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ORIGINAL PAPER

Exploring diet and status in the Medieval and Modern periods of Asturias, Spain, using stable isotopes from bone collagen

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Abstract
This study explored the relationship between paleodietary patterns and social inequality in rural human populations from Medieval (AD 600–1499) and Modern (AD 1500–1800) Asturias, Spain. Diets were investigated through stable carbon and nitrogen isotopes from a sample of burials from eight cemetery sites ($n = 80$). Social status was inferred by burial location, where individuals interred within church buildings (*ad sanctos*) were compared to those buried in cemeteries. While Medieval and Modern society was strongly hierarchical, burial location is only one factor in determining the status and diet of individuals. It was hypothesized that *ad sanctos* burials would have elevated $\delta^{15}N$ values as a reflection of high-status individuals consuming protein-rich diets in comparison to lower-status peasant populations; however, results found no significant differences in $\delta^{15}N$ values between those buried in *ad sanctos* compared to those buried in cemeteries. Rather, the results of our paleodietary reconstruction indicate that the difference in $\delta^{13}C$ values is statistically significant between burial location, where *ad sanctos* burials have more elevated $\delta^{13}C$ than commoner individuals. These elevated $\delta^{13}C$ values suggest that those buried in places of prestige often consumed a different diet (more C_4 resources) from than those buried outside of church walls.

Keywords Bioarchaeology · Asturias · Spain · Paleodiet · Stable isotopes · Social status · Ad sanctos burial

Introduction

Paleodietary studies provide a unique way to evaluate the lives and food consumption patterns of individuals in the past, and provide a window into the relationship between diet and culture. Recent research using stable isotopes to explore diet in Spain has been conducted on Medieval human populations from Galicia (López-Costas 2012); the Basque country (Quirós Castillo et al. 2012; Scott and Poulson 2012; Lubritto et al. 2017; Lubritto et al. 2013; Ortega et al. 2013; Quirós Castillo 2013; Quirós Castillo et al. 2013); Valencia and Aragon (Mundee 2009; Alexander et al. 2015); Alicante (Salazar-Garcia et al. 2014; Salazar-García et al. 2016); Pamplona (Prevedorou et al. 2010); Madrid (García Collado 2012); the Balearic Islands of Majorca (Garcia et al. 2004); Granada (Molina González et al. 2016; Jiménez-Brobeil et al. 2016); and Ibiza and Formentera (Fuller et al. 2010; Nehlich et al. 2012). An isotope study using only faunal remains from the Early and High Middle Ages was also conducted on samples from the Basque Country, Castile, and Leon to explore medieval animal husbandry practices (Sirignano et al. 2014).

Recent explorations of social status and diet in Medieval societies using stable isotopes include studies from Madrid (García Collado 2012), the Basque Country (Quirós Castillo et al. 2012; Lubritto et al. 2013), Bavaria (Czermak et al. 2006), Great Britain (Lamb et al. 2014; Müldner et al. 2009; Müldner and Richards 2005), Belgium (Polet and Katzenberg 2003), Denmark (Yoder 2012), and Italy (Reitsema and Vercellotti 2012). Like Medieval society, Medieval food culture was hierarchical in nature (Adamson 2004); thus, the use of stable isotope studies to explore the relationship between diet and social status can provide insight regarding aspects of social inequality in European history.

The goal of this paper is to explore whether significant dietary differences existed within the largely rural peasant communities of Medieval and Modern Asturias, Spain. This research specifically examined dietary differences between

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perceived common and higher status elite individuals, as inferred by their burial location in order to explore aspects of social inequality in Medieval Asturias society. This study discusses stable carbon and nitrogen isotope analysis of 80 human burials from rural Medieval and Modern Christian church cemeteries located in Asturias, Spain (MacKinnon 2015; Passalacqua and MacKinnon 2016). The organization of space according to social status and hierarchy was commonplace in Medieval European communities. For this study, social status was inferred by burial location as the mortuary practice of *ad sanctos* burial suggests higher status individuals were interred within the church, whereas the general population was buried outside the church in cemeteries (Ariès 1981; Passalacqua 2012; Naji 2005; Vercellotti et al. 2011). Individuals buried *ad sanctos* during the Medieval period are more likely to have been aristocratic clergy or members of the nobility, and therefore are expected to have had greater access to the highest quality, most expensive, and rarest food resources. In the Modern period however, burial locations could simply be purchased irrespective of nobility or standing within the hierarchy of the Church. For this reason, only *ad sanctos* burials from the Medieval period will be compared in regard to social status. Because of the widespread practice of *ad sanctos* burial, it is predicted that *ad sanctos* burials will show evidence of higher dietary quality compared to commoner burials, including higher $\delta^{15}N$ values, suggesting greater consumption of higher trophic level food resources. The concept of *ad sanctos* can be applied at varying scales, examining proximity to locations or relics within churches, or the proximity to locations in relation to the cemetery; we use this term simply to differentiate between burials within the church or outside the church in the cemetery as this was the highest resolution of data available for this study.

Medieval and Modern mortuary practices

Medieval and Modern society's response to death in the form of burial and funeral rites is complex and fluid, being integrated with issues of personal, family, and community identity, the use of space, and the ordering of society and social behavior (Harding 2002; Zadoro-Rio 2003; Passalacqua 2012). Customarily, care for the dead is a reflection of how individuals, families, and groups within a society understood themselves and negotiated religious and social conflicts (Gordon and Marshall 2000). This section of the paper will briefly describe the mortuary traditions commonly practiced in Spain during the Medieval and Modern periods. Although the "the dead do not bury themselves" (Pearson 1999), their interment in a Medieval context does provide insight into social structure.

During the Medieval period in Western Europe, the most prestigious burial location was inside the church itself, especially near the altar. The desire to be buried in a privileged position has nearly always the prerogative of societal elites; however, exceptions to the rule exist. A wealthy person choosing a churchyard burial as an expression of humility was a rare occurrence (Harding 2002). For instance, the abbot Amatus of Remiremont in Gaul (d. 627 or 628) requested a humble burial near the church's doorway from where his monks, fearing the consequences of an inappropriately self-effacing burial location, later disinterred his remains and moved them to the altar (Effros 2002). Final burial location reflects how the living viewed the status of the deceased, a status which continued after death.

The development of using sacred space as a commodity (e.g., *ad sanctos* burial practices) demonstrates the complex political and socioeconomic factors surrounding death and burial. Officially, the Church never sold the grave locations, but rather space was exchanged for a charitable donation to atone for the sins of the deceased (Eire 1995). In response, a sort of "black market" trade in prestigious grave sites developed and was later outlawed by the Council of Toledo (1582) which issued a decree that graves could not be bought and sold by the laity (Eire 1995).

As sacred space became more limited, the church hierarchy established rules concerning who could be buried in the most esteemed locations. As in life, preference was given first to high-ranking monastics, followed by clergy, and then the nobility, while all others in good standing with the Church (i.e., baptized Christians) were to be buried in the consecrated grounds of the cemetery (Ariès 1981). The high altar was the most prestigious location, followed by the interior of the church closest to the altar, and lastly the vestibule. Elites were buried in the center of the community while those on the margins of society were buried on the periphery (Harding 2002). Prisoners, murderers, and the excommunicated could not be buried within the church or the consecrated cemetery and instead were buried face down in the fields or alongside roads, cremated, or thrown into rivers (Ariès 1981; Gordon and Marshall 2000). With few exceptions, high-ranking clergy and the nobility occupied graves within the inner sanctuary of the church building. Not only was burial in a privileged location legally required if requested and paid for by final will and testament, it was also reinforced by society's recognition of the power of high-status individuals (Harding 2002; Salisbury 1985; Zadoro-Rio 2003). In doing so, social roles were reinforced and reaffirmed.

Around the fourteenth century, it had become common practice to create more room for new burials by exhuming older graves and storing the bones in ossuaries within the church or in charnel houses built in the cemetery for this purpose (Ariès 1981). In Romanesque churches, like those in Asturias, small compartments in the walls of the church that open toward the outside were designed to hold skeletal remains after the flesh had decayed or been removed through boiling (Ariès 1981). These compartments were then sealed and marked with an epitaph.

In the 1600s, perhaps due to a lack of space available inside most churches and an increased awareness of sanitation and hygiene, the emphasis on being buried *ad sanctos* appears to have diminished somewhat in importance and feasibility. With the rise of middling and merchant classes, individuals outside of the nobility had the finances to discreetly purchase prestigious burial locations. The practice of the laity purchasing grave sites continued in defiance of the Council of Toledo's legislation against it, as it was an important source of income for local parishes. Moreover, if the parish priest also happened to be the nephew, younger brother, or son of a wealthy patron, the exchange of goods for graves was a convenient means of keeping money in the family (Eire 1995). The decoupling of wealth from nobility in the Modern era redefined the status of prestigious burial locations.

During the Modern period, in response to social, political, and economic changes, individuals more often requested burial in the proximity of previously buried family members, preferring burial locations that solidified their kinship, rather than social power (Harding 2002, 1992; Eire 1995). No longer did individuals negotiate for prestigious burial locations near the relics of saints, but instead preferred to be buried near the bones of their relatives. For this reason, this study does not explore social differences as inferred by burial location within Modern populations.

Stable isotopes

Stable isotopes are atoms of the same element with the same number of protons but a different number of neutrons (Fry 2006). Unlike radioisotopes, stable isotopes do not decay over time. Isotopes are identical except for the number of neutrons in the nucleus that make some isotopes "light" (fewer neutrons) and others "heavy" (more neutrons). Heavy isotopes react more slowly in chemical reactions than the light isotopes, creating a reaction difference known as fractionation (Fry 2006).

The underlying principles of fractionation enable dietary reconstruction and analysis of food webs (Schoeller 1999). Plant photosynthetic pathways vary in nature based on the mechanism they use to fix atmospheric CO_2, which in turn reflects adaptive mechanisms plants use to maximize the efficiency of carbon fixation in different environments (Heaton 1999; O'Leary 1981, 1988). During photosynthesis, an enzyme catalyzes fixation of atmospheric CO_2 into plant sugars (Fry 2006). Carbon isotopes are preferentially routed into plant tissues depending on the type of photosynthetic pathway the plant uses (C_3, C_4, or CAM). C_3 plants utilize Calvin-Benson-Bassham photosynthesis that discriminates more against the heavier ^{13}C isotope when incorporating CO_2 (Bassham et al. 1950; Beerling 2007). This includes most plants found in temperate regions including trees, shrubs, and legumes. Carbon isotope values for C_3 plants average -26.7 ± 2.7 permil (1SD) ($n = 370$) (Cerling et al. 1998, p. 163).

In contrast, C_4 plants include tropical grasses like maize, millet, amaranth, sugarcane, and sorghum, which utilize Hatch-Slack photosynthesis and discriminate less against heavier ^{13}C when incorporating CO_2. Due to these different photosynthetic pathways, C_4 plants (e.g., millet) have average $\delta^{13}C$ stable isotope values around -12.5 ± 1.1 permil (1SD) ($n = 455$) (Cerling et al. 1998). CAM plants can overlap the distributions of both C_3 and C_4 plants depending on the amount of daytime photosynthesis used; however, these plants were not available in Spain and will not be considered further. In marine ecosystems, carbon is derived from dissolved bicarbonate, submerged aquatic plants, marine algae, and phytoplankton (Fry 2006). Carbon isotope values from marine ecosystems often overlap with C_4 plants (Ambrose 1993; Schoeninger and DeNiro 1984).

Unlike carbon, nitrogen isotopes reflect the trophic level of consumers within a food web, where consumers on each tier of the web are elevated by approximately 2–4 permil over their diet (Schwarcz and Schoeninger 1991). Herbivores, omnivores, and carnivores fall into different places in the food web based on $\delta^{15}N$, which is reflected in the isotopic composition of their tissues (DeNiro and Epstein 1981). For example, herbivores demonstrate very low $\delta^{15}N$ values whereas carnivores at the top of the food chain have the most elevated $\delta^{15}N$ values. Marine fish often have more elevated $\delta^{15}N$ values than freshwater fish due to longer food chains in marine environments (Schoeninger and DeNiro 1984; Schoeninger et al. 1983; Schoeninger 1995).

The Medieval and Modern menu

An agriculture system based on wheat, barley, legumes, sheep, and goats had been firmly established in Iberia by the fourth millennium BC (Barker 1985). In Asturias, Spain, commoners consumed rye, barley, and some wheat (Peña-Chocarro et al. 2019). Rye was readily available as it tends to better tolerate winter weather and grows well in this region of northern Spain (Post 1985). Because of elevated precipitation, grain was stored in *hórreos* (regionally distinctive stone granaries supported above the ground by four posts) for protection from rodents and to inhibit mold through improved ventilation.

Planting fields with grains followed by legumes, such as beans, peas, chickpeas, and lentils, replenishes soil fertility through nitrogen fixation. The resulting bean crop was used for both human and animal consumption. Pigs, for example, were finished on beans to fatten them before being butchered for meat (Barker 1985). Because of their ability to fix nitrogen in the soil, legumes have lower $\delta^{15}N$ values than other plants. Humans and animals that primarily consume legumes as a staple may have very low $\delta^{15}N$ values if meat is not consumed as part of the diet (Katzenberg and Saunders 2008).

Although many beans were used for fodder, the large Asturian white bean called *fabes* is key to the traditional stew called *fabada*, which is made with cured pork and sausage. Legume stews made without meat would have made appropriate high-protein meals during the meatless days of Lent. After 1492, many Old World beans were displaced by New World varieties that had superior yield and protein content (Crosby 1972).

In addition to new bean varieties, additional New World C_3 plants that became cultigens in Spain included the chili pepper, tomato, and eventually the potato. Of these new crops, chili peppers were the first to be cultivated as soon as 1493, while the potato remained underutilized until the 1670s (Chabrán 2002). Ultimately, the tomato and chili pepper, which butchers used to flavor and color sausage, became thoroughly integrated into Spanish cuisine (Chabrán 2002).

New World C_4 crops include amaranth (*Amaranthus tricolor*) and maize (*Zea mays*). Amaranth was cultivated in Iberia as a horticultural novelty, and not as a food source. In contrast, maize became a staple crop by the 1600s (Galinat 1992; Newsom 2009). Maize grew extremely well in poor soils and had no natural pests in western Europe, which allowed Asturian farmers to cultivate land that was previously unsuitable for agriculture (Crosby 1972). In 1670, John Locke recalled from his travels that the people of France were eating a grain called *bled d'Espagne* ("Spanish wheat") that was imported from northern Spain, where both people and their livestock were consuming maize (Locke and Lough 1953). By 1700, landowners encouraged their tenants to grow maize because it yielded more calories per unit of land than other crops and produced a surplus suitable for animal fodder (Ringrose 1998; Fernandez 1990).

Old World C_4 crops include sugar, millet, and sorghum. The Moors first introduced sugar (*Saccharum officinarum*) as a spice to southern Spain in the eighth century (Mintz 1985). Sugar production in Spain was localized to the southern Mediterranean coast and later to the Atlantic islands, although sugar itself was not widely available in northern Spain. Sugar was scarce and first used as a medicine, a spice-condiment, and a decorative luxury rather than a sweetener (Mintz 1985). As early as the 1300s, slave labor was firmly rooted as the most profitable way to manufacture sugar in the eastern Mediterranean (Galloway 1977). In the 1500s, sugar and slavery were institutions imported to the New World, and by 1516, Spain first shipped sugar grown in the West Indies to Europe where it became an increasingly common commodity among all social classes (Mintz 1985).

Two highly adaptable and fast-growing C_4 grains native to east Africa and cultivated in Europe are millet and sorghum. In Africa, millet is found in porridges, weaning foods, fermented products, couscous, and other foods that were foreign to Medieval western Europeans who viewed millet as unpalatable and relegated it to animal fodder despite its high nutritional value (Vietmeyer 1996).

While finger millet and pearl millet are the two varieties that are grown most commonly outside of Africa, foxtail millet (*Setaria italica*) and broomcorn millet (*Panicum miliaceum*) are known cultivars in the Asturias region (Moreno-Larrazabal et al. 2015). Crops favoring warm weather may have been more productive in the tenth and twelfth centuries during the Medieval Climatic Anomaly (MCA), a period of higher temperatures recorded in dendrochronology and glacial cores that lasted from roughly 950 to 1250 (Hughes and Diaz 1994; Lamb 1965; Mann 2002; Payne 2011).

Sorghum (*Sorghum tricolor*) first appeared in written documentation in Italy in the 1600s, where it was used to make brooms and brushes, and not as a food source (Vietmeyer 1996). Sorghum grows exceptionally fast and thrives in marginal areas where other cereals fail. Sorghum naturally occurs in white, yellow, brown, and red varieties and at least one sorghum variety is adaptable to waterlogging and can survive for several weeks in standing water (Vietmeyer 1996). Sorghum of this variety could have grown in the rainy environment of Asturias, assuming the soil was properly drained; however, despite its nutritional values and versatility as a food source, sorghum was looked down upon as a "coarse" grain fit only for animals and the poor (Vietmeyer 1996).

The eleventh century writings of Andalusian historian and geographer Al-Bakri (d. 1094) described a type of cereal grain growing productively in Galicia, the region west of Asturias, that may have been millet, but is possibly sorghum, as he described red and white varieties (Watson 1983). It is unknown to what degree sorghum and millet were cultivated in Asturias, but presumably both crops would have grown better during the mild and warm periods of the MCA from roughly 950 to 1250.

There is little published work specifically regarding available foodstuffs from medieval or modern Spanish archaeological sites (Alexander et al. 2015; Grau-Sologestoa 2014; Grau-Sologestoa 2016; Grau-Sologestoa 2017). Grau-Sologestoa (2014) offers a review of the zooarchaeological literature of the Iberian Peninsula arguing that only recently have such studies been pursued. Recently, Grau-Sologestoa (2016) examined faunal remains from 11 early medieval sites from the Basque Country in Spain and found that while typically cattle were the most frequently found, followed by sheep/goat, and finally pig, there was a high degree of variability between sites in terms of the relative proportions of species consumed. Grau-Sologestoa (2017) then expanded this sample with additional sites in numerous regions in Spain and found similar variability, noting that cattle were particularly common in rural sites.

Meat consumption differences between the socioeconomic classes

The lack of zooarchaeological research and its relation to diet compounds the relative lack of records regarding the daily diet of individuals from Asturias, or Spain generally, during the Medieval or Modern periods. However, higher consumption of protein is often an indicator of higher status, and Quirós Castillo (2013) found evidence for sex-biased access to protein. Furthermore, faunal remains from early medieval sites in the Basque Country in Spain indicate rural commoners were consuming greater amounts of protein, suggesting these populations were emulating high-status dietary patterns (Grau-Sologestoa 2016). While we will attempt to give a brief discussion of diet during these periods, Grau-Sologestoa (2017) argues that the diets of high-status individuals likely changed throughout the Medieval period, and that such diets were likely characterized by the consumption of a wide variety of species reflecting their greater access to diverse foodstuffs.

Predominately, nobility shunned vegetables as “poor foods” and instead consumed large quantities of meat, with dishes including veal, suckling kid (*cabritos*), suckling pig (*cochinillo*), and unweaned lamb (*lechazo*) (Roden 2011). In contrast, commoners consumed relatively little meat in their diet other than pork from the annual slaughter of the family pig, or beef or mutton culled from the herd before winter (Fernandez 1990). Even dairy products from cow, sheep, and goat were relatively scarce as such animals were selected for plowing fields, fertilizer (manure), or wool, rather than for milk production. Sheep were valued primarily for their wool and secondarily for their cheese, both of which could be harvested continuously for several seasons. When population levels were high, vegetable foods were consumed, but when population decreased, such as after the Black Death, people at all levels of society consumed more meat purchased with surplus income from higher wages (Boserup 1985).

Waterfowl and birds retained a special status as these were considered a “cold” food and, like fish, were acceptable to consume during fasting days (Cosman 1976). Chickens became increasingly more common through the Medieval period, and genetic analysis of chicken bone in archaeological assemblages indicates a shift in chicken husbandry practices between the ninth and twelfth centuries that favored an allele associated with increased egg production and reduced aggression (Loog et al. 2017). Loog et al. (2017) attribute the spread of this allele to Catholic fasting practices and changes in food preference during the Medieval period. The popularity of the chicken may have facilitated the introduction of the turkey in the sixteenth century. The turkey was introduced to Spain from the Americas in 1523 and, along with chili peppers, represented the first New World foodstuffs to be integrated into the Spanish diet (Chabrán 2002). Unlike chickens that were primarily kept for egg production, turkeys were raised for consumption on special occasions and feast days (Roden 2011).

Because olives did not grow well in Asturias, cooking was done with lard procured from pigs (Salisbury 1985). Pigs often roamed freely to forage upon wild acorns, and contracts were drawn up to extend grazing rights to the owners of the swineherds from the owners of the oak woodlands (Salisbury 1985). Rural peasants and town dwellers alike raised pigs that were allowed to roam the streets and consume excess garbage (Tannahill 1973). Later, when pigs were penned up on small family plots, they were finished with acorns for the last three months to put on additional fat (Roden 2011). The meat from pigs could also be preserved for an extended period of time compared to other mammalian species (Muñiz 1992). Since Islam and Judaism forbid the consumption of pork (Grau-Sologestoa 2017), the prevalence of pork and its products found in Spanish dishes may stem from the need of converts to prove their allegiance to Catholicism during the Inquisition (Roden 2011).

Marine and aquatic resources

The Church prescribed fasting during the seasons of Lent and Advent as well as Wednesdays, Fridays, Saturdays, and on the evenings of great feasts. This fasting regime amounted to abstinence from meat for nearly half the year. Monastic communities and the aristocracy were the greatest consumers of the expensive marine resources that would have been predominately inaccessible to the lower classes. Marine resources from the Cantabrian Sea and Atlantic Ocean were in high demand in the Middle Ages as the emphasis on fasting from flesh meats grew in popularity and practice. Ascetics taught that fasting tamed the passions and disciplined the body. As such, the demand for fish increased between the beginning of Advent in late autumn and the end of Lent in spring when marine fishing was the least accessible, thus increasing the demand for dried fish which could be purchased, salted, and stored in advance of the fasting period (Whited et al. 2005; Woolgar 2000).

The demand for fish soared when the Catholic Church approved the consumption of fish on Fridays during periods of fasting. To obtain fresh sources of fish, artificial ponds like those created around Avilés, an Asturian city on the Cantabrian coast, were created to farm salmon (González García and Ruiz de la Peña Solar 1972). Despite the presence of artificial ponds, most of which were privately owned by the nobility or clergy, fresh fish was still too expensive for commoners and unsustainable aquaculture practices could not keep up with the demand (Fagan 2006). The demand for fish escalated after 1300, and new sources of fish protein were sought from the sea (Fagan 2006). Asturian streams and rivers contain eel, salmon, and trout. Visigoth law stated that those with property bordering a freshwater stream were permitted to net half the stream in order to catch fish, but not to block the stream entirely so that those without waterfront property could fish downstream (Salisbury 1985). Over time, increasing agriculture, urbanization, development, and range herding may have inadvertently damaged watersheds through sediment deposition and animal waste pollutants (Woolgar 2000). Eventually, freshwater fish became a rare resource, further reinforcing their status as an elite foodstuff.

Materials

This study explored Medieval and Modern diets in human burials from eight sites within Asturias, Spain (Fig. 1). Faunal remains from an additional ninth site were also included. A simplified two-phase chronology based on Passalacqua (2012) was utilized to categorize sites by time period. These two categories are the Medieval period, which corresponds to AD 600 to 1499, and the Modern period, which corresponds to AD 1500 to 1800. As four sites span multiple time periods, individuals were categorized into one of two time periods based on individual assessment of that burial by the original excavating archaeologists.

A. *Medieval Necropolis of Castro de Chao Samartín* was originally a Bronze Age settlement occupied by the Romans until the second century AD when it was abandoned after a catastrophic earthquake. After six centuries of disuse, Asturians in the eighth century returned to the site and established the necropolis (Villa Valdés et al. 2008). Analysis of the human burials suggests the Medieval population was stationary with a low prevalence of skeletal disease or nutritional stress indicators, consistent with a relatively healthy local population, rather than a population fluctuating with migratory pilgrims (Villa Valdés et al. 2008). Radiocarbon dating of the skeletal

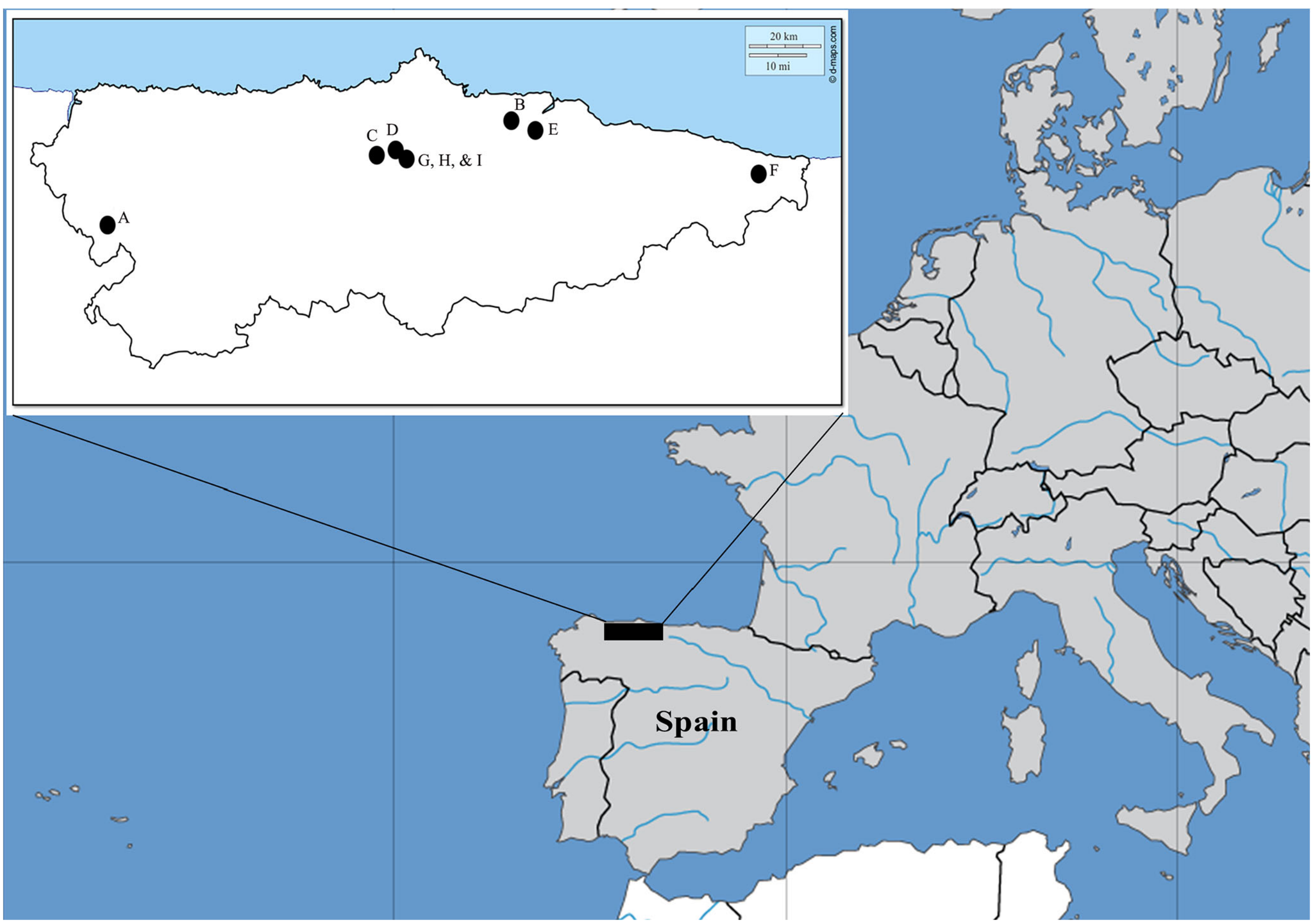

Fig. 1 Map of the principality of Asturias, Spain. The archaeological site locations included in this study are indicated by letter. (A) Medieval Necropolis of Castro de Chao Samartín. (B) The Early Medieval Cemetery of the Church of San Salvador de Valdediós. (C) The Medieval Cemetery of the Church of San Pedro de Nora. (D) The Medieval Cemetery of the Church of San Miguel de Lillo. (E) The Church of San Julián de Viñón. (F) The Church of San Pedro de Plecín. (G) The Catedral de San Salvador in Oviedo. (H) The Hospital and Church of San Juan Bautista, and the Colegio San Isidoro Oviedo. (I) Castiellu de Llagú, Latores, Oviedo. Map credit: David Liuzzo - Own work, CC BY-SA 3.0 https://commons.wikimedia.org/w/index.php?curid=1135831

remains from the cemetery provides an interval of AD 629 to 1470 (Villa Valdés et al. 2008).

B. *The Early Medieval Cemetery of the Church of San Salvador de Valdediós* is located approximately 5.7 miles (9.3 km) from the city of Villaviciosa and was consecrated in AD 892 during the reign of Alfonso III (c. AD 848–910). Although the church and its necropolis have been in use from AD 900 to 1800, only burials that date chronologically to AD 900 to 1200 were available for study (Passalacqua 2012). Some of these burials contain intentional deposits of shell, mainly marine mollusks, as well as evidence of small fires having burned on top of the graves, which suggests that this community practiced unique funerary rituals in the Middle Ages (Fernández Conde and Alonso Alonso 1992). Burial b.4, included in this study, is one of these aforementioned burials that contained a deposit of shells (Fernández Conde and Alonso Alonso 1992). The presence of shells within burials (e.g., Jaca, Spain) has been associated with pilgrim burials, and the number of shells within the burial may correspond to the number of times the individual made the pilgrimage (Mundee 2009). In Asturias, Spain, the scallop is an important symbol of Saint James and the pilgrimage to Santiago de Compostela; however, the particular types of marine shell associated with burial b.4 were not identified to the level of species.

C. *The Medieval Cemetery of the Church of San Pedro de Nora* is located in the municipality of Las Regueras along the River Nora. Burials were differentiated chronologically by their distinct burial typologies and site stratigraphy which date them to the twelfth to fifteenth centuries (Adán Alvarez et al. 1997; Martinez Faedo and Adán Alvarez 1995).

D. *The Medieval Cemetery of the Church of San Miguel de Lillo* was consecrated by King Ramiro I (c. AD 842–850) in 848. The church was originally built to accompany a royal country palace that was converted to a church in the twelfth century. Burials for this study are from graves recovered from the exterior of the church and date to 1100–1400 (Passalacqua 2012). While this structure may have held important significance to the aristocracy, individuals included in this study from this site have been categorized as "common" based on their location outside of the church.

E. *The Church of San Julián de Viñón* was excavated in 2005 and dates to approximately 1400–1800 (Passalacqua 2012). The majority of burials represent common burials that date to 1400–1800; however, two (b. 96 and b. 39) recovered from within the apse of the church are thought to be higher status individuals that date to the Pre-Romanesque founding of the church in the twelfth century (Passalacqua 2012).

F. *The Church of San Pedro de Plecín* (known as San Salvador prior to the fourteenth or fifteenth centuries) is a late-Romanesque Church located in Alles, the capital city of the municipality of Peñamellera Alta. The earliest burials date to the eleventh century and were recovered from the southern side of the church (Adán Alvarez 1995). Two burials from 1300 to 1500 were located within the church. One of these (b. 121) contained a coin from the reign of Alfonso V of Portugal (1438–1481) (Adán Alvarez 1995). Until the eighteenth century, the prosperous Mier family financed the church and was buried within a family crypt; however, when they withdrew their patronage in 1778, the church fell into disrepair (Adán Alvarez 1995).

G. *The Catedral de San Salvador in Oviedo* is a minor basilica located in Asturias' capital, Oviedo. Fruela I founded the cathedral in AD 781. Pilgrims on the Way of St. James often visited the reliquary of San Salvador on their way to Santiago de Compostela in Galicia (Davies and Davies 1982). Renovation work uncovered three *ad sanctos* burials (b. 19, b.20, and b. 21) located in limestone sarcophagi typical of high-status medieval burials, possibly dating to the tenth century (García de Castro Valdés 2002). The quality of the limestone sarcophagi and their privileged location within the cathedral suggests that these individuals were aristocratic clergy (García de Castro Valdés 2002). An additional burial, b. 77, was uncovered from an *ad sanctos* location within the Church.

H. *The Hospital and Church of San Juan Bautista, and the Colegio San Isidoro Oviedo,* is unique from the other sites included in this study because of the presence of a hospital administered by the Catholic Church that functioned until the eighteenth century. Alfonso VI established the hospital and church in 1096 (García de Castro Valdés 2002). Common burials (b. 34, b. 35, b. 36, b. 83, b. 84, b. 85) from this cemetery surrounding the exterior of the church date to 1300–1600 based in part on coins discovered in the same stratigraphic level (García de Castro Valdés 2002). Historic documents indicate that pilgrims visiting the Cathedral of San Salvador used the hospital, and that Alfonso VI established it for this purpose (García de Castro Valdés 2002). Hospitals during the Medieval period were not only places of rest and rehabilitation for the sick, but served many purposed in their communities, such as providing for the poor and the elderly, and offering beds for pilgrims and travelers (Bownes et al. 2018).

I. *Castiellu de Llagú* is an additional ninth site from where faunal remains were obtained; however, no human skeletal remains were available from this location. This site is located approximately 10 km southwest of Oviedo and was largely destroyed by the construction of a quarry.

The individuals included in this project largely represent rural peasants. The majority of the sites included in this study are smaller churches from the mountainous and rural region of Asturias. While rural peasants of the time are often considered to have been subsistence farmers, Grau-Sologestoa (2016, p. 48) suggests that many of these farmers were actually not only self-sufficient, but also produced enough goods to generate a surplus. A lack of artifacts or grave goods in Christian burials is common at this time and thus precludes further refinement of status or wealth, aside from the practice of *ad sanctos* burial.

Individuals from these cemeteries were split into two groups reflecting their relative status as indicated by their *ad sanctos* mortuary context; "commoners" represent those individuals buried outside of the church walls and "elites" were those individuals buried within the church walls (Passalacqua 2012). The use of commoner and elite are relative terms meant to differentiate individuals that were likely relatively wealthy in terms of social and/or financial capital (elites), and individuals that were likely relatively poor in terms of such capital (commoners). In theory, individuals with more social and/or financial capital would have had life experiences which would have differentiated them from others, potentially manifesting in terms of different health or dietary signatures. Using only traditional skeletal indicators of health, Passalacqua (2012) found no significant differences between these two groups.

Methods

For this study, 87 adult individuals were initially sampled. Of those, 80 samples yielded results that met quality standards based on atomic C/N ratios and collagen yields. Each burial was then assigned a unique tracking number (b. number). Age-at-death estimates were based on methods found in Buikstra and Ubelaker (1994) as well as Uhl and Passalacqua (2009). Sex was estimated using latent profile analysis (LPA) in Mplus for all individuals considered to be adults (those with fused long bone epiphyses) (Passalacqua 2012; Passalacqua et al. 2013).

Approximately 1–2 g of bone was obtained from each individual. Non-pathological bone was preferentially selected over pathological bone. In addition to the human samples, 42 faunal elements representing cattle, pig, sheep/goat, indeterminate artiodactyl, dog, rodent, chicken, small bird, and freshwater and marine fish were obtained from the same region and time periods and analyzed to create an isotopic baseline for the local food web. Ideally, multiple samples from each site would be needed to create site-specific baselines; however, large enough samples were not available for this purpose. Faunal bones with diagnostic features were compared with the California State University, Chico (CSU, Chico), zooarchaeology reference collection for species identification in an effort to differentiate between domesticated and wild animals. Finally, for some under-represented taxa (e.g., freshwater and marine fish), faunal data were included from the published literature from western Europe (Müldner and Richards 2005, 2007; Fuller et al. 2012). To compare human values to the faunal baseline, a food web was created using stable isotope data derived from faunal remains from the archaeological sites and from published literature. All collagen samples were prepared at CSU, Chico, following protocols outlined in Ambrose (1993) and Schwarcz and Schoeninger (1991). Samples were cleaned to remove surface contaminants first by mechanical abrasion with a diamond-studded Dremel bit followed by successive ultrasonic cleansing washes of distilled, deionized water (dH_2O), 95% ethanol, and 100% ethanol. Samples were submerged in 40 mL of a 0.25 M solution of hydrochloric acid (HCL) and refreshed periodically until completely demineralized. Next, samples were rinsed three times with dH_2O to remove any residual acid. Samples were them soaked for 24 h in a 0.125 M solution of sodium hydroxide (NaOH) to remove humics and other contaminants.

After 24 h, the remaining NaOH was thoroughly removed by subjecting the samples to five successive rinses of dH_2O. Once rinsed and dried, 15 mL of dH_2O ($pH \approx 3$) was added to solubilize the collagen pseudomorphs. Each sample was then heated overnight in an oven set at 70 °C. The resulting collagen was then poured from the centrifuge tube into a Teflon cup and dried in the oven. The addition of dH_2O ($pH \approx 3$) followed by pouring off the remaining liquid into a Teflon cup was repeated twice or until all the collagen was solubilized. The dried collagen that accumulated within the Teflon cup was then rehydrated by the addition of 3 mL of dH_2O ($pH \approx 3$) and the resulting liquid collagen was poured into a glass vial. After the collagen within the glass vial was frozen, it was freeze-dried and weighed for mass spectrometry.

The prepared collagen samples were analyzed at the UC Davis Stable Isotope Facility in the Department of Plant Sciences. Between 1.5 and 2.0 mg of freeze-dried collagen was weighed into tin capsules. Values for $\delta^{13}C$ and $\delta^{15}N$ were obtained by a PDZ Europa ANCA-GSL elemental analyzer, interfaced with a PDX Europa 20-20 isotope ratio mass spectrometer (internal precision ± 0.2‰ for $\delta^{13}C$ and ± 0.3‰ for $\delta^{15}N$).

The easiest and most reliable way of evaluating diagenesis is collagen yield expressed as a percent of the original processed bone weight (van Klinken 1999) and the atomic C/N ratio (DeNiro 1985). Dividing the final collagen sample weight by the starting bone sample weight produces the collagen yield. Eighty human samples and 37 faunal samples were included based on adequate collagen yields and C/N ratios within the acceptable range. This included 11 samples that had good C/N ratios but collagen yields that were inaccurately recorded due to balance error. However, these samples had visible collagen in the vials. Due to small sample sizes and non-normal distributions, the Mann-Whitney U test was used for all sample comparisons using IBM SPSS Statistics v. 19. For all statistical analyses, an alpha level of 0.05 is used as a threshold for statistical significance (i.e., $\alpha = 0.05$).

Results and discussion

The results of the analysis of the faunal remains from Asturias indicate that cattle (*bos*) were fed predominately a C_3 diet of wild grasses while pig (*sus*), sheep (*ovis*), and goat (*capra*) consumed a mixed C_3/C_4 diet (Table 1). Individual results of faunal remains by species are presented in Table 2. These data suggest that transhumant cattle were feeding on wild C_3 grasses away from villages while pig, sheep, and goat were kept closer to home and fed a diet more consistent with humans. Results from a dog and a rodent plot most similarly to humans, which suggests that these animals were consuming a diet that likely included kitchen refuse.

Both chickens and smaller birds show a high C_4 diet. In other areas of Spain, the use of millet as chicken feed has been documented (Alexander et al. 2015). It may be that chickens were intentionally fed millet or possibly sorghum, or that they were consuming wild C_4 grasses and forbs native to western Europe. Notable across fauna species is the elevated $\delta^{15}N$ signature. The mean $\delta^{15}N$ of chickens is 9.1 permil and the mean $\delta^{15}N$ value of small birds is 7.8 permil. While both chickens and small birds likely consumed insects that elevated their $\delta^{15}N$ levels, chickens raised in enclosures may have been consuming plants growing nearby which could have been elevated in ^{15}N due to exposure to chicken manure.

Compared to chickens and small birds, herbivores also had lower $\delta^{15}N$ levels, consistent with consumption of plants; the mean $\delta^{15}N$ value of cattle is 5.1 ± 1.0 permil (range = 3.5 to 6.8‰). In contrast, the mean $\delta^{15}N$ values of pigs (7.4‰), sheep/goat (7.0‰), and artiodactyls (6.1‰) are somewhat elevated and may indicate consumption of plants and possibly animal protein from rubbish piles, as pigs and goats are known to be opportunistic feeders. Among pigs and sheep/goat, there is the wide range of values in both $\delta^{13}C$ and $\delta^{15}N$. The range for ovis/capra $\delta^{13}C$ is 9.1 permil and the range for pig $\delta^{15}N$ is 6.2 permil. These wide ranges indicate that individuals of these species were not eating a homogenous diet; however, this may also reflect that the faunal samples were derived from several different archaeological sites. Higher $\delta^{15}N$ for some of these faunal samples may reflect manuring practices, which can enrich the soil in ^{15}N.

Before comparing human to faunal values using the food web, stable isotope values of faunal bone collagen were adjusted to account for fractionation between food resources and the consumer's tissues. The construction of a food web is a two-step process. First, to account for fractionation between bone collagen and muscle tissue, the mammalian $\delta^{13}C$ collagen values were adjusted by −2.4 permil and the marine fish $\delta^{13}C$ collagen values by −3.7 permil (DeNiro and Epstein 1978). Mean values are shown on a bivariate plot where each box represents the minimum and maximum values of faunal tissue (see Fig. 2). To directly compare the adjusted faunal tissue values with humans, the $\delta^{13}C$ collagen and $\delta^{15}N$ collagen must also be adjusted. The human $\delta^{13}C$ collagen values

Table 1 Stable isotope data from faunal bone collagen from Asturias, Spain, including $\delta^{13}C$, adjusted $\delta^{13}C$, and $\delta^{15}N$

Common name	Scientific name	n[a]	Average $\delta^{13}C$ (‰)	Adjusted average $\delta^{13}C$ (‰)[b]	$\delta^{15}N$ (‰)
Cattle	*Bos taurus*	10	−21.6 ± 0.6	−24.0 ± 0.6	5.1 ± 1.0
Pig	*Sus scrofa*	5	−21.7 ± 0.9	−24.1 ± 0.9	7.4 ± 2.4
Sheep and/or goat	*Ovis aries -Capra hircus*	7	−19.2 ± 3.2	−21.6 ± 3.2	7.0 ± 2.0
Juvenile goat	*Capra hircus*	1	−20.9	−23.3	6.0
Even-toed ungulates	*Artiodactyla*	6	−21.6 ± 1.7	−23.9	6.1 ± 2.3
Dog	*Canis familiaris*	1	−19.1	−21.5	9.0
Rodent	*Rodentia*	1	−17.1	−19.5	9.3
Chicken	*Gallus gallus*	2	−15.7	−18.1	9.1
Small bird	*Passeriformes*	2	−16.0	−18.4	7.8
Marine fish	–	2	−15.6	−19.3	11.4
Marine fish[c]	–	49	−14.5 ± 1.8	−18.2 ± 1.8	12.3 ± 3
Freshwater fish[d]	–	52	−22.3 ± 4	−26 ± 4	12 ± 0.5

[a] Number of samples, standard deviations provided when $n > 2$

[b] Mammals are adjusted by −2.4 permil, and marine fish are adjusted by −3.7 permil to correct for fractionation between bone collagen and muscle tissue (DeNiro and Epstein 1978)

[c] Additional marine fish values were adapted from Müldner and Richards (2007), Müldner and Richards (2005), and Fuller et al. (2012)

[d] Freshwater fish values were adapted from Müldner and Richards (2007) and Fuller et al. (2012)

Table 2 Stable isotope data from faunal bone collagen from Asturias, Spain ($n = 37$), including $\delta^{13}C$, $\delta^{15}N$, C/N, and % collagen yield

Unique ID	Catalog number	Common name	Scientific name	Site	$\delta^{13}C$ (‰)	Adjusted $\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C/N	% collagen yield
AF002	Cdo Portico Cata E Nivel 8	Cow	*Bos taurus*	G	− 21.9	− 24.3	4.2	3.3	10
AF005	Cdo Portico Cata E Nivel 8	Cow	*Bos taurus*	G	− 22.2	− 24.6	5.6	3.6	2
AF008	CdO Portico Cata C ex tumba	Cow	*Bos taurus*	G	− 22	− 24.4	5.4	3.3	15
AF037	EAO Co-02333	Cow	*Bos taurus*	G	− 22	− 24.4	5.5	3.4	3
AF096	SSV Santa Maria de Valdedios B-236-94	Cow	*Bos taurus*	B	− 22.3	− 24.7	3.5	3.3	13
F2	CR5/03/NA	Cow	*Bos taurus*	I	− 20.3	− 22.7	5.6	3.3	2
F3	CLL/00/NA	Cow	*Bos taurus*	I	− 21.2	− 23.6	4.9	3.3	12
F6	C10/XX/NA	Cow	*Bos taurus*	I	− 21.3	− 23.7	5.2	3.3	6
F8	SPN/91/J8/NIII b	Cow	*Bos taurus*	C	− 21.1	− 23.5	4.2	3.3	4
F10	CdO/91/CE/NII	Cow	*Bos taurus*	G	− 21.4	− 23.8	6.8	3.4	3
AF003	Cdo Portico Cata E Nivel 8	Pig	*Sus scrofa*	G	− 20.7	− 23.1	7.7	3.4	6
AF054	SML 90-27-2	Pig	*Sus scrofa*	D	− 22.6	− 25	8.8	3.4	12
AF074	SJ T39 U129	Pig	*Sus scrofa*	H	− 21.7	− 24.1	7.4	3.3	5
F1	CR5/03/NA	Pig	*Sus scrofa*	I	− 20.7	− 23.1	9.6	3.4	1
F7	SPN/91/J8/NIII a	Pig	*Sus scrofa*	C	− 22.6	− 25.0	3.4	3.5	13
AF009	Cdo Portico Cata E Nivel 2	Sheep or goat	*Ovis aries–Capra hircus*	G	− 22.2	− 24.6	5.7	3.3	5
AF036	EAO Co-02333	Sheep or goat	*Ovis aries–Capra hircus*	G	− 21.1	− 23.5	6.9	3.4	11
AF097	SSV Santa Maria de Valdedios B-236-94	Sheep or goat	*Ovis aries–Capra hircus*	B	− 16.9	− 19.3	7.8	3.3	17
AF103	SPP 1991 interior estructure	Sheep or goat	*Ovis aries–Capra hircus*	F	− 19.5	− 21.9	9.4	3.3	16
AF105	SPP Trina N2	Sheep or goat	*Ovis aries–Capra hircus*	F	− 13.1	− 15.5	9.4	3.3	22
AF112	SML 90-27-1	Sheep or goat	*Ovis aries–Capra hircus*	D	− 20.2	− 22.6	4	3.3	21
F9	SPN/91/J8/NIII c	Sheep or goat	*Ovis aries–Capra hircus*	C	− 21.3	− 23.7	5.7	3.4	0
AF010	Cdo Portico Cata E Nivel	Juvenile goat	*Capra hircus*	G	− 20.9	− 23.3	6.0	3.4	3
AF006	Cdo Portico Cata E Nivel 8	Even-toed ungulate	*Artiodactyla*	G	− 22.9	− 25.3	5.2	3.4	5
AF035	SPN i9-39 No 3	Even-toed ungulate	*Artiodactyla*	C	− 22.2	− 24.6	3.5	3.3	6
AF110	SML 90-26-11/1	Even-toed ungulate	*Artiodactyla*	D	− 18.9	− 21.3	10.3	3.4	12
F4	CLL/00/C12/B36	Even-toed ungulate	*Artiodactyla*	I	− 22	− 24.4	5.6	3.3	0
F5	CLL/00/C12/B36	Even-toed ungulate	*Artiodactyla*	I	− 22.3	− 24.7	5.3	3.4	6
AF006	Cdo Portico Cata E Nivel 8	Even-toed ungulate	*Artiodactyla*	G	− 22.9	− 25.3	5.2	3.3	5
AF035	SPN i9-39 No 3	Dog	*Canis familiaris*	C	− 19.1	− 21.5	9.0	3.2	6
AF057	SML 90-27-5	Rodent	*Rodentia*	D	− 17.1	− 19.5	9.3	3.7	84
AF079	SML 90-27-2	Chicken	*Gallus gallus*	D	− 15.5	− 17.9	9.1	3.3	22
AF094	SSV T8	Chicken	*Gallus gallus*	B	− 15.9	− 18.3	9.2	3.4	8
AF028	CdO Sanemiento de la Catedral 1991 No 3b	Small bird	*Passeriformes*	G	− 13.4	− 15.8	9.5	3.2	16
AF056	SML 90-27-4	Small bird	*Passeriformes*	D	− 18.6	− 21.0	6.1	3.3	33
AF055	SML 90-27-3	Marine fish	–	D	− 14.5	− 18.2	7.1	3.6	27
AF078	SML 90-27-2	Marine fish	–	D	− 16.8	− 20.5	15.6	4.0	87

Site codes: A—Medieval Necropolis of Castro de Chao Samartín; B—The Early Medieval Cemetery of the Church of San Salvador de Valdediós; C—The Medieval Cemetery of the Church of San Pedro de Nora; D—The Medieval Cemetery of the Church of San Miguel de Lillo; E—The Church of San Julián de Viñón; F—The Church of San Pedro de Plecín; G—The Catedral de San Salvador in Oviedo; H—The Hospital and Church of San Juan Bautista, and the Colegio San Isidoro Oviedo; I—Castiellu de Llagú, Latores, Oviedo

were adjusted by + 5 permil (these values became less negative) to account for fractionation (Ambrose and Norr 1993; Tieszen and Fagre 1993; van der Merwe and Vogel 1978). The human $\delta^{15}N$ collagen values were decreased by 3 permil to adjust for the trophic effect (DeNiro and Epstein 1981; DeNiro and Schoeninger 1983). As no freshwater fish remains were available for study, the range for freshwater fish values presented here is adapted from Müldner and Richards (2005,

2007) and Fuller et al. (2012). The purpose of this food web is to discuss food sources (i.e., meat), rather than faunal values and to compare humans to this plot as a way to illustrate human diet.

Isotopic values and demographic information by site for the 80 human samples selected for this study are reported in Table 3. Of these, 61 date to the Medieval period (pre-1500) and 19 date to the Modern period (post-1500). Due to poor skeletal preservation, sex could not be estimated reliably for most individuals. For the purposes of this study, probable males were grouped with males, and probable females were grouped with females; however, there were no statistically significant differences between the isotopic values of males and females ($p > 0.05$, Mann Whitney *U*).

Overall, $\delta^{13}C$ isotope values for all adults from Medieval period burials ($n = 61$) vary from − 20.1 to − 10.7 permil with a mean of − 18.3 ± 1.8 permil (1SD), whereas $\delta^{15}N$ values vary from + 8.7 to + 13.9 permil with a mean of + 10.3 ± 1.2 permil (1SD). Values of $\delta^{13}C$ for Modern period adults ($n = 19$) vary from − 19.4 to − 13.1 permil with a mean of − 17.6 ± 2.2 permil (1SD), and $\delta^{15}N$ values vary from + 8.1 to + 11.6 permil with a mean of + 9.9 ± 0.9 permil (1SD). No significant differences in either $\delta^{13}C$ or $\delta^{15}N$ were observed between time periods ($p > 0.05$, Mann Whitney *U*). Bone collagen $\delta^{13}C$ and $\delta^{15}N$ values are plotted in Fig. 3 for Medieval and Modern period burials.

Adults who consumed the highest trophic level foods were found in graves located in Oviedo, the capital of Asturias. Elevated $\delta^{15}N$ and low $\delta^{13}C$ values come from terrestrial C_3 environments (e.g., omnivorous animals such as pig or goat) and aquatic ecosystems (high-trophic level freshwater). This suggests that individuals buried in Oviedo had greater access to high-trophic-level foods compared to those buried in the rural countryside. Comparison of human bone collagen $\delta^{13}C$ and $\delta^{15}N$ values with faunal values and expected floral values indicate that both Medieval and Modern period adults primarily consumed C_3-based terrestrial resources, such as grains, the meat of herbivores and omnivores, and possible freshwater fish (Fig. 2). For eight burials (see lower right pane of Fig. 3), high $\delta^{13}C$ values and low $\delta^{15}N$ values are consistent with significant consumption of C_4 grains, such as millet and sorghum. Four of these burials date to the Medieval period and four date to the Modern period. Marine resources appear to have contributed little to diet overall. Individuals who could afford marine fish probably consumed it on occasion, perhaps during periods of fasting, but marine resources were not a dietary staple. However, results suggest that some individuals, namely those buried in locations of privilege, did consume freshwater fish in addition to other high-trophic-level animal protein from C_3 terrestrial ecosystems.

Status differences in diet

Status differences in diet were evaluated by comparing both $\delta^{13}C$ and $\delta^{15}N$ values between individual common and *ad sanctos* burials (Fig. 4). For all common adults from

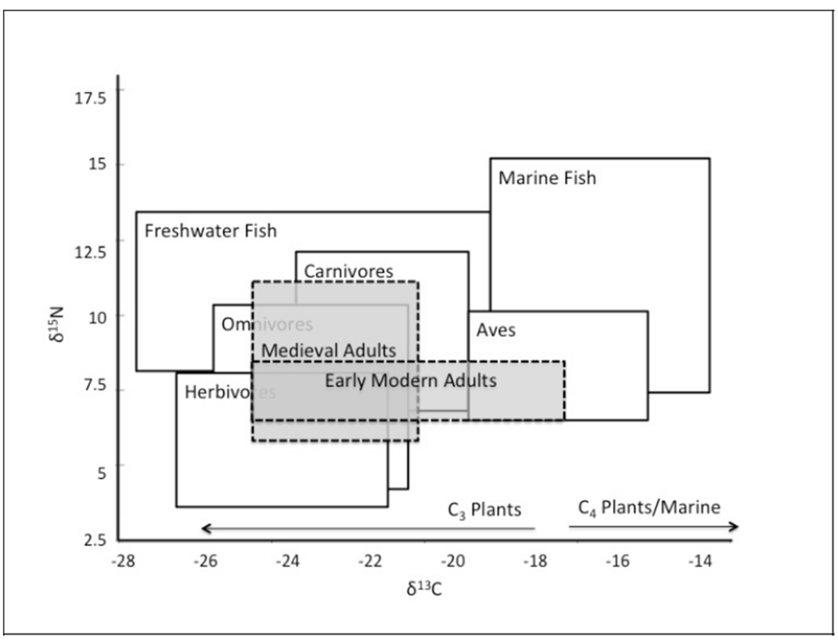

Fig. 2 Food web for Medieval and Modern Asturias. Faunal values for mammals were adjusted by − 2.4 permil, and marine fish were adjusted by − 3.7 permil to correct for fractionation between bone collagen and muscle tissue (DeNiro and Epstein 1978). Additional marine fish values were adapted from Müldner and Richards (2007), Müldner and Richards (2005), and Fuller et al. (2012). Freshwater fish values were adapted from Müldner and Richards (2005) and Fuller et al. (2012). Human $\delta^{13}C$ collagen values were adjusted by + 5 permil to account for fractionation (Ambrose and Norr 1993; Tieszen and Fagre 1993; van der Merwe and Vogel 1978). The human $\delta^{15}N$ collagen values were adjusted by − 3 permil to adjust for the trophic effect (DeNiro and Epstein 1981; DeNiro and Schoeninger 1983)

Table 3 Stable isotope data from human bone collagen from Asturias, Spain (n = 80), including δ13C, δ15N, C/N, and % collagen yield, with details of burial location

Unique ID	Catalog number	Site	δ13C (‰)	δ15N (‰)	C/N	% collagen yield	Sex	Median age-at- death	Burial location	Time period
2	SSV 4CP	B	− 19.3	9.5	3.4	2	F	53	Cemetery	Medieval
3	SSV 5	B	− 19.0	10	3.3	3	F	–	Cemetery	Medieval
4	SSV 12	B	− 19.6	9.4	3.2	2	M	65	Cemetery	Medieval
5	SSV 13	B	− 18.0	12.2	3.3	4	M	51	Cemetery	Medieval
6	SSV 16	B	− 19.0	9.4	3.3	4	I	–	Cemetery	Medieval
7	SSV 17	B	− 19.0	9.2	3.2	10	M	73	Cemetery	Medieval
8	SSV 18	B	− 18.6	9.5	3.3	3	M	40	Cemetery	Medieval
9	SSV 19	B	− 19.2	9.7	3.3	3	M	60	Cemetery	Medieval
10	SSV 22	B	− 19.2	8.8	3.3	4	F	30	Cemetery	Medieval
11	SML 29P	D	− 17.6	10.1	3.3	20	M	53	Cemetery	Medieval
12	SML IP	D	− 17.2	10.1	3.3	14	I	–	Cemetery	Medieval
13	SML 1	D	− 18.9	11.5	3.3	4	F	–	Cemetery	Medieval
14	SML 2	D	− 19.3	9.4	3.4	12	M	66	Cemetery	Medieval
15	SML 3CP	D	− 19.0	9.9	3.3	–	M	75	Cemetery	Medieval
16	SML 4	D	− 17.1	10.3	3.3	17	F	48	Cemetery	Medieval
17	SML 5	D	− 19.0	9.5	3.3	1	F	–	Cemetery	Medieval
19	CdO 1	G	− 18.9	12.5	3.3	–	M	65	*Ad sanctos*	Medieval
20	CdO 2	G	− 18.8	13.0	3.3	27	M	55	*Ad sanctos*	Medieval
21	CdO 3	G	− 18.5	10.3	3.2	–	M	17.5	*Ad sanctos*	Medieval
22	SPP Ct 2	F	− 13.0	9.8	3.3	4	I	–	*Ad sanctos*	Medieval
23	SPP 11	F	− 14.7	10.0	3.3	5	M	47	*Ad sanctos*	Modern
25	SPP 28	F	− 13.1	10.1	3.3	–	M	–	*Ad sanctos*	Modern
29	SPP 47	F	− 16.8	9.0	3.3	1	M	–	*Ad sanctos*	Medieval
30	SJ 6	H	− 18.6	8.1	3.3	6	F	20	Cemetery	Modern
32	SJ 12	H	− 13.5	9.4	3.5	2	F	–	Cemetery	Modern
33	SJ 17CP	H	− 19.4	10.5	3.3	–	M	40	Cemetery	Modern
34	SJ 25	H	− 19.1	12.4	3.3	2	I	–	Cemetery	Medieval
35	SJ 28	H	− 20.1	10.0	3.4	1	M	26	Cemetery	Medieval
37	SJ 34CP	H	− 19.7	10.5	3.5	–	F	15	*Ad sanctos*	Modern
39	SJV 2	E	− 16.5	9.2	3.2	8	F	70	*Ad sanctos*	Medieval
40	SJV 5CP	E	− 18.5	9.6	3.4	40	M	60	Cemetery	Modern
41	SJV 7	E	− 17.6	9.7	3.4	1	F	55	Cemetery	Modern
42	SJV 8	E	− 19.3	9.6	3.2	6	M	50	Cemetery	Modern
43	SJV 11	E	− 18.6	10.8	3.6	0	I	50	Cemetery	Modern
44	SJV 27CP	E	− 16.8	9.3	3.3	–	F	74	Cemetery	Modern
45	SJV 37	E	− 19.0	11.6	3.3	6	F	20	Cemetery	Modern
46	SJV 60	E	− 19.0	9.0	3.4	4	F	–	Cemetery	Modern
47	SJV 65	E	− 19.1	8.6	4.0	–	M	54	Cemetery	Modern
48	SJV 68	E	− 18.5	10.0	3.2	4	F	48	Cemetery	Modern
50	SPN 98	C	− 18.8	11.3	3.3	16	I	–	Cemetery	Medieval
51	SPN HET	C	− 18.9	11.0	3.3	18	I	–	Cemetery	Medieval
52	SPN Osar	C	− 19.1	11.2	3.3	16	I	–	Cemetery	Medieval
53	SPN II	C	− 13.1	9.4	3.3	3	M	–	Cemetery	Medieval
54	SPN TI	C	− 19.8	8.8	3.3	2	I	–	Cemetery	Medieval
55	SPN NIII	C	− 18.8	11.2	3.4	3	I	–	Cemetery	Medieval
56	SPN Inh5CP	C	− 19.7	9.2	3.3	7	M	40	Cemetery	Medieval
57	CCS 27	A	− 19.3	9.9	3.4	1	I	–	Cemetery	Medieval
58	CCS 28	A	− 19.3	9.6	3.3	2	I	–	Cemetery	Medieval
59	CCS 40	A	− 18.8	10.0	3.3	2	I	–	Cemetery	Medieval
61	CCS 42	A	− 17.8	9.8	3.3	–	I	–	Cemetery	Medieval
72	CCS T38	A	− 18.8	10.2	3.3	11	I	–	Cemetery	Medieval
76	CCS T43	A	− 18.9	11.4	3.3	8	I	–	Cemetery	Medieval
77	CdO box 0016	G	− 18.4	12.1	3.3	13	I	–	*Ad sanctos*	Medieval
80	SJ 38	H	− 19.4	10.7	3.3	8	M	–	*Ad sanctos*	Modern
81	SJ 20 U46	H	− 19.3	9.5	3.3	11	I	–	*Ad sanctos*	Modern
83	SJ T15 U38	H	− 19.4	10.7	3.3	14	I	–	Cemetery	Medieval
84	SJ T27 U84	H	− 17.2	12.5	3.3	4	I	–	Cemetery	Medieval
85	SJ T26 U84	H	− 19.4	11.5	3.3	9	I	–	Cemetery	Medieval
86	SJ T27 U83	H	− 18.9	13.0	3.3	3	I	–	Cemetery	Medieval
87	SJ Superior box 4662 C13	H	− 17.5	11.0	3.3	7	M	–	Cemetery	Modern
92	SJ 00 T2	H	− 13.5	10.1	3.3	16	I	–	Cemetery	Modern
96	SJV 05/A/E1	E	− 19.0	9.8	3.3	12	M	–	*Ad sanctos*	Medieval
99	SML 90–26–3	D	− 18.2	10.3	3.3	16	I	–	Cemetery	Medieval
100	SML 90–26–14	D	− 18.2	10.3	3.3	6	I	–	Cemetery	Medieval

Table 3 (continued)

Unique ID	Catalog number	Site	δ13C (‰)	δ15N (‰)	C/N	% collagen yield	Sex	Median age-at- death	Burial location	Time period
104	SML box 2815	D	− 12.2	9.2	3.3	24	I	–	Cemetery	Medieval
105	SML 89–18–6	D	− 10.7	10.9	3.3	18	I	–	Cemetery	Medieval
106	SML TA7	D	− 19.5	9.8	3.3	10	I	–	Cemetery	Medieval
108	SML 90–26–11–2	D	− 17.3	10.5	3.4	11	M	–	Cemetery	Medieval
109	SML 90–26–21	D	− 18.6	9.5	3.3	9	M	–	Cemetery	Medieval
110	SML 90–26–16	D	− 19.3	10.5	3.3	16	M	–	Cemetery	Medieval
112	SML 90–26–16	D	− 18.8	13.9	3.3	15	M	–	Cemetery	Medieval
114	SPN 82	C	− 16.4	10.2	3.3	14	I	–	*Ad sanctos*	Medieval
115	SPN 98	C	− 18.6	10.7	3.3	32	I	–	Cemetery	Medieval
116	SPN ap c81	C	− 18.7	11.1	3.3	24	I	–	Cemetery	Medieval
119	SPN 91/D4/Inh5	C	− 18.6	10.2	3.4	9	M	–	Cemetery	Medieval
120	SPN Zone I–7	C	− 19.6	8.9	3.3	5	I	–	Cemetery	Medieval
121	SPP estructura Cata E	F	− 17.9	8.7	3.3	12	I	–	Cemetery	Medieval
122	SSV T6	B	− 18.9	9.5	3.3	11	I	–	Cemetery	Medieval
126	SSV Oseos T6	B	− 18.8	9.6	3.3	14	M	–	Cemetery	Medieval
128	SSV Cata X T17	B	− 19.1	9.2	3.3	13	I	–	Cemetery	Medieval

Site codes: A—Medieval Necropolis of Castro de Chao Samartín; B—The Early Medieval Cemetery of the Church of San Salvador de Valdediós; C—The Medieval Cemetery of the Church of San Pedro de Nora; D—The Medieval Cemetery of the Church of San Miguel de Lillo; E—The Church of San Julián de Viñón; F—The Church of San Pedro de Plecín; G—The Catedral de San Salvador in Oviedo; H—The Hospital and Church of San Juan Bautista, and the Colegio San Isidoro Oviedo; I—Castiellu de Llagú, Latores, Oviedo

Medieval period burials ($n = 52$), $\delta^{13}C$ isotope values vary from − 20.1 to − 10.7 permil with a mean of − 18.4 ± 1.8 permil (1SD), whereas $\delta^{15}N$ values vary from + 8.7 to + 13.9 permil with a mean of + 10.3 ± 1.1 permil (1SD). For Medieval period adult *ad sanctos* burials ($n = 9$), $\delta^{13}C$ isotope values vary from − 19 to − 13 permil with a mean of − 17.4 ± 1.9 permil (1SD), whereas $\delta^{15}N$ values vary from + 9 to + 13 permil with a mean of + 10.7 ± 1.5 permil (1SD). These differences are statistically significant for $\delta^{13}C$ (Mann Whitney U, $p < 0.05$) but not for $\delta^{15}N$ (Mann Whitney U, $p > 0.05$). The lack of statistically significant $\delta^{15}N$ value differences among *ad sanctos* burials may be due to small sample size.

The individuals with the most elevated $\delta^{15}N$ values, suggesting greater access to high-trophic-level food sources, were all buried in or near the capital of Asturias, Spain. These sites are the Cathedral of Oviedo (site B), the Church of San Juan Bautista, also in Oviedo (site H), and the Church of San Miguel de Lillo (site D), which is located on a hillside overlooking Oviedo. The only exception is b. 5, who was buried in the cemetery of the Church of San Salvador de Valdediós (site B) which is located northeast of the capitol.

Of the individuals with the most elevated $\delta^{15}N$ values, only three (b. 19, b. 20, and b. 77) were from *ad sanctos* burials within the Cathedral of San Salvador in Oviedo (Fig. 5). Two of these burials (b. 19 and b. 20) were males with a median age-at-death of 65 years and 55 years, respectively (Passalacqua 2012). Burial 19 had a $\delta^{13}C$ value of − 18.9 permil and a $\delta^{15}N$ value of + 12.5 permil, and b. 20 had a $\delta^{13}C$ value of − 18.8 permil and a $\delta^{15}N$ value of + 13.0 permil. These individuals likely consumed a diet rich in freshwater fish and/or high-trophic-level animal protein from a C_3 terrestrial environment (e.g., C_3 plants and herbivore and omnivore meat). In contrast, b. 21, a male interred in a limestone sarcophagus (similar to b. 19 and b. 20), was unusual in that his median age-at-death was 17.5 years (Passalacqua 2012) and he actually had a much lower $\delta^{15}N$ value. This young individual had a $\delta^{13}C$ value of − 18.5 permil and a $\delta^{15}N$ value of + 10.3 permil. Despite being buried in the same high-status location as the other, older males, the paleodietary reconstruction of b. 21 suggests that this individual consumed a diet consisting of lower trophic animal protein compared to other *ad sanctos* burials. His young age-at-death and possibly lower quality diet relative to the individuals he was buried nearby may suggest underlying health issues. The discrepancy between this individual's diet and status as inferred by burial location is but one example of the need to assess individual social status using multiple lines of evidence.

Burial 5, a male with a median age-at-death of 51 years old, was buried in the church of San Salvador de Valdediós (Fig. 5). This individual's $\delta^{13}C$ was − 18 permil and his $\delta^{15}N$ was + 12.2 permil, values which are unlike all of the individuals he was buried alongside in Valdediós, but similar to individuals buried in or near Oviedo. He likely consumed high-trophic-level animal protein from a C_3 terrestrial ecosystem or freshwater fish. As members in a monastic community typically consumed the same diet, this individual was either non-local, or consumed a diet vastly different from those around him, perhaps indicative of high-status within the monastic community.

Interestingly, the highest $\delta^{15}N$ value recorded in this study is from an individual (b. 112) who was not buried *ad sanctos*, but rather was buried within the cemetery outside the church building of San Miguel de Lillo (Fig. 5). This particular church building was constructed to accompany a palace and sits on a hillside overlooking Oviedo. B. 112 had the most elevated $\delta^{15}N$ value in the sample at + 13.9 permil, but a somewhat low $\delta^{13}C$ value of − 18.8 permil compared to many other individuals. This isotope signature suggests consumption of freshwater fish, a high-status fasting food. While this individual was not buried within the building itself (*ad sanctos*), it may indicate that the location as a whole may have been reserved for use by high-status individuals, and that even those buried in outside of the church walls were of higher status than the average individual in the region.

In contrast, individuals with low $\delta^{15}N$ values and elevated $\delta^{13}C$ values, suggesting a low-protein diet with ample contribution from C_4 plants, were buried at several locations throughout Asturias, including the Church of San Miguel de Lillo (b. 104 and b.105), the Church of San Pedro de Plecin (b. 22), and the Church of San Pedro de Nora (b. 53) (Fig. 5). These individuals could have been members of monastic communities who consumed an ascetic diet of millet and sorghum (low status, C_4 foods) as an expression of piety, although there are many other possibilities.

When the sites are viewed collectively, each shows some level of distinct regional dietary pattern (Fig. 5). This likely reflects the difficulties in transporting goods through the mountainous regions of Asturias resulting in a diet composed of primarily of locally produced resources. Despite the treacherous conditions of overland transportation and a lack of navigable rivers, populations were not immobile. Numerous pilgrimage routes between Asturian communities were well-traveled during the Middle Ages. These routes linked pilgrims with churches and cathedrals throughout the region, with many pilgrims staying overnight at monasteries along the route. Site-specific distinctions may reflect conformities in the communal diet of monastic communities where outliers represent traveling pilgrims or visiting clergy.

Pilgrims were not the only individuals that moved from one location to another during these periods; however, many of the

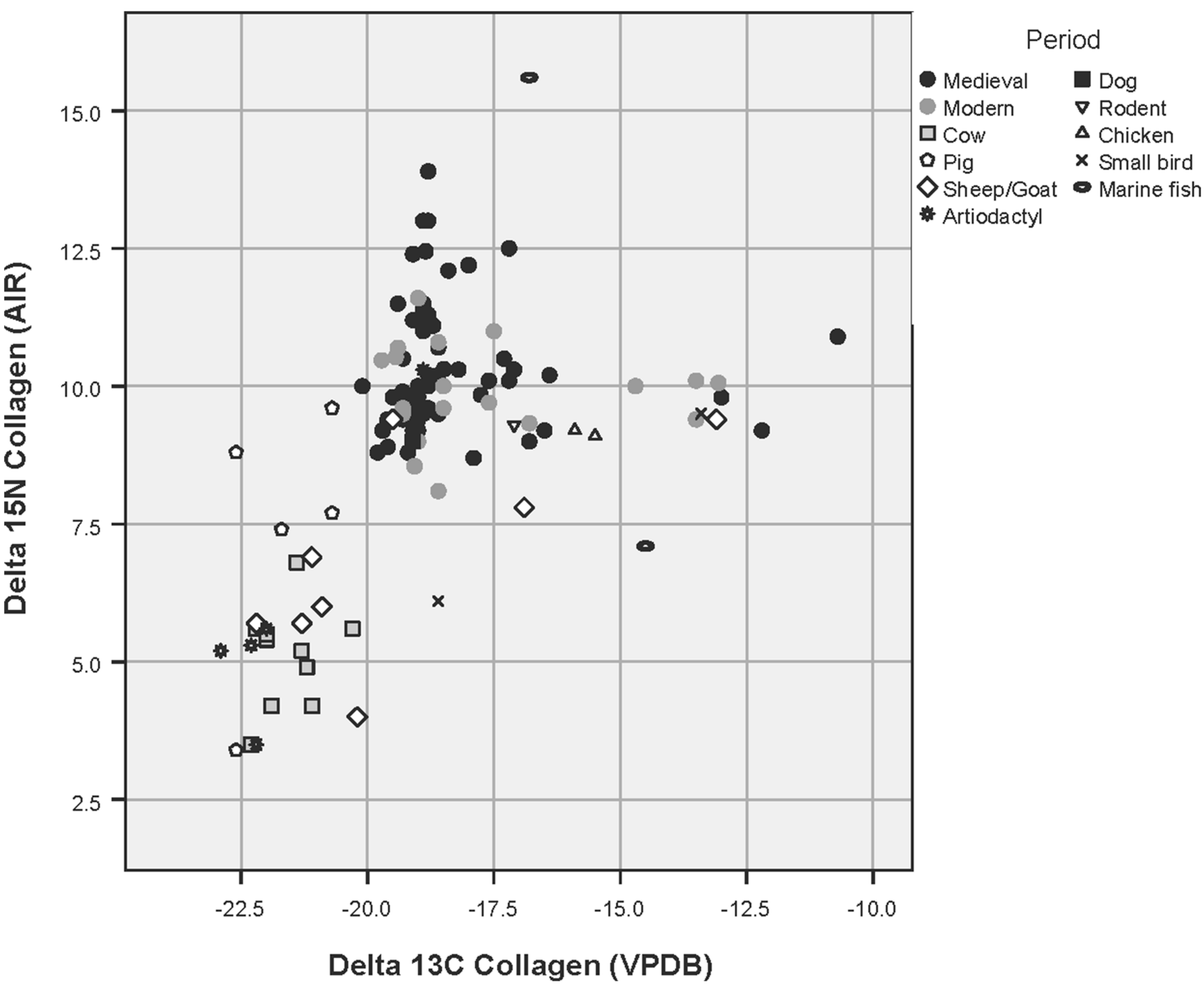

Fig. 3 Plot of bone collagen $\delta^{13}C$ and $\delta^{15}N$ values for Medieval and Modern period humans from Asturias

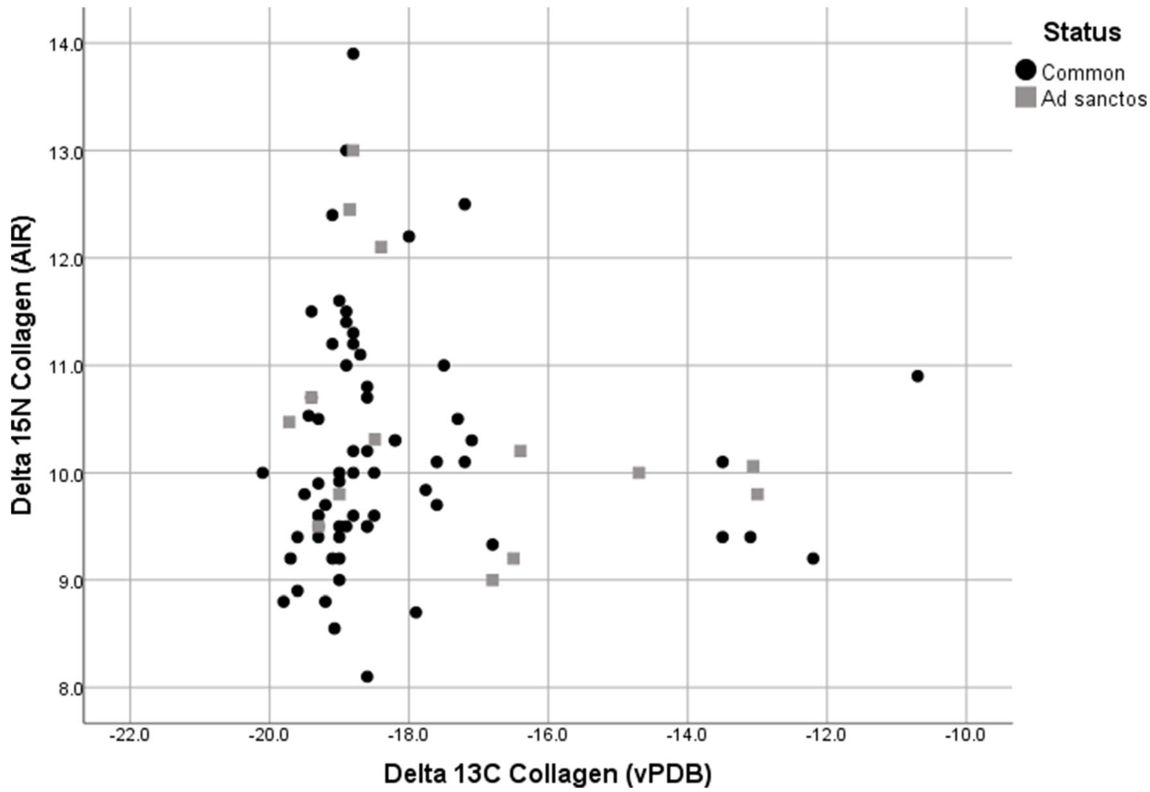

Fig. 4 Plot of bone collagen δ^{13}C and δ^{15}N values for Medieval period humans from common and *ad sanctos* burial locations

sites within this sample were located along, or near routes for the Camino de Santiago pilgrimage, suggesting there may be a higher number of pilgrims within these cemeteries than in other regions of Spain. Further, pilgrims may have been moving greater distances over shorter periods of time which would likely make them more visible based on isotopic values. Without some additional evidence, such as written records or perhaps the inclusion of a scallop shell suggesting the individual completed their pilgrimage to Santiago de Compostela in Galicia, it is not currently possible to differentiate between pilgrims or other non-local individuals found within cemeteries.

Conclusion

Previous research suggests that burial location alone is simply not a significant variable when attempting to infer the status of the decedent (Passalacqua 2012; Passalacqua and MacKinnon 2016). However, this research indicates that burial location can be used in conjunction with other data to comment on the status of individuals and groups of individuals. Specifically, these results demonstrate that burial location (e.g., commoner vs. *ad sanctos* burial) may correspond to dietary patterns that reflect social status via differential access to dietary resources.

The diet of most Medieval and Modern Asturians was predominately based on plants and animal protein from local C_3 terrestrial environments. Cereal grains were the foundation of diet, likely rye for the commoners and wheat for the upper classes, supplemented by seasonal animal protein during fast-free periods. Some C_4 plant resources did contribute to diet, either as plant foods or as feed for animals. In the Medieval period, this C_4 signature is likely indicative of millet, which may have been supplemented or displaced by maize in the 1600s. Any minor dietary differences between the Medieval and Modern periods are likely a reflection of greater C_4 plant consumption in the Modern period. However, this contribution is small, as most individuals appear to have continued to consume similar resources as those before them, primarily eating foods that were locally produced.

It was hypothesized that *ad sanctos* burials of elites would have isotope values that differentiated them from commoner burials; specifically, we expected to find elevated δ^{15}N in elites as a reflection of their consumption of high-trophic-level terrestrial and aquatic resources in comparison to common individuals. However, we found that it was not δ^{15}N, but δ^{13}C values that distinguished common burials from *ad sanctos* burials in these samples. The difference in δ^{13}C values was statistically significant between burial location type, where *ad sanctos* burials had more elevated δ^{13}C than commonly buried

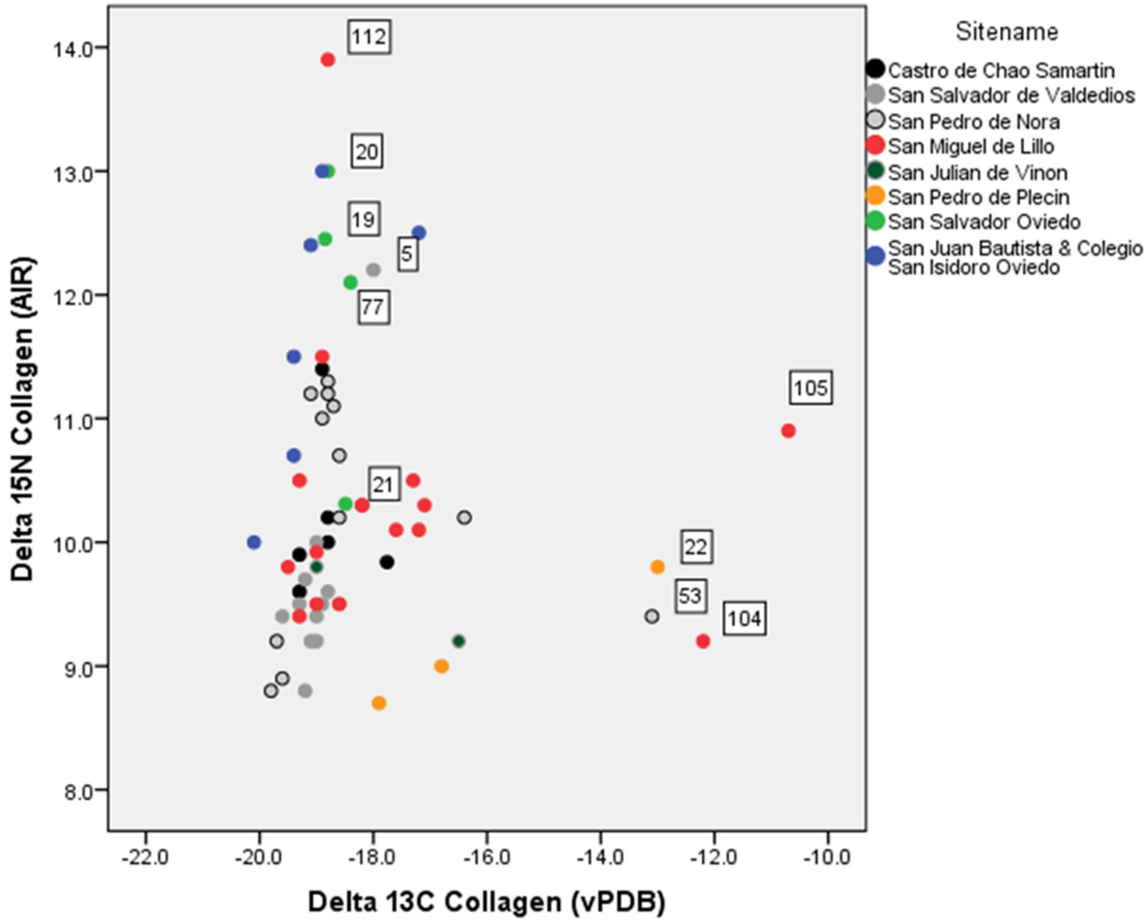

Fig. 5 Plot of bone collagen δ^{13}C and δ^{15}N values for Medieval period humans by archaeological site. Select *ad sanctos* and commoner burials referred to in the text are labeled

individuals. These elevated δ^{13}C values could suggest that those buried in places of prestige consumed greater amounts of protein from animals fed C_4 resources, such as chickens, with some possible contribution of fish to the diet. Further research expanding these analyses to additional sites and additional individuals as well as the inclusion of zooarchaeological data related to animal husbandry and butchering would assist in developing a more detailed picture of diet and lifeways in general for individuals living in Asturias, Spain, during these periods.

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References

Adamson MW (2004) Food in medieval times. Food through history. Greenwood Press, Westport, pp 1–256

Adán Alvarez G (1995) San Salvador/San Pedro de Plecin (Alles). Actuacion arqueologica y sintesis historica. In: Excavaciones Arqueologicas en Asturias 1991–1994. Servicio de Publicaciones, Granada-Colloto-Oviedo, pp 308–317

Adán Alvarez G, Martinez Faedo L, Diaz Garcia F (1997) San Pedro de Nora – Evolucion constructiva y restauraciones. In: Hevia Blanco J (ed) La Intervención En La Arquitectura Prerromanica Asturiana. Universidad de Oviedo, Vice-Rectorado de Extension Universitaria, Servicio de Publicaciones, Oviedo, pp 161–182

Alexander MM, Gerrard CM, Gutiérrez A, Millard AR (2015) Diet, society, and economy in late medieval Spain: stable isotope evidence from Muslims and Christians from Gandía, Valencia. Am J Phys Anthropol 156:263–273

Ambrose SH (1993) Isotopic analysis of paleodiets: methodological and interpretive considerations. In: Sandford MK (ed) Investigations of ancient human tissue: chemical analyses in anthropology. Gordon and Breach, Philadelphia, pp 59–130

Ambrose SH, Norr L (1993) Experimental evidence for the relationship of the carbon isotope ratios of whole diet and dietary protein to those of bone collagen and carbonate. In: Lambert JB, Grupe G (eds) Prehistoric human bone: archaeology at the molecular level. Springer-Verlag, Berlin, pp 1–37

Ariès P (1981) The hour of our death. Knopf, New York
Barker G (1985) Prehistoric farming in Europe. Cambridge University Press, Cambridge
Bassham JA, Benson A, Calvin M (1950) The path of carbon in photosynthesis viii the role of malic acid. J Biol Chem 185:781–787
Beerling DJ (2007) The emerald planet: how plants changed Earth's history. Oxford University Press, Oxford
Boserup E (1985) The impact of scarcity and plenty on development. In: Rotberg RI, Rabb TK (eds) Hunger and history: the impact of changing food production and consumption patterns on society. Cambridge University Press, Cambridge
Bownes J, Clarke L, Buckbery J (2018) The importance of animal baselines: using isotope analysis to compare diet in British medieval hospital and lay population. J Archaeol Sci Rep 17:103–110
Buikstra JE, Ubelaker DH (eds) (1994) Standards for data collection from human skeletal remains. Arkansas Archaeological Survey Research Series No 44, Fayetteville, pp 1–206
Cerling TE, Ehleringer JR, Harris JM (1998) Carbon dioxide starvation, the development of C_4 ecosystems, and mammalian evolution. Phil Trans R Soc Lond B353:159–171
Chabrán R (2002) Medieval Spain. In: Adamson MW (ed) Regional cuisines of medieval Europe. Routledge, New York
Cosman MP (1976) Fabulous feasts: medieval cookery and ceremony. George Braziller, Inc., New York
Crosby AW (1972) The Columbian exchange: biological and cultural consequences of 1492. Greenwood Press, Connecticut
Czermak A, Ledderose A, Strott N, Meier T, Grupe G (2006) Social structures and social relations—an archaeological and anthropological examination of three early medieval separate burial sites in Bavaria. Anthropol Anz 64(3):297–310
Davies H, Davies M (1982) Holy days and holidays: the medieval pilgrimage to Compostela. Associated University Presses, Inc., East Brunswick
DeNiro MJ (1985) Postmortem preservation and alteration of in vivo bone collagen isotope ratios in relation to Palaeodietary reconstruction. Nature 317:806–809
DeNiro MJ, Epstein S (1978) Influence of diet on the distribution of carbon isotopes in animals. Geochim Cosmochim Acta 42:495–506
DeNiro MJ, Epstein S (1981) Influence of diet on the distribution of nitrogen isotopes in animals. Geochim Cosmochim Acta 45:341–351
DeNiro MJ, Schoeninger MJ (1983) Carbon isotope ratios of bone apatite and animal diet reconstruction—reply. Nature 301(5896):178–178
Effros B (2002) Caring for body and soul: burial and the afterlife in the Merovingian world. Pennsylvania State University Press, Pennsylvania
Eire CMN (1995) From Madrid to purgatory: the art and craft of dying in sixteenth-century Spain. Cambridge University Press, Cambridge
Fagan B (2006) Fish on Friday: feasting, fasting and the discovery of the New World. Basic, New York
Fernandez RL (1990) A simple matter of salt: an ethnography of nutritional deficiency in Spain. University of California Press, Berkeley
Fernández Conde FJ, Alonso Alonso GA (1992) Excavaciones en el Yacimiento Arqueológico de Valdediós (Villaviciosa). In: Excavaciones Arqueologicas en Asturias 1987-1990, Granada-Colloto-Oviedo, Servicio de Publicaciones pp 171–178
Fry B (2006) Stable isotope ecology. Springer, New York
Fuller BT, Márquez-Grant N, Richards MP (2010) Investigation of diachronic dietary patterns on the islands of Ibiza and Formentera, Spain: evidence from carbon and nitrogen stable isotope ratio analysis. Am J Phys Anthropol 143:512–522
Fuller BT, Müldner G, Van Neer W, Ervynck A, Richards MP (2012) Carbon and nitrogen stable isotope ratio analysis of freshwater, brackish and marine fish from Belgian archaeological sites (1st and 2nd millennium AD). J Anal At Spectrom 27:807–820
Galinat WC (1992) Maize: gift from America's first peoples. In: Foster N, Cordell LS (eds) Chilies to chocolate: food the Americas gave the world. University of Arizona Press, Tucson, pp 47–60
Galloway JH (1977) The Mediterranean sugar industry. Geogr Rev 67(2): 177–194
García Collado MI (2012) Food as a social marker: stable isotopes and palaeopathological analysis on an Early Medieval rural community in Spain. Gózquez de Arriba (San Martín de la Vega, Madrid, Spain), 6th to 8th centuries. MSc Thesis, Durham University
García de Castro Valdés C (2002) Informe sobre las excavaciones arqueológicas realizadas en el solar N 3 de la calle Schulz (Antiguo Colegio San Isidoro) y en la misma calle Schulz de la ciudad de Oviedo (Febrero 2000-Abril 2001)
Garcia EM, Subrià E, Richards MP (2004) Régime et société d'après l'analyse des isotopes stables: l'exemple de la population de « Can Reinés » (Mallorca, Espagne, 600 ap. J.C.). Antropo 7:171–176
González García I, Ruiz de la Peña Solar JI (1972) La Economia Salinera en la Asturias Medieval. Asturiensia Medievalia 1:11–155
Gordon B, Marshall G (2000) The place of the dead: death and remembrance in late medieval and modern Europe. Cambridge University Press, Cambridge
Grau-Sologestoa I (2014) The zooarchaeology of medieval Alava in its Iberian context, BAR International Series, vol 2769. BAR Publishing, Oxford
Grau-Sologestoa I (2016) Faunal remains and social inequality in the Basque Country during the Early Middle Ages. In: Quirós Castillo JA (ed) Social complexity in early medieval rural communities: the North-Western Iberia archaeological record. Archaeopress Publishing Ltd, Oxford
Grau-Sologestoa I (2017) Socio-economic status and religious identity in medieval Iberia: the zooarchaeological evidence. Environ Archaeol 22(2):189–199
Harding V (1992) Burial choice and burial location in later medieval London. In: Bassett S (ed) Death in towns: urban responses to the dying and dead, 100–1600. Leicester University Press, Leicester, pp 119–135
Harding V (2002) The dead and the living in Paris and London, 1500–1670. Cambridge University Press, Cambridge
Heaton THE (1999) Spatial, species, and temporal variations in the $^{13}C/^{12}C$ ratios of C_3 plants: implications for palaeodiet studies. J Archaeol Sci 26:637–649
Hughes MK, Diaz HF (1994) Was there a 'medieval warm period', and if so, where and when? Clim Chang 26(2–3):109–142
Jiménez-Brobeil SA, Laffranchi Z, Maroto RM, Sánchez FL, Huertas AD (2016) How royals feasted in the court of Pedro I of Castile: a contribution of stable isotope study to medieval history. J Archaeol Sci Rep 10:424–430
Katzenberg MA, Saunders SR (2008) Biological anthropology of the human skeleton. John Wiley and Sons, Inc., New Jersey
Lamb HH (1965) The early medieval warm epoch and its sequel. Palaeogeogr Palaeoclimatol Palaeoecol 1:13–37
Lamb AL, Evans JE, Buckley R, Appleby J (2014) Multi-isotope analysis demonstrates significant lifestyle changes in King Richard III. J Archaeol Sci 50:559–565
Locke J, Lough J (1953) Locke's travels in France, 1675–1679, as related in his journals, correspondence and other papers. Cambridge University Press, Cambridge
Loog L, Thomas MG, Barnett R, Allen R, Sykes N, Paxinos PD, Lebrasseur O, Dobney K, Peters J, Manica A, Larson G, Eriksson A (2017) Inferring allele frequency trajectories from ancient DNA indicates that selection on a chicken gene coincided with changes in medieval husbandry practices. Mol Biol Eval 34(8):1981–1990
López-Costas O (2012) Antropología de los Restos Óseos Humanos de Galicia: Estudio de la Población Romana y Medieval Gallega. Tesis Doctoral, Universidad de Granada

Lubritto C, Sirignano C, Ricci P, Passariello I, Quirós Castillo JA (2013) Radiocarbon chronology and paleodiet studies on the medieval rural site of Zaballa (Spain): preliminary insights into the social archaeology of the site. Proceedings of the 21st International Radiocarbon Conference 55(2–3):1222–1232

Lubritto C, Garcia-Collado MI, Ricci P, Altieri S, Sirignano C, Quiros Castillo JA (2017) New dietary evidence on medieval rural communities of the Basque Country (Spain) and its surroundings from carbon and nitrogen stable isotope analyses: social insights, diachronic changes and geographic comparison. Int J Osteoarchaeol 27(6):984–1002

MacKinnon AT (2015) Dietary reconstruction of medieval and modern Spanish populations using stable isotopes of carbon and nitrogen. Master's Thesis, Department of Anthropology, California State University, Chico

Mann ME (2002) Medieval climatic optimum. In: In: Munn T (ed) Encyclopedia of global environmental change. MacCracken MC, Perry JS (eds) Vol 1. The earth system: physical and chemical dimensions of global environmental change Chichester, John Wiley & Sons, ltd pp 514-516

Martinez Faedo L, Adán Alvarez G (1995) La Iglesia Prerromanica de S. Pedro de Nora (Las Regueras). In: Excavaciones Arqueologicas en Asturias 1991-1994. Granada-Colloto-Oviedo, Servicio de Publicaciones pp 286–292

Mintz SW (1985) Sweetness and power: the place of sugar in modern history. New York, Viking

Molina González F, Cámara Serrano JA, Delgado Huertas A, Jiménez Brobeil SA, Nájera Colino T, Riquelme Cantal JA, Spanedda L (2016) Problemas cronológicos y análisis de dieta en la Edad del Bronce de los Altiplanos granadinos: El caso del Cerro de la Virgen (Orce, Granada, España). Del neolític a l'edat del bronze en el Mediterrani occidental: estudis en homenatge a Bernat Martí Oliver, pp 451-463

Moreno-Larrazabal A, Teira-Brión A, Sopelana-Salcedo I, Arranz-Otaegui A, Zapata L (2015) Ethnobotany of millet cultivation in the north of the Iberian Peninsula. Veg Hist Archaeobot 24:541–554

Müldner G, Richards MP (2005) Fast or feast: reconstructing diet in later medieval England by stable isotope analysis. J Archaeol Sci 32:39–48

Müldner G, Richards MP (2007) Stable isotope evidence for 1500 years of human diet at the City of York, UK. Am J Phys Anthropol 133:682–697

Müldner G, Montgomery J, Cook G, Ellam R, Gledhill A, Lowe C (2009) Isotopes and individuals: diet and mobility among the medieval bishops of Whithorn. Antiquity 83:1119–1133

Mundee M (2009) An isotopic approach to diet in medieval Spain. In: Baker S, Gray A, Lakin K, Madgwick R, Poole K, Sandias M (eds) Food and drink in archaeology volume 2. Prospect Books, Devon, pp 64–72

Muñiz DCM (1992) Pig husbandry in Visigoth Iberia: fact and theory. Archaeofauna: Int J Archaeozool 1:147–155

Naji S (2005) Death and remembrance in medieval France: a case study from the Augustinian monastery of Saint-Jean-des-Vignes, Soissons. In: Rakita G, Buikstra JE, Beck LA, Williams SR (eds) Interacting with the dead: perspectives on mortuary archaeology for the new millennium. University Press of Florida, Gainesville, pp 173–189

Nehlich O, Fuller BT, Marquez-Grant N, Richards MP (2012) Investigation of diachronic dietary patterns on the islands of Ibiza and Formentera, Spain: evidence from sulfur stable isotope ratio analysis. Am J Phys Anthropol 149:115–124

Newsom LA (2009) Caribbean maize: first farmers to Columbus. In: Staller JE, Tykot RH, Benz BF (eds) Histories of maize. Left Coast Press, Walnut Creek, CA, pp 325–335

O'Leary MH (1981) Carbon isotope fractionation in plants. Phytochem 20:553–567

O'Leary MH (1988) Carbon isotopes in photosynthesis. Bioscie 38:328–335

Ortega LA, Guede I, Cruz Zuluaga M, Alonso-Olazabal A, Murelaga X, Niso J, Loza M, Quirós Castillo JA (2013) Strontium isotopes of human remains from the San Martín de Dulantzi Graveyard (Alegría-Dulantzi, Álava) and population mobility in the early middle ages. Quat Int 303:54–63

Passalacqua NV (2012) Health and demography in medieval Asturias, Spain. Doctoral Thesis, Michigan State University

Passalacqua NV, MacKinnon AT (2016) A historical bioarchaeology approach to health, status, and diet of medieval Asturias, Spain. In: Quirós JA (ed) Demografía, paleopatologías, y desigualdad social en la noroeste peninsular en época medieval. Universidad del País Vasco, País Vasco, pp 63–82

Passalacqua NV, Zhang Z, Pierce SJ (2013) Sex determination of human skeletal populations using latent profile analysis. Am J Phys Anthropol 151:538–543

Payne SG (2011) Spain: a unique history. University of Wisconsin Press, Wisconsin

Pearson MP (1999) The archaeology of death and burial. Texas A&M University Press, Texas

Peña-Chocarro L, Guillem P-J, Alonso N, Antolín F, Teira-Brión A, Tereso JP, Montes Moya EM, López Reyes D (2019) Roman and medieval crops in the Iberian Peninsula: a first overview of seeds and fruits from archaeological sites. Quat Int 499:49–66

Polet C, Katzenberg MA (2003) Reconstruction of the diet in a mediaeval monastic community from the coast of Belgium. J Archaeol Sci 30:525–533

Post JD (1985) Food storage, climatic variability, and epidemic disease in preindustrial Europe, the mortality peak in the early 1740s. Cornell University Press, New York

Prevedorou EM, Díaz-Zorita B, Romero A, Buikstra JE, Paz de Miguel Ibáñez M, Knudson KJ (2010) Residential mobility and dental decoration in early medieval Spain: results from the eighth century site of Plaza del Castillo, Pamplona. Dental Anthropol 23(2):42–52

Quirós Castillo JA (2013) Los Comportamientos Alimentarios del Campesinado Medieval en el País Vasco y su entorno (siglos VIII-XIV). Historia Agraria 59:13–41

Quirós Castillo JA, Ricci P, Sirignano C, Lubritto C (2012) Paleodieta e Società Rurali Altomedievali dei Paesi Baschi Alla Luce dei Marcatori Isotopici di C e N (Secoli V-XI). Archeologia Medievale 39:87–92

Quirós Castillo JA, Ricci P, Sirignano C, Lubritto C (2013) Identidades y ajuares en las necrópolis altomedievales. Estudios isotópicos del cementerio de San Martín de Dulantzi, Álava (siglos VI-X). Arch Esp Arqueol 86:215–232

Reitsema LJ, Vercellotti G (2012) Stable isotope evidence for sex- and status-based variations in diet and life history at medieval Trino Vercellese, Italy. Am J Phys Anthropol 148:589–600

Ringrose D (1998) Spain, Europe, and the 'Spanish Miracle', 1700–1900. Cambridge University Press, Cambridge

Roden C (2011) The food of Spain. Harper Collins, New York

Salazar-Garcia DC, Richards MP, Nehlich O, Henry AG (2014) Dental calculus is not equivalent to bone collagen for isotope analysis: a comparison between carbon and nitrogen stable isotope analysis of bulk dental calculus, bone and dentine collagen from same individuals from the Medieval site of El Raval (Alicante, Spain). J Archaeol Sci 47:70–77

Salazar-García DC, Romero A, García-Borja P, Subirà ME, Richards MP (2016) A combined dietary approach using isotope and dental buccal-microwear analysis of human remains from the Neolithic, Roman and Medieval periods from the archaeological site of Tossal de les Basses (Alicante, Spain). J Archaeol Sci Rep 6:610–619

Salisbury JE (1985) Iberian popular religion, 600 B.C. to 700 A.D.: Celts, Romans, and Visigoths. E. Mellen Press, New York

Schoeller DA (1999) Isotope fractionation: why aren't we what we eat? J Archaeol Sci 26(6):667–673
Schoeninger MJ (1995) Stable isotope studies in human evolution. Evol Anthr 4(3):83–98
Schoeninger MJ, DeNiro MJ (1984) Nitrogen and carbon isotopic composition of bone collagen from marine and terrestrial animals. Geochim Cosmochim Acta 48:625–639
Schoeninger MJ, DeNiro MJ, Tauber H (1983) Stable nitrogen isotope ratios of bone collagen reflect marine and terrestrial components of prehistoric human diet. Science 220:1381–1383
Schwarcz HP, Schoeninger MJ (1991) Stable isotope analyses in human nutritional ecology. Yearb Phys Anthropol 34:283–321
Scott GR, Poulson SR (2012) Stable carbon and nitrogen isotopes of human dental calculus: a potentially new non-destructive proxy for Paleodietary analysis. J Archaeol Sci 39:1388–1393
Sirignano C, Grau Sologestoa I, Ricci P, García-Collado MI, Altieri S, Quirós Castillo SA, Lubritto C (2014) Animal husbandry during early and high middle ages in the Basque Country (Spain). Quatern Int 346:138–148
Tannahill R (1973) Food in history. Stein and Day, New York
Tieszen LL, Fagre T (1993) Effect of diet quality and composition on the isotopic composition of respiratory CO_2, bone collagen, bioapatite, and soft tissues. In: Lambert JB, Grupe G (eds) Prehistoric human bone: archaeology at the molecular level. Springer, Berlin, pp 121–155
Uhl NM, Passalacqua NV (2009) A comparison of estimated age-at-death distributions using bioarchaeological and forensic methods. Poster presented at the American Association of Physical Anthropology 78th annual meeting. Chicago, Illinois
van der Merwe NJ, Vogel JC (1978) ^{13}C content of human collagen as a measure of prehistoric diet in Woodland North America. Nature 276:815–816
van Klinken GJ (1999) Bone collagen quality indicators for paleodietary and radiocarbon measurements. J Archaeol Sci 26(6):687–695
Vercellotti G, Stout SD, Boano R, Sciulli P (2011) Intrapopulation variation in stature and body proportions: social status and sex differences in an Italian medieval population (Trino Vercellese, VC). Am J Phys Anthropol 145(2):203–214
Vietmeyer ND (ed) (1996) Lost crops of Africa. Board on Science and Technology for International Development, Washington DC
Villa Valdés Á, Montes López R, Hevia González S, Passalacqua NV, Wilson AC, Cabo Pérez L (2008) Avance Sobre el Estudio de la Necrópolis Medieval del Chao Samartín en Castro (Grandas de Salime, Asturias). Territorio, Sociedad y Poder 3:57–82
Watson AM (1983) Agricultural innovations in the early Islamic world. Cambridge University Press, Cambridge
Whited TL, Engels JI, Hoffman RC, Ibsen H, Verstegen W (2005) Northern Europe: an environmental history. Santa Barbara, ABC-CLIO
Woolgar CM (2000) 'Take this penance now, and afterwards the fare will improve': seafood and late medieval diet. In: Starkey DJ, Reid C, Ashcroft N (eds) England's sea fisheries: the commercial sea fisheries of England and Wales since 1300. Chatham Publishing, London, pp 36–44
Yoder C (2012) Let them eat cake? Status-based differences in diet in medieval Denmark. J Archaeol Sci 39:1183–1193
Zadoro-Rio E (2003) The making of churchyards in parish territories in the early-medieval landscape of France and England in the 7th-12th centuries: a reconsideration. Mediev Archaeol 47(1):1–19