A.D. 888	A.D. 718-1011	3.2	2.5	18.5
1 ^d	42SL197	subadult		-15.8	11.7	A.D. 914	A.D. 817-1007		3.5	19.5
2	"	adult		-13.2	11.3	A.D. 660	A.D. 570- 776	3.4	3.2	27
4a	"	8		-16.2	12	A.D. 888	A.D. 718-1011		3.7	22.9

Table 2. $\delta^{13}\text{C}$, $\delta^{15}\text{N}$, Calibrated Dates and Preservation for Great Salt Lake Wetlands Burials.										
Burial	Site	Age	Sex	$\delta^{13}\text{C}$ 0%	$\delta^{15}\text{N}$ 0%	Calibrated Date	Calibrated 2 σ Range	Atomic C/N	Bone %N ^a	Collagen Yield ^b
W. Warren (21750/15)		adult		-12.0	11.2	A.D. 883	A.D. 688- 998	3.2	3.3	21.9
Willard Mds. (11349)		adult		-13.7	10.5	A.D. 779	A.D. 667- 891	3.2	3.1	19.6
Willard Mds ^e FS 1/97		adult		-11.9	10.8	A.D. 789	A.D. 670- 974	3.3	1.4	9.2
Willard Mds ^f (Fs 1/108)		adult		-18.0	12.9	A.D. 1295	A.D. 1237-1403	3.2	1.9	10.3
Note: For CAMS laboratory numbers and dates bp see Coltrain and Stafford 1999:Table 4.1										
^a Percent nitrogen in whole bone by weight										
^b Percent collagen in whole bone by weight										
^c Burials recovered in the Great Salt Lake wetlands project (Simms et al. 1991)										
^d Jordan River burials (Schmitt et al. 1994)										
^e 42B030										
^f 42B076										

Table 3. Skeletal Pathologies in Burials Analyzed for Stable Isotopes.

Burial	¹³ C ‰	Age	Pathology
3	-18.4	33-37	Ravaged by lesions suggestive of metastatic carcinoma; numerous pathological fractures; SN lumbar vert; 2 phalanges fused; PT; DJD; MMD; TL; moderate DW;
11	-17.2	1.5-2.5	Slight cribra orbitalia; TL; EH; sclerotic mastoid development
14	-14.8	40-44	SN several verts; DJD; MMD; TL; extreme DW
16	-15.5	60+	DJD; PT; extreme DW
17	-12.8	25-30	EH
20	-17.6	30-34	DJD; TL
21	-18.8	25-29	TL
22	-19.0	10.5-11.5	LL proximal humeri
23	-18.1	20-30	EH
28	-18.2	44-49	Innominate and sacrum partially fused; DJD; MMD; TL; PT; LL rt humerus
32	-17.9	25-34	5th lumbar collapsed; MMD; TL; extreme DW
33	-18.5	Adult	TL
35	-18.4	2.5-3.5	Slight cribra orbitalia; MMD; TL
37	-17.5	30-44	DJD
40	-18.3	9.5-10.5	LL lft tibia; exostosis superior margin 2nd rib; TL
43	-17.2	16-20	DJD; TL
47	-12.7	45-49	DJD; TL; SN L2 and L5; diploic mastoid development; rapid DW
48	-13.6	10-12.5	TL
52	-14.8	12.5-13.5	MMD
53	-10.8	37-43	Lft innominate fused to femur anterior at 90° elevated 10-15° above horizontal; lft lower limb bones smaller than rt; bowed femora; SN lumbar verts; DJD; cervical verts 2-4 fused; MMD; TL
55	-10.0	18-22	TL
56	-11.3	18-20	TL
57	-13.5	6.5-7.5	Craniostenosis; MMD; TL
58	-10.2	20-24	DJD; TL; LL 7th cervical vert;
61	-15.1	50-60	DJD; LL T4; TL; PT; necrotic, eburnation lft patella; extreme DW
64	-17.0	18-23	MMD; TL
65	-18.2	45+	DJD; PT
66	-18.3	Subadult	Cribra obitalia
68	-18.0	50-59	Spina bifida occulta L5; DJD; PT; MMD; TL; DW
69	-17.9	6mo./1.5	Diploic mastoid development
70	-18.5	6.5-7.5	Moderate deciduous DW, multiple episodes of growth disruption w/TL
76	-17.3	25-29	Extreme DW; TL
77	-14.4	50+	Severe DJD; extreme DW
78	-19.2	Adult	Extreme DW
83	-10.2	45+	Extreme DW; DJD
84	-16.7	50+	Extreme DW; DJD

Note: SN=Schmorl's node; PT=palatine torus; DJD=degenerative joint disease; MMD=mixed mastoid development; TL=transverse lines; DW=dental wear; EH=enamel hypoplasia; LL=lytic lesion.
Sources: Fawcett and Simms 1993; Owsley et al. 1996; Simms et al. 1991

Table 4. ^{13}C , ^{15}N Values for Periods I, II and III.

Period	n	Calibrated Age A.D.	Mean ^{13}C ‰	Range	Per Mil Range	Mean ^{15}N ‰ ^a	Range	Per Mil Range
I	12	400-850	-15.1 ± 2.3	-19.2/-11.9	7.3	12.0 ± .9	10.5/13.0	2.5
II	32	850-1150	-15.7 ± 3.1	-19.8/-10.0	9.8	12.2 ± .6	10.9/13.4	2.5
III	13	1150-1450	-18.1 ± 0.6	-19.1/-17.2	1.9	12.4 ± .8	11.6/14.4	2.8

^a ^{15}N means do not include nursing infant Burials 35, 36, 39 and non-indigenous Burials 49, 73

Table 5. Stable Isotope Values on Injun Creek (42WB34) Fauna,
Modern Plant Taxa from Stillwater Wetlands and Other
Modern and Archaeological Plant Taxa.

Species	Common Name	^{13}C ‰	^{15}N ‰	Atomic C/N	Source
<i>Ovis canadensis</i>	bighorn sheep	-20.0	8.4	3.0	Injun Creek (42Wb34)
<i>Ovis canadensis</i>	bighorn sheep	-20.6	8.7	2.9	
<i>Odocoileus hemionus</i>	mule deer	-20.0	6.0	2.9	
<i>Odocoileus hemionus</i>	mule deer	-19.7	6.1	2.9	
<i>Cervus elaphus</i>	elk	-19.6	6.3	3.0	
<i>Antilocapra americana</i>	pronghorn	-19.2	7.9	2.9	
<i>Canis lupus</i>	gray wolf	-19.2	9.6	3.0	
<i>Ondatra zibethibus</i>	muskrat	-22.0	6.8	3.0	Modern/Fish Springs, UT ^a
<i>Castor canadensis</i>	beaver	-21.3	5.4	3.0	Injun Creek (42Wb34)
<i>Lutra canadensis</i>	river otter	-22.5	13.6	3.0	
<i>Ezethizon dorsatum</i>	porcupine	-18.6	7.8	3.0	
<i>Thomomys talpoides</i>	pocket gopher	-20.1	9.9	2.9	
<i>Sylvilagus</i> sp.	rabbit	-20.1	6.6	2.9	
<i>Lepus</i> sp.	hare	-21.4	5.9	2.9	
Rodentia	rodent	-19.0	11.4	3.0	
<i>Microtus montanus</i>	mic. rodent	-17.7	9.5	2.9	
<i>Branta canadensis</i>	Canada goose	-15.5	10.6	3.1	
<i>Branta c. maxima</i>	Canada goose	-20.2	7.0	3.0	
<i>Anas platyrhynchos</i>	mallard duck	-20.8	7.3	2.9	
<i>Anas</i> sp.	duck	-22.0	7.3	3.1	
<i>Pelecanus</i> sp.	pelican	-17.1	12.8	3.1	
<i>Larus</i> sp.	gull	-15.9	17.0	2.9	
Catostomidae	sucker	-23.8	8.7	3.0	
<i>Scirpus acutus</i>	bulrush seed	-25.8	6.3		Stillwater Wetlands, NV ^b
<i>Scirpus paludosis</i>	nut grass	-25.6	4.3		
<i>Oryzopsis hymenoides</i>	indian ricegrass	-23.3	2.6		
<i>Pinus monophyla</i>	pinyon	-21.2	1.0		
<i>Amaranthus</i> sp. (n=5)	amaranthus seed	-12.4 ± .4	3.4 ± .2		Modern/GSL Valley, UT ^c
<i>Atriplex confertifolia</i>	shadscale seed	-14.1	9.9		Modern/Fish Springs, UT
<i>Echinochloa crus.</i> (n=2)	barnyard grass sd	-10.3 ± .0	11.2 ± .5		Modern/UT Dept of Agri. ^d
<i>Sporobolus cryptandrus</i>	indian dropseed	-12.1	2.8		

<i>Zea mays</i> kernel (n=2)	Chapalote popcorn	-10.2 ± .1	4.5 ± .0	Modern/Native Seed Search ^e
	Maize Rojo Dent	-10.7 ± .2	1.7 ± .7	
	Acoma Flour Corn	-11.7 ± .3	2.5 ± .4	
	Manzano Yellow	-12.0 ± .1	3.0 ± .7	
<i>Zea m.</i> kernel	Cochiti Blue	-11.8	6.0	
	Tarahumara Flint	-9.8	.7	
<i>Zea m.</i> charred cob	Fremont maize	-10.5	6.3	Pharo Village (42MD190)
	(central Utah)	-10.6	4.2	Nephi Mounds (42JB2)
		-10.5	2.9	Snake Rock Village (42SV5)
		-10.0	3.4	Evans Mound (42IN40)
		-10.7	4.8	Median Village (42IN124)
<i>Zea m.</i> uncharred cob (n=3)	Formative maize	-9.8 ± .1	7.4 ± 3.6	Canyonlands (42SA1477)
	(southeast Utah)	-9.3 ± .3	8.6 ± .9	Bernheimer Alcove (42SA736)
		-9.6 ± .4	7.3 ± .1	Gates Roost (42KA178)
		-9.5 ± .9	10.9 ± 5.0	Alice Hunt Survey (42GR176)
<i>Allenrolfea occ.</i> (n=2)	pickleweed seed	-25.5 ± 1.1	6.0 ± 2.7	Modern/UT ^f
<i>Chenopodium sp.</i> (n=2)	goosefoot leaf	-27.1 ± .2	8.0 ± 2.3	Modern/Fish Springs, UT
<i>Oryzopsis hymenoides</i>	indian ricegrass	-22.5	4.1	
<i>Quercus emoryi</i>	acorn nut meat	-25.2	.3	Modern/Payson, AZ ^g
<i>Rosa sp.</i>	rose hip	-23.6	6.3	Modern/Box Elder Co., UT ^h
<i>Scirpus sp.</i>	bulrush seed	-27.4	4.5	Modern/Fish Springs, UT
<i>Typha latifolia</i>	cattail rhizome	-28.2	3.5	
<i>Allium sp.</i>	wild onion	-29.0	-3.0	Modern/Salt Lake Co., UT ⁱ
<i>Balsamorhiza sp.</i>	balsam tuber	-25.6	- .5	
<i>Lewisia rediviva</i>	bitterroot tuber	-26.7	-1.9	Modern/Nevada
<i>Periderida gairdneri</i>	yampa tuber	-25.9	3.5	Modern/Wasatch Co., UT

^aFish Springs Wildlife Refuge samples collected 1999

^bSchoeninger 1999:Table 8.1

^cCollected 1991

^dObtained from the UT Department of Agriculture 1993

^ePurchased from Native Seed Search, AZ, 1995

^fFloating Island, UT, sample collected mid-1990s; Fish Springs sample, 1999

^gCollected 1998

^hCollected 2001

ⁱAll tubers collected 2001

Table 6. ^{13}C , ^{15}N Values, Sites and Means for Great Salt Lake
Wetlands Burials by Sex.

Female				Male			
Burial	Site	^{13}C ‰	^{15}N ‰	Burial	Site	^{13}C ‰	^{15}N ‰
3	42WB48	-18.4	12.3	14	42WB185a	-14.8	13.0
21	42WB269	-18.8	12.3	15	42WB185a	-18.4	13.0
27	42WB269	-18.9	12.2	16	42WB185c	-15.5	12.2
28	42WB269	-18.2	12.4	20	42WB269	-17.6	12.5
32	42WB286	-17.9	12.3	23	42WB269	-18.1	12.9
37	42WB318	-17.5	13.2	33	42WB304	-18.5	11.9
43	42WB320	-17.2	14.4	47	42WB324	-12.7	11.9
61	42BO73	-15.1	12.3	49	42WB324	-19.2	
64	42BO579	-17.0	13.0	53	42WB324	-10.8	12.3
68	42BO599	-18.0	12.0	55	42WB324	-10.0	12.4
76	42WB185c	-17.3	11.6	56	42WB324	-11.3	12.4
84	42WB32	-16.7	11.2	58	42WB324	-10.2	12.6
				77	42BO700	-14.4	11.7
				83	42WB32	-10.2	10.9
Mean $\delta^{13}\text{C}$	(n=12)	-17.6 ± 1.1 ‰			(n=14)	-14.4 ± 3.5 ‰	
Mean $\delta^{15}\text{N}$		12.4 ± .8 ‰				12.3 ± .6 ‰	

Table 7. Mean ^{13}C Values for Great Salt Lake Wetlands
Burials by Age Category.

Age Category	Age Range	n	Mean ^{13}C ‰	General Category
1	0-5	4	-17.5 ± .8	Infant
2 ^a	6-11	8	-16.8 ± 2.8	Child
3	12-16	3	-16.9 ± 1.9	Subadult
4 ^b	17-24	7	-14.8 ± 4.2	Young Adult
5 ^c	25-45	18	-16.8 ± 2.5	Adult ≤45
6 ^d	45+	9	-15.4 ± 2.7	Adult >45

^aIncludes Burial 48

^bIncludes Burials 27, 43

^cIncludes Burial 23 and all "Adults" in Table 2

^dIncludes Burials 28, 47

Table 8. Mean ^{13}C , ^{15}N for Plant Resources and Fremont Fauna.

Sample	n	Mean ^{13}C ‰	Mean ^{15}N ‰
Plant Resources			
Modern C ₄ Plants	9	-12.1 ± 1.2	7.0 ± 4.2
Modern Aboriginal Maize	10	-11.0 ± 1.0	3.1 ± 2.0
Arch. Maize Charred	5	-10.5 ± .3	4.3 ± 1.3
Arch. Maize Uncharred	12	- 9.6 ± .2	8.6 ± 1.7
Modern C ₃ Plants	9	-25.6 ± 2.1	4.7 ± 2.5
Modern Tubers	4	-26.8 ± 1.5	-.5 ± 2.9
Fauna			
Bison (<i>Bison bison</i>)	16	-19.0 ± .8	7.3 ± .5
Other Large Mammals	6	-19.9 ± .5	7.2 ± 1.2
Small Mammals	9	-20.3 ± 1.6	8.5 ± 2.8
Waterfowl	6	-18.6 ± 2.8	10.3 ± 4.0
Fish (Catostomidae)	1	-23.8	8.7
Carnivore (<i>Canis lupus</i>)	1	-19.2	9.6

Table 9. *Bison bison* ^{13}C , ^{15}N Values from Fremont Sites adjacent to the Great Salt Lake Wetlands.

Site	Skeletal Element	^{13}C ‰	^{15}N ‰	Atomic C/N
Bear River 3 ^a	distal tibia	-19.5	7.4	3.5
	maxilla	-18.2	8.0	3.5
	distal radius	-17.0	6.9	3.5
Levee Site ^b	phalange	-19.4	7.0	3.5
	maxilla	-20.0	7.5	3.5
	astragalus	-18.3	7.3	3.5
Bear River 1 ^c	mandible	-18.9	7.7	3.5
	distal humerus	-18.5	7.4	3.6
	distal humerus	-19.4	6.3	3.6
	mandible	-19.9	6.5	3.6
	distal humerus	-19.6	6.8	3.4
Bear River 2 ^d	long bone shaft	-19.7	7.6	3.3
	mandible	-19.4	7.2	3.5
	maxilla	-18.6	8.0	3.4
	long bone shaft	-19.8	6.9	3.4
42SL285 ^e	distal tibia	-18.1	8.0	3.5

^a42B098 (Shields and Dalley 1978)

^b42B0107 (Fry and Dalley 1979)

^c42B055 (Aikens 1966)

^d42B057 (Aikens 1967)

^eFremont residential base, downtown Salt Lake City, Utah, (Rood personal communication 1999)

Table 10. ^{13}C Values for Fremont Village Burials with a Subset
of AMS Radiocarbon Dates.

Site	Burial	^{13}C ‰	^{15}N ‰	Date B.P.	Calibrated 2 Range	Calibrate Intercept Date
Evans Mound	Fs210.57	-7.6	10.4			
Evans Mound	Fs267.16	-10.2	9.6			
Evans Mound	Fs1276.83	-8.7	10.7			
Backhoe Village	76As1.16.20	-7.4	10.0			
Backhoe Village	76As1.37.51	-7.6	10.6			
Caldwell Village	3	-8.8	11.9			
Caldwell Village	2	-8.4	10.7			
Caldwell Village	4	-8.2	10.8			
Caldwell Village	6	-11.0	10.9			
Salina Sisters ^a	1	-8.4	10.5	1100 ± 50	A.D. 869-1023	A.D. 973
Salina Sisters ^b	2	-8.0	10.6	1030 ± 60	A.D. 890-1162	A.D. 1014
Smoking Pipe ^c		-9.2	10.6	1130 ± 60	A.D. 778-1020	A.D. 914
42SV1060 ^d		-9.5	10.4			

^aBillat and Billat 1988; CAMS-12275

^bBillat and Billat 1988; CAMS-10213

^cCAMS-10212

^dBurial mound in Gooseberry Valley adjacent to Nawthis Village (Figure 1; Metcalfe 1984)

Table 11. Mean ^{13}C and ^{15}N for Fremont Burials by Diet.

Sample	n	Mean ^{13}C ‰	Mean ^{15}N ‰
GSL Wetlands High C_4 Diets	15	-12.2 ± 1.4	11.8 ± .7
GSL Wetlands Mixed Diets	11	-15.5 ± .7	11.9 ± .6
GSL Wetlands C_3 Diets	31	-18.2 ± .7	12.5 ± .6
Fremont Village Diets	13	- 8.7 ± 1.1	10.6 ± .5

Table 12. Paired t-test for Significant Differences in
Fremont ¹³C by Diet.

	t-value	df	p value
GSL High C ₄ :Mixed Diets	-14.474	10	<.0001
GSL High C ₄ :C ₃ Diets	-21.205	14	<.0001
GSL Mixed:C ₃ Diets	-22.751	10	<.0001
Fre Vill:GSL High C ₄ Diets	- 5.991	12	<.0001
Fre Vill:GSL Mixed Diets	-14.868	10	<.0001
Fre Vill:GSL C ₃ Diets	-28.924	12	<.0001

Table 13. Paired t-test for Significant Differences in
Fremont ¹⁵N by Diet.

	t-value	df	p value
GSL High C ₄ :Mixed Diets	-.385	9	.7094
GSL High C ₄ :C ₃ Diets	1.656	14	.1200
GSL Mixed:C ₃ Diets	2.025	9	.0735
Fre Vill:GSL High C ₄ Diets	5.654	12	.0001
Fre Vill:GSL Mixed Diets	6.176	9	.0002
Fre Vill:GSL C ₃ Diets	8.509	12	<.0001

Table 14. C₄ Plant Foods Native
to the Great Basin from Ethnohistoric Records.

Genus and Species	Common Name	Remarks	Reference
<i>Amaranthus</i> spp. ^a	amaranth	cultivated	Chamberlin 1911
		very important	Palmer 1878
<i>Atriplex canescens</i> ^b	saltbush	used	Chamberlin 1911
			Palmer 1878
			Fowler 1992
<i>A. confertifolia</i> ^b	shadscale	very important	Chamberlin 1911
			Fowler 1992
<i>A.</i> spp. ^b		used	Chamberlin 1911
<i>Carex</i> spp. ^c	sedge	medicinal use	Chamberlin 1911
<i>Echinochloa crusgalli</i> ^d	barnyard grass	used	Steward 1938
<i>Eragostis</i> spp. ^e	lovegrass	used	Steward 1938
<i>Euphorbia</i> spp. ^b	spruge	medicinal use	Train et al. 1957
<i>Sporobolus cryptandrus</i> ^a	sand dropseed	much used	Palmer 1878
<i>Suaeda depress</i> ^b	seepweed	used	Chamberlin 1911
<i>S. torreyana</i> ^a	seepweed	medicinal use	Train et al. 1957

^aDownton 1975

^bWelki and Caldwell 1970

^cSmith and Epstein 1971

^dCerling 1993

^eRaghavendra and Das 1978

Table 15. Comparison of Period I and II Population Means against
Mean Male ¹³C Less 42WB324 Males.

Great Salt Lake Wetlands	¹³ C ‰
Period I Population Mean	-15.1 ± 2.3
Period II Population Mean	-15.7 ± 3.1
Mean Male Value less 42WB324 Males	-15.9 ± 2.9