



## Resilience and local dietary adaptation in rural Poland, 1000–1400 CE

Laurie J. Reitsema<sup>a,\*</sup>, Tomasz Kozłowski<sup>b</sup>, Douglas E. Crews<sup>c</sup>, M. Anne Katzenberg<sup>d</sup>, Wojciech Chudziak<sup>e</sup><sup>a</sup> Department of Anthropology, University of Georgia, Athens, GA 30602, United States<sup>b</sup> Department of Anthropology, Nicolaus Copernicus University, ul. Lwowska 1, 87-100 Toruń, Poland<sup>c</sup> Department of Anthropology, The Ohio State University, Columbus, OH 43210, United States<sup>d</sup> Department of Archaeology, University of Calgary, Calgary, Alberta T2N 1N4, Canada<sup>e</sup> Institute of Archeology, Nicolaus Copernicus University, ul. Szosa Bydgoska 44/48, 87-100 Toruń, Poland

## ARTICLE INFO

## Article history:

Received 25 August 2016

Revision received 6 November 2016

Accepted 9 November 2016

## Keywords:

Stable isotopes

Medieval

Resilience

Paleodiet

Carbon

Nitrogen

## ABSTRACT

In Europe during the medieval period, new constraints were introduced to the balance of people's food production, distribution and consumption. As a proxy indicator of diet, stable isotope ratios from osseous remains offer a window into past human lifeways and the adoption of new dietary regimes. We report stable carbon and nitrogen isotope results of a large diachronic study of skeletons from Poland's Pomeranian region in the Vistula River valley, using concepts of resilience, agency, and transition in bioarchaeological research frameworks to explain pace of diet change and intra-population variations in diet. Two skeletal samples are from 10 to 13th century Kałdus, an economic center of the early Piast dynasty, and two are from 12 to 14th century Gruzno, a neighboring agricultural village. Humans exhibit a mean  $\delta^{15}\text{N}$  value of  $9.8 \pm 0.9\text{‰}$ , a mean  $\delta^{13}\text{C}_{\text{coll}}$  value of  $-19.4 \pm 0.9\text{‰}$ , and a mean  $\delta^{13}\text{C}_{\text{ap}}$  value of  $-12.74 \pm 1.30\text{‰}$ . Despite similar time periods and shared geographic region, Kałdus and Gruzno differ markedly in terms of fish and millet consumption. Diet does not change according to expectations based on the Christianization, urbanization, and marketization of Poland at this time. Rather than broad national trends affecting what people ate, more significant influences on diet appear to have been local sociodemographic conditions, to which people adjusted in ways that enabled them to retain fundamental aspects of their daily lives spanning the medieval period.

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## 1. Introduction

Diet is one of humans' most fundamental biocultural adaptations, reflecting a balance between energy expenditure, environmental constraint, and nutritional demand, embedded in contexts of varied cultural norms. Social differentiation, systems of production and exchange, religion-based dietary restrictions, and other cultural transitions introduce constraints and prospects to this balance over time, which people can manage in many ways. Adoption of new dietary behaviors is a central research focus in anthropology, reflecting aspects of indigenous resistance (VanDerwarker et al., 2013), destabilization (Kuhnlein and Receveur, 1996), social organization and reorganization (Morehart and Eisenberg, 2010) and changing health (Mailer and Hale, 2015). Isotopic studies of past human populations complement anthropology's ethnographically based understandings of how people mediate demographic and sociopolitical transitions

impacting health and behavior, and of how malleable people are in adjusting diets to new cultural, environmental, and biological circumstances.

Transition and change are of thematic importance in bioarchaeology. With the advantage of deep time and the human skeletal record as data, bioarchaeologists are well-positioned to query population-level changes in diet, health, and activity concomitant with large-scale social, political, demographic, and economic transitions. Adaptive responses to large-scale changes were "the founding and first wave of theoretical engagement in bioarchaeology" (Agarwal and Glencross, 2011: 1–2), and a major foothold for the field of bioarchaeology was gained from systematic, compiled studies of biocultural consequences of one of the most significant cultural changes of the human experience, the transition to agriculture (Cohen and Armelagos, 1984; Cohen and Crane-Kramer, 2007; see reviews by Armelagos, 2003 and Gage and DeWitte, 2009). Perhaps owing to this legacy, studying transitions is the bread and butter of the discipline.

Evolutionary frameworks are used to interpret bioarchaeological data, and bioarchaeology has been described as a "field committed to understanding the adaptation and the evolution of

\* Corresponding author at: Department of Anthropology, University of Georgia, 250 Baldwin Hall, Jackson St., Athens, GA 30602, United States.

E-mail address: [reitsema@uga.edu](mailto:reitsema@uga.edu) (L.J. Reitsema).

social systems” (Armélagos, 2003: 27) and one which “[uses] the analysis of skeletons to measure the effects of social, political, and economic *transformations* on health and illness” (Armélagos, 2003: 29; italics added). Decades of developments in evolutionary theory have expanded neo-Darwinian evolutionary perspectives to embrace cultural and developmental sources of variation and adaptation (Jablonka and Lamb, 2005), yet arguably, evolutionary approaches in biological anthropology continue to prioritize “trait-based natural selection and the use of cost-benefit analyses in explaining human behavioral action” (Fuentes, 2016: S13). Expectations that diet and lifestyle adjustments stem from exterior forces, habitual in bioarchaeology, may be contrasted with the concepts of agency and resilience, in which external pressures do not change people’s lifestyles as expected, because people either resist, reshape our environments, or adjust in unlooked-for ways. Whereas evolutionary predictions involving adaptation and change may be adequate to explain human organization on broad time scales, the “noise” of people’s behavior on short time scales may be incompatible with this perspective. While concepts of agency and resilience do not specifically describe stasis or a lack of change, they do describe the capacity of a system to dampen the upset of external transition. Agency refers to human beings’ capacity to act with intentional and conscious choice (Smith, 2013). Resilience refers to “the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks” (Walker et al., 2004). These two concepts, agency and resilience, are closely related because resilience of a socioecological system is greatest when that system has the ability to self-organize into new strategies in the face of exterior forces (Carpenter et al., 2001).

Foodways in particular may be quite resilient in the face of exterior forces, owing to how deeply embedded social identity is in diet and eating behaviors (Counihan, 1999; Holtzman, 2006; Mintz and Du Bois, 2002; Twiss, 2012). Aspects of diet may change without abolishing fundamental characteristics of the menu (cf., Weismantel, 1989). In the present study, we consider concepts of resilience and agency in examining human dietary response to a shifting medieval sociopolitical milieu in the context of rural Poland, contrasting national with local influences on human diet. We apply stable carbon and nitrogen isotope analysis to a large sample of rural peasants from two sites in Poland that differed in their function: Kałdus, a regional commercial/trade hub in decline, and Gruczno, an agricultural village. The four cemeteries included span 1000–1400 CE in 100–150 year increments.

Our first goal is to test the hypothesis that human diet in rural communities of medieval Europe was impacted by broad, national changes. In this paper, we use the term “national” to refer to events widely affecting the geopolitical entity of Poland, without implying the population shared a sense of national identity. A second goal is exploring the rate at which people may have adopted these changes. Specifically, we examine whether there were increases in (1) food diversity, a reflection of trade through interregional and international connectedness, and (2) socioeconomic differentiation, as evidenced by patterned isotopic heterogeneity, including sex-based variations. We also explore whether fish consumption increased at the sites, concomitant with Christian fasting directives that prescribed fish instead of terrestrial animal meat more than 200 days *per annum* (Kloczowski, 2000; Woolgar, 2000). If rural settlements are affected by broad, national trends, we expect to see these predicted changes in diet between 1000 and 1400 CE. Conversely, rural inhabitants may have elected to adhere to traditional foodways, thus exhibiting few changes in isotopic signatures over time, or to make small-scale or unforeseen adjustments in during sociopolitical upheaval, in which case diet change would not track with expectations for change described above.

## 2. Bioarchaeological stable isotope research in medieval Europe

Use of stable isotope data in paleodietary studies derives from the fact that isotopic ratios of different types of food are preserved in the tissues of consumers (DeNiro and Epstein, 1978, 1981; van der Merwe and Vogel, 1978; Vogel and van der Merwe, 1977). Stable carbon isotope ratios in tissues provide information about the ecosystem of a consumer, distinguishing between terrestrial versus marine niches (Chisholm et al., 1982), and between broad classes of plants (DeNiro and Epstein, 1978; Smith and Epstein, 1971). Stable nitrogen isotope ratios reveal information about an organism’s trophic position in the local food chain, distinguishing between carnivores, omnivores and herbivores, and between aquatic and terrestrial food webs (DeNiro and Epstein, 1981; Schoeninger and DeNiro, 1984; Steele and Daniel, 1978). Both carbon and nitrogen stable isotope ratios in plants at the base of the food web are subject to microenvironmental variations and anthropogenic land modifications, meaning not all variation in stable isotope ratios is directly attributable to differences in foods consumed among individuals or populations (Makarewicz and Sealy, 2015; Szpak, 2014; Tieszen, 1991).

Widely applied to examine broad-scale prehistoric agricultural and prehistoric/early historic demographic transitions, stable isotope data increasingly are applied to identify variable dietary patterns in medieval Europe (Alexander et al., 2015; Bourbou et al., 2011; Ciaffi et al., 2013; Fuller et al., 2003; Garvie-Lok, 2001; Halffman and Velemínský, 2015; Herrscher, 2003; Kjellström et al., 2009; Müldner and Richards, 2005, 2007; Polet and Katzenberg, 2003; Quintelier et al., 2014; Reitsema et al., 2010; Reitsema and Vercellotti, 2012; Richards et al., 2006; Schutkowski et al., 1999). Large skeletal samples, refined chronologies, and the contextual information frequently available for the medieval period are boons for hypothesis testing and population research. In much of Europe, the medieval period spans approximately one thousand years of demographic, political and economic transition. Some of these transitions were sweeping, marked, and well-documented (e.g., Christianization, marketization, and urbanization), while others were regional, small-scale, and undocumented. Related changes in settlement structure, occupational differentiation, and food access through trade are reasoned to impact human diet and health by affecting nutrition, disease transmission and resource access (Steckel, 2004). Archaeological medieval diet reconstructions point to a considerable range of variation in human diets in the first two millennia CE. Early and continued focus of biochemical research on the United Kingdom increasingly is being supplemented by work from further east in Europe, which is fortunate, given interregional differences in what constitutes medieval lifestyles. Stable isotope analysis has been applied in a limited number of contexts in modern-day Poland (e.g., Neolithic: Kozłowski et al. (2013), Popieszny (2015); Bronze Age: Pokutta (2013); Iron Age: Reitsema (2012); Roman era: Reitsema and Kozłowski (2013)).

## 3. Biocultural context

Poland is located at the seam of eastern and western Europe, and provides a conduit from the Baltic Sea to inland regions. Poland’s history is marked by migration, cultural diffusion, and multiculturalism. Ethnographically-based questions regarding food access, changing production systems, and dietary choices in the past are well-cast in the context of Poland. In Poland, the medieval period (commencing in 966 CE with the baptism of the Piast state’s leader Prince Mieszko) represented a relatively abrupt shift from a tribal existence to a socially, economically, and religiously diverse population (Buko, 2008; Gieysztor et al., 1979). At the turn

of the 11th century, Poland's first territories were united, a common religion – Christianity – was widely adopted, the Piast state was created and recognized throughout Europe, and market economies developed, with subsequent changes in socioeconomic differentiation and settlement structure.

### 3.1. The Kałdus and Gruczno settlements and their cemeteries

Osseous remains are from two medieval settlements, including Kałdus (in the medieval period, the site referred to as Kałdus was known by the Latin name *Culmine*) and Gruczno, located on opposite sides of the Vistula River (Fig. 1). Thousands of individuals were interred at cemeteries of these settlements, which have been the subject of extensive archaeological and biological anthropological inquiry (Bojarski, 1995; Chudziak, 2003; Kozłowski, 2012; Piontek and Kozłowski, 2002).

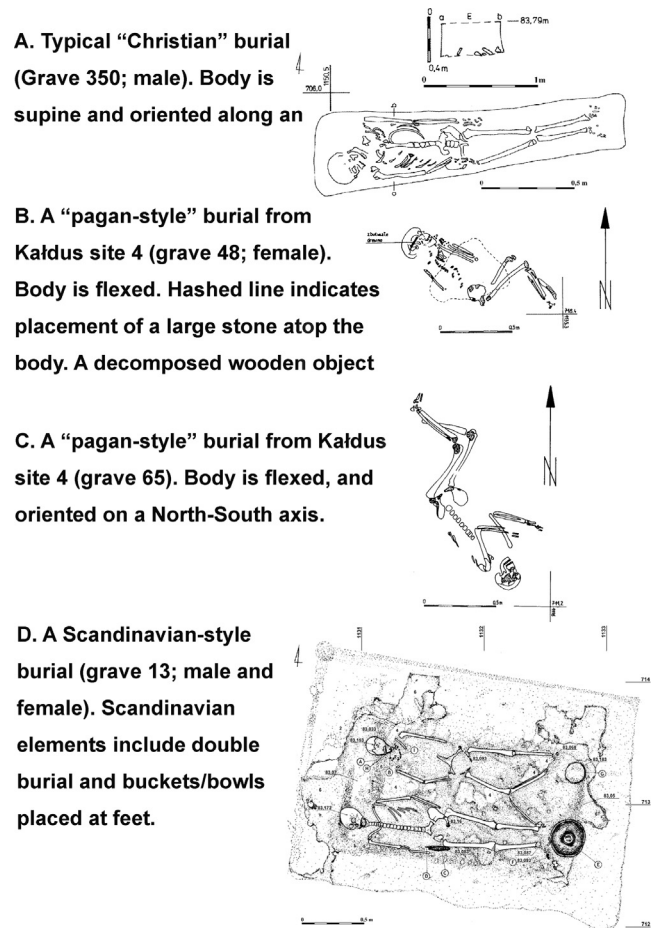
Kałdus is located near modern-day Chełmno on the east bank of the Vistula River (Fig. 1), in a valley at the edge of moraine plateau, just east of Lake Starogrodzkie, a shallow oxbow lake that existed at the time of medieval occupation (Krzymińska, 2004; Makowiecki, 2010: 29). Medieval Kałdus was a regional economic hub in the early medieval period that gradually declined in importance with the rise of larger centers nearby (e.g., Toruń) (Chudziak, 1997). Kałdus is situated around a large mound, artificially built up by humans prior to the medieval period, known as Mount Saint Lawrence, believed to be a sacred location for pre-medieval pagan rituals and social gatherings (Chudziak, 2003; with summary in English). Its role as a sacred place made Kałdus a target of Christianizing activity in the 10–11th century CE. This is perhaps best evidenced by construction of a basilica, begun, but not completed, in the early 11th century CE. In the 1030s, following continued tensions between Christians and pagans, a “pagan reaction” occurred, which resulted in the temporary collapse of the Piast state, and the razing of the incomplete basilica (Chudziak, 1997, 2010).

Kałdus is represented by two cemeteries. Kałdus site 4 dates to the second half of the 10th century to the early 13th century CE, but most burials are from 10th and 11th centuries. Kałdus site 1 dates to the 12th century to the early 13th century. Since 1997, more than 430 skeletons have been excavated from Kałdus site 4, and more than 120 skeletons from Kałdus site 1.

Kałdus site 4 is characterized by considerable heterogeneity in burial style (Fig. 2). During the earliest period of Christianization in Poland (10th c. CE), inhumation was introduced as the most



Fig. 1. Map of sites (by Joseph Lanning).



Images courtesy of the Nicolaus Copernicus University Institute of Archaeology Archive

Fig. 2. Burial heterogeneity at Kałdus.

important aspect of a Christian burial. As decades passed, other Christian elements became widespread including burial in a supine position, without grave goods, and on an East-West axis. At Kałdus site 4, burials (inhumations) occur in flexed positions, with grave goods including flint, knives, and jewelry (especially temporal rings, which adorned women's heads in the early medieval period), objects placed atop the body, and/or on a North-South axis, thereby representing compromises between old and new burial styles. Some burials exhibit luxury elements, including buckets or bowls, double graves, and evidence for wood chambers grave and wood coffins (Biermann, 2008; Janowski and Kurasiński, 2003). The existence of immigrants or cultural elements from Scandinavia in this inland region of North-Central Poland attests to the nature of Kałdus as well-connected with other regions. Some of the individuals buried with “pagan” elements – for example, those placed on their sides, burial in the fetal position, or with objects atop their bodies – are examples of possible precautions against the deceased rising from the grave (Barber, 1988), as was likely the case for individual K4-48-F from Kałdus site 4 who was buried flexed, and with a large stone atop her body (Fig. 2B). The presence of pagan “hang-ons” at Kałdus likely reflect both the relatively recent conversion of the Piast state, as well as the geographic relationship to pagan Prussia and its cultural influences. In contrast, more graves in the later cemetery at Kałdus from site 1 are Christian-style burials located supine on an East-West axis, suggesting a more widespread adherence to Christian burial customs in this later period.

Two skeletal samples are from cemeteries Gruczno, a rural village located opposite Kałdus on the West bank of the Vistula River. Gruczno developed as a small Piast tribal settlement in the 7–8th

century CE. A defensive stronghold was constructed in the 9–10th century CE (Bojarski, 1995). In the late 10th and 11th centuries, the stronghold complex collapsed, and the settlement was temporarily depopulated. As the Piast state developed and grew, later in the 11th century, people returned to Gruczno and a small farming community was established. The cemetery of Gruczno site 1, located atop the pre-state open settlement, was used from the 12 to 13th century, and contained 460 burials. By the 13th century, the village was thriving and more populous, although still chiefly agricultural. The Gruczno site 2 cemetery, located atop the pre-state stronghold, was in use in the 13–14th century, and contained 1297 burials. In both cemeteries, bodies are oriented on an East–West axis. At Gruczno site 1, a third of the graves contain objects such as knives, flint, or items of personal adornment, including some with Teutonic coins. At Gruczno site 2, grave objects are rare, suggesting a stronger influence of Christianity on burial customs. Teutonic coins are found in some site 2 graves. Bioarchaeological evidence suggests living conditions at Gruczno may have been worse than at other contemporary medieval Polish sites (Bojarski, 1995; Kozłowski, 1993; Piontek and Kozłowski, 2002).

### 3.2. Shifting political and ethnic sands

The four cemeteries examined in the present study span the 400 years following Polish state formation and Christianization in 963–992 CE. A powerful force in advancing Christianization throughout Europe in the first millennium was the conversion of political leaders. Their conversion marked “official” Christianization of a polity, which accelerated missionary activity and frequently led to the anathematization of other religions. We do not know precisely how successful Christianizing efforts were in spiritually converting the peasantry. Christian-style burials represent a public activity that may have reflected a wish to appear Christian more than it reflected actual Christian beliefs, but it took several generations following state-wide conversion for graves in Poland to show purely Christian elements.

Prior to state formation, modern-day Poland was occupied by autonomous but variously affiliated tribes engaging in agriculture and animal husbandry. Poland’s history is characterized by borders that frequently shift, even occasionally vanishing, and the medieval period was no exception. Consolidation of the Polish state’s power and lands during the medieval period was repeatedly interrupted. Attacks from Prussia, which had resisted Christianization for many centuries, resulted episodically in loss of northern territory. In the case of the Tatar invasions of the 13th century, entire towns were destroyed and regions significantly depopulated (Gieysztor et al., 1979). Revolts also threatened Poland’s borders, and in the 11th century, this affected the Chełmno region, including Kałdus and Gruczno, with the reversion of the area to paganism and the rejection of state leadership. Competing interests of regional dukes periodically saw Poland partitioned into duchies.

During the later medieval period, the Teutonic Order of Knights confronted the Polish state and Slavic identity (Knoll, 2008; Piskorski, 2008; Zamoyski, 2007). Poland invited the ethnically German Teutonic Order in 1226 CE to defend the northern frontier from Prussian (pagan) military activity (Zamoyski, 2007). The initial heart of the Teutonic Order’s territory was in the Chełmno region, and in 1253–1257 CE it built a stronghold at Starogród, near Kałdus. The cemeteries (10th to early 13th centuries) at Kałdus appear to pre-date Teutonic influence, but Teutonic coins excavated from graves at both Gruczno site 1 and site 2 (12–14th centuries) attest to interaction between the Teutonic Order and Gruczno’s inhabitants. Poland’s border with Germany was already diffuse (e.g., Mucha and Piontek, 1983), and Germanic cultural influences had percolated into the Chełmno region prior to the establishment of a Teutonic “state”. The Teutonic Order encouraged and oversaw a

more formal Germanization in the Chełmno region after the 13th century, including stimulating German immigration to the region: “German settlers poured in, often encouraged by Polish rulers seeking to repopulate areas devastated by the Tatars...the influx of landless knights and farmers from Germany also increased the German element in rural areas...” (Zamoyski, 2007: 34). Furthermore, the Teutonic Order exerted a strong influence on agriculture and exchange through its affiliation with the Hanseatic League, offering yet another vector for Germanic traditions and foodways to take root in some regions of Poland. The relationship between the Teutonic Order and Poland eventually decayed into open conflict. It was not until 1466 with the Treaty of Toruń that the Teutonic Order was effectively ousted, and the Chełmno region returned to Polish authority. We regard Germanization as a local influence on diet and lifestyle in medieval Poland, varying with geography and the extent of cross-cultural exposure.

### 3.3. Evidence for diet

The medieval diet in North-Central Poland was broad, supported by availability of wild and domestic terrestrial animals (especially pigs, fowl, and cattle), freshwater and migratory fish, and extensive arable land for cereals, vegetables, and fruits, not to mention foods available through trade routes crisscrossing the state, such as marine fish. Cereals formed the base of the diet, especially wheat, a C<sub>3</sub> plant, and millet, a C<sub>4</sub> plant (Dembińska, 1999; Makowiecki, 2006, 2007, 2010; Polcyn and Abramów, 2007; Reitsema et al., 2010; Reitsema and Kozłowski, 2013). A less-often mentioned C<sub>4</sub> plant in medieval Polish diet is *Digitarium sanguinalis*, known today as Polish millet or crabgrass, and known in historic times as “sown manna” (Dembińska, 1999; Łuczaj et al., 2012; Waller and Lewis, 1979). Its seeds are small and harvested by hand, thus sown manna was more likely an elite food than a daily staple, and likely contributed few calories to diet, unlike millet.

Even among the general populace in medieval Poland, meat was “considered a basic food to be consumed on a daily basis” (Dembińska, 1999: 83). Beef, pork, and poultry, including organ meat and dairy, were the commonest forms of meat. Pig is the most common domestic animal represented in faunal assemblages at Kałdus, followed by cow, sheep/goat and chicken. Milk and cheese consumption would have been low in medieval Poland on account of the relatively small size of dairy animals (Makowiecki, 2006, 2010), although eggs of domestic fowl likely were accessible and eaten often (Dembińska, 1999; Dzieduszycka, 1985). How these resources were distributed within the population through time is unclear from plant and animal assemblages.

Compared to other medieval Polish sites, including those on the coast, fish remains are unusually numerous at Kałdus (Makowiecki, 2003, 2006). This is particularly true of Kałdus site 4, where fish comprise 28.6% of the number of faunal identified specimens present (NISP) (compared to just 2.9% at Kałdus site 1) (Makowiecki, 2010). At Kałdus, carp is particularly numerous in faunal assemblages (40% NISP) (Makowiecki, 2010). Freshwater fish from the Vistula River and its associated oxbow lakes and tributaries, such as cyprinids, pike, sturgeon, and marine fish imported from the Baltic Sea, such as herring, would have been accessible to the village population (Makowiecki, 2001, 2006). Marine fish are, however, poorly represented in faunal assemblages: herring comprises less than 3% of the total fish NISP at Kałdus.

## 4. Materials and methods

The sample for isotopic analysis consisted of bones, most often ribs, from 133 humans aged 20 years and older, and fauna from the settlement contexts at Kałdus. Demographic information for all

**Table 1**  
Demographic, isotopic, and bone quality data from all four sites.

Sample ID	Sex	Age (Years)	Collagen %N	Collagen %C	Collagen $\delta^{15}\text{N}_{\text{Air}}$ (‰)	Collagen $\delta^{13}\text{C}_{\text{VPDB}}$ (‰)	Carbonate $\delta^{13}\text{C}_{\text{VPDB}}$ (‰)	Coll (%)	Collagen C/N	Carbonate C.I.	Carbonate C/P
<i>Kaldus</i>											
K4-010	F	25–30	5.5	15.6	10.6	-17.1	-11.00	10.0	3.3	3.9	0.12
K4-101*	F	25–35	15.2	42.3	10.1	-19.6	-13.20	nd	3.2	4.2	0.1
K4-122	F	25–35	5.3	15.3	9.2	-19.5	-13.02	10.7	3.4	4.0	0.12
K4-139	M	25–35	14.9	41.6	8.9	-18.5	-12.67	nd	3.3	4.0	0.12
K4-013A*	M	25–35	12.2	34.8	11.3	-17.7	-12.12	13.0	3.3	3.8	0.14
K4-013B*	F	20–25	10.0	27.7	9.5	-16.4	-10.02	15.0	3.2	3.2	0.19
K4-014	M	35–55	12.0	34.0	11.0	-17.3	-11.30	12.5	3.3	3.3	0.19
K4-159	M	35–55	14.5	40.6	9.4	-19.6	-12.67	nd	3.3	4.1	0.1
K4-164	M	35–55	13.0	37.1	9.9	-17.8	-12.20	9.8	3.3	3.3	0.17
K4-177	F	25–35	15.4	43.1	10.5	-16.3	-9.64	nd	3.3	3.4	0.17
K4-185*	F	25–35	15.1	42.2	9.7	-18.6	nd	nd	3.3	nd	nd
K4-186	F	22–28	3.5	9.9	8.7	-19.0	-13.08	11.8	3.4	3.8	0.12
K4-192	F	25–30	6.3	17.8	10.9	-20.3	-14.20	7.7	3.3	4.4	0.09
K4-199*	M	25–35	10.7	30.9	10.8	-18.0	nd	7.1	3.4	nd	nd
K4-210*	F	45–55	11.3	32.6	10.8	-18.2	-12.60	13.9	3.4	3.5	0.16
K4-225	F	25–35	8.9	25.8	10.5	-18.0	-11.21	3.1	3.4	3.8	0.16
K4-229*	M	25–35	15.0	41.7	9.8	-18.6	-12.32	nd	3.2	3.6	0.15
K4-230	M	35–55	9.6	28.0	10.4	-18.9	-12.63	13.3	3.4	3.6	0.18
K4-231	M	25–30	5.9	18.5	8.7	-17.8	nd	0.0	3.6	nd	nd
K4-243*	F	25–35	nd	nd	9.0	-19.6	-13.25	0.0	3.5	3.7	0.14
K4-254	M	30–35	11.7	33.5	11.1	-19.7	nd	7.7	3.3	nd	nd
K4-256A	F	35–45	13.2	36.9	10.7	-19.3	-11.98	14.0	3.3	3.5	0.17
K4-256B	M	35–40	10.8	30.9	10.5	-17.8	-11.40	15.0	3.3	3	0.24
K4-261A	M?	25–55	12.5	35.4	10	-18.7	-9.23	15.0	3.3	3.3	0.25
K4-261B	M?	25–35	7.8	23.5	11.2	-18.1	-10.47	6.7	3.5	3.7	0.17
K4-263*	F	25–30	12.7	35.6	10.5	-19.1	-12.35	12.0	3.3	3.0	0.22
K4-264*	M	30–50	12.3	34.7	9.9	-17.6	nd	6.7	3.3	nd	nd
K4-267	F	25–30	12.9	36.3	10.0	-19.3	nd	10.0	3.3	nd	nd
K4-031*	M	50–60	10.6	30.3	9.9	-18.7	-12.39	20.8	3.3	2.7	0.27
K4-032	F	25–35	13.1	36.6	9.7	-19.0	nd	14.3	3.3	nd	nd
K4-364*	M	nd	9.7	28.1	10.4	-16.5	-10.58	4.5	3.4	4.0	0.17
K4-041	M	35–55	7.4	22.3	10.3	-16.7	-10.23	0.0	3.5	3.1	0.21
K4-048	F	50–60	9.0	26.1	11.9	-18.3	-10.90	8.2	3.4	3.4	0.18
K4-060*	M	30–40	14.4	40.0	11.1	-20.1	-14.05	11.5	3.2	3.6	0.14
K4-064	M	25–35	10.6	30.4	10.1	-19.2	-10.24	8.8	3.4	3.4	0.18
K4-075	F	35–45	10.7	30.2	9.6	-19.5	nd	14.3	3.3	nd	nd
K4-086	F	25–30	5.2	15.2	10.0	-19.1	-13.07	20.0	3.4	4.1	0.11
K1-100	F?	nd	11.5	31.6	9.8	-19.3	-11.28	15.7	3.2	3.5	0.18
K1-101*	F	nd	12.3	35.4	11.2	-19.6	-9.79	8.0	3.4	3.2	0.25
K1-109*	M	nd	12.8	36.5	10.0	-18.8	-12.08	7.7	3.3	3	0.28
K1-011*	F	40–60	12.7	35.5	9.0	-19.2	-12.10	8.3	3.3	3.4	0.17
K1-119*	F	>20	10.8	29.7	9.6	-19.1	-13.70	2.4	3.2	3.2	0.21
K1-012	M	25–35	15.3	42.5	10.4	-19.6	-13.61	nd	3.2	3.6	0.15
K1-124*	F	55–60	12.0	34.6	10.8	-19.8	-13.09	11.3	3.4	3.4	0.18
K1-129*	F	25–35	15.3	42.6	10.0	-19.6	-13.34	nd	3.2	3.6	0.16
K1-013*	F	35–55	14.2	40.3	9.9	-19.3	-13.66	22.2	3.3	3.4	0.18
K1-131*	M	55–65	11.8	32.6	9.2	-19.3	-13.41	7.1	3.2	3.1	0.23
K1-138*	M	40–50	12.3	34.3	10.4	-19.6	-13.45	11.4	3.2	3.6	0.15
K1-016*	M	35–55	15.4	42.6	10.8	-19.6	-13.85	nd	3.2	3.6	0.16
K1-018	M	16–20	12.2	34.7	9.4	-20.5	-13.18	3.1	3.3	3.6	0.15
K1-021*	F	25–35	13.1	37.0	10.2	-19.9	-13.41	8.3	3.3	3.7	0.14
K1-022*	M	35–45	15.5	43.0	10.8	-19.7	-13.82	nd	3.2	3.6	0.16
K1-027*	M	35–55	11.1	32.0	11.0	-18.7	-11.71	8.8	3.4	3.3	0.21
K1-031*	F	30–40	11.4	31.8	10.8	-19.6	-13.33	17.7	3.2	3.4	0.18
K1-033	M	25–35	7.0	19.2	11.2	-19.3	-12.96	0.0	3.2	3.1	0.21
K1-039*	M	30–35	13.5	38.4	10.6	-19.4	-12.80	11.3	3.3	3.4	0.17
K1-045*	M	35–55	14.5	40.5	11.6	-20.0	-13.87	8.8	3.3	3.7	0.15
K1-005*	F	25–35	15.3	42.6	11.2	-20.3	-15.40	nd	3.2	3.4	0.17
K1-051*	F	55–60	12.4	35.7	10.4	-19.9	-13.61	13.0	3.4	3.4	0.19
K1-057*	M	50–60	11.0	32.0	10.6	-19.0	-15.40	18.6	3.4	3.1	0.23
K1-058*	F	25–35	13.5	38.4	8.7	-19.3	-7.89	12.5	3.3	3.8	0.21
K1-007*	F	35–45	13.2	36.7	10.0	-19.7	-13.24	8.1	3.3	3.4	0.17
K1-080	M	45–55	10.5	29.2	9.7	-19.3	-12.66	5.2	3.2	3.4	0.20
K1-082*	M	35–55	10.7	31.1	9.7	-18.9	-11.56	20.7	3.4	3.5	0.17
K1-085	F	35–55	13.4	37.9	9.2	-19.7	-13.36	8.7	3.3	3.3	0.19
K1-093*	M	35–55	10.1	29.5	10.0	-18.9	-8.24	12.5	3.4	3.7	0.20
K1-097	F	25–30	14.6	40.7	10.6	-20.0	-13.68	nd	3.2	3.5	0.17
<i>Gruczno</i>											
G1-205*	F	nd	11.7	33	9.1	-19.8	-13.46	nd	3.3	3.3	0.23
G1-208	M?	35–55	11.5	32.8	9.2	-19.9	nd	nd	3.3	nd	nd
G1-209	M	22–35	12.8	35.6	9.5	-19.9	-12.23	10.8	3.3	3.6	0.16
G1-212*	F	35–55	13.7	38.3	8.8	-20.3	-12.58	11.3	3.3	3.3	0.20

Table 1 (continued)

Sample ID	Sex	Age (Years)	Collagen %N	Collagen %C	Collagen $\delta^{15}\text{N}_{\text{Air}}$ (‰)	Collagen $\delta^{13}\text{C}_{\text{VPDB}}$ (‰)	Carbonate $\delta^{13}\text{C}_{\text{VPDB}}$ (‰)	Coll (%)	Collagen C/N	Carbonate C.I.	Carbonate C/P
G1-213	F	35–55	11.7	33	10.3	–19.5	nd	9.8	3.3	nd	nd
G1-265	M	35–55	10.9	31	9.3	–19.7	–12.70	4.3	3.3	nd	nd
G1-271*	M?	22–35	5.4	17.9	10.7	–20.6	–12.24	2.1	3.9	3.1	0.23
G1-272*	M?	35–55	13.7	38.0	8.6	–19.4	nd	nd	3.2	3.1	0.21
G1-275*	M	35–55	13.1	36.5	9.4	–19.9	–13.82	9.6	3.2	2.8	0.26
G1-300*	M	22–35	11.7	32.5	10.1	–19.4	–13.09	nd	3.2	3.0	0.24
G1-307	F	22–35	11.5	31.6	8.7	–20.1	–13.91	11.8	3.2	3.5	0.16
G1-308	F	22–35	11.8	32.7	9.1	–19.8	–12.44	5.3	3.2	3.5	0.14
G1-309	M	22–35	8.4	23.1	9.1	–19.6	–11.72	6.5	3.2	3.7	0.16
G1-321	F	35–55	13.4	37.1	9.9	–19.2	–13.57	13.0	3.2	3.8	0.12
G1-329	M	22–35	12.8	35.4	9.2	–20.0	–13.36	20.0	3.2	nd	nd
G1-331	F	35–55	12.8	35.2	8.4	–20.0	–13.20	15.8	3.2	3.4	0.16
G1-332	F	nd	11.5	32.0	9.3	–19.3	–12.75	30.8	3.2	3.6	0.15
G1-342*	F	22–35	13.1	36.7	8.6	–20.4	–13.31	9.5	3.3	3.4	0.19
G1-343	F	>55–60	9.9	28.6	9.2	–20.6	nd	6.0	3.4	nd	nd
G1-347	M	35–55	12.3	34.2	9.5	–19.7	–12.72	17.6	3.2	2.1	0.22
G1-349	M	22–35	12.4	34.2	9.7	–19.5	–12.97	7.7	3.2	3.7	0.16
G1-357*	M	22–35	13.4	36.9	8.8	–19.7	–12.04	18.2	3.2	3.5	0.16
G1-360	M	35–55	13.0	36.4	9.1	–19.6	–14.21	nd	3.3	3.2	0.22
G1-362	M	35–55	12.9	35.5	9.8	–19.5	–13.20	20.8	3.2	3.5	0.15
G1-364*	M	22–35	13.2	36.4	9.6	–19.5	–13.11	10.7	3.2	3.5	0.16
G1-369*	F	35–55	9.6	26.8	10.0	–19.0	–12.67	15.8	3.3	3.2	0.21
G1-372*	M	35–55	9.0	25.3	9.4	–19.5	–13.40	13.3	3.3	3.8	0.14
G1-042	M	35–55	14.0	39.1	8.1	–20.1	–13.48	nd	3.3	3.7	0.14
G1-050*	F	nd	13.7	37.9	8.4	–20.5	–13.25	17.1	3.2	3.4	0.17
G1-051	F	35–55	12.9	36.3	9.8	–20.1	–12.48	0.0	3.3	3.5	0.17
G1-054*	F	nd	5.5	18.4	9.6	–19.2	nd	5.6	3.9	nd	nd
G1-673	F	22–35	11.6	32.2	9.6	–19.8	–13.62	23.5	3.2	3.6	0.15
G1-760	F	22–35	7.5	20.9	9.4	–20.1	–11.12	8.0	3.3	3.3	0.18
G1-766	F	22–35	12.2	33.5	11.2	–20.1	–13.62	15.2	3.2	3.2	0.22
G2-1012	F	22–35	12.9	35.5	9.8	–19.9	–13.45	14.3	3.2	3.1	0.23
G2-1039	F	22–35	11.5	31.8	10.1	–20.1	–13.35	27.3	3.2	2.9	0.26
G2-1055	M	35–55	9.3	25.8	8.8	–19.5	–11.69	4.8	3.2	3.0	0.24
G2-1058	M	35–55	12.2	33.6	9.0	–20.1	–12.76	nd	3.2	2.8	0.33
G2-1065	M	22–35	11.9	33.1	8.6	–19.9	–12.31	25.0	3.2	3.2	0.22
G2-1091	F	22–35	12.8	35.2	8.5	–20.2	–12.53	20.0	3.2	2.9	0.31
G2-1092	M	35–55	11.8	32.6	9.9	–19.5	–13.86	16.7	3.2	3.1	0.23
G2-1093	M	35–55	12.2	33.8	10.3	–19.9	–12.63	26.7	3.2	3.0	0.29
G2-1150	M	35–55	13.0	35.8	10.7	–19.9	–13.26	12.5	3.2	3.4	0.18
G2-1154	F	22–35	13.2	36.4	8.9	–20.0	–13.40	15.0	3.2	3.5	0.16
G2-1169	M	35–55	11.3	31.3	8.8	–20.0	–13.91	26.7	3.2	3.3	0.19
G2-1184	F	nd	7.7	21.3	8.1	–19.9	–13.50	20.0	3.2	3.0	0.24
G2-1199	F	nd	13.5	37.3	9.1	–20.0	–13.87	19.0	3.2	3.3	0.19
G2-1302	F	22–35	10.8	29.9	9.3	–20.5	–13.87	28.6	3.2	3.4	0.17
G2-1303	M	22–35	12.3	33.8	7.6	–19.9	–13.16	21.1	3.2	3.0	0.24
G2-1309	F	nd	11.1	30.9	9.8	–20.3	–12.97	14.3	3.2	3.0	0.27
G2-1317	F	nd	13.6	37.3	8.8	–19.9	–13.60	12.5	3.2	3.2	0.21
G2-1411	M	22–35	12.0	33.2	8.0	–20.2	–12.85	12.5	3.2	3.5	0.17
G2-1518	M	nd	5.3	14.6	9.5	–19.9	–12.81	0.0	3.2	3.6	0.16
G2-1530	F	30–35	12.4	35.4	8.6	–20.4	–14.52	3.6	3.3	3.4	0.16
G2-1549	F	nd	10.0	31.8	9.2	–20.5	–13.93	0.0	3.7	3.2	0.19
G2-1563	F	20–30	8.8	30.3	9.2	–20.7	–14.28	0.0	4.0	3.4	0.19
G2-1576	F	25–30	9.1	27.6	9.0	–20.1	–13.76	2.6	3.5	2.9	0.28
G2-1580	F	20–50	13.8	38.6	9.4	–19.6	–13.37	2.4	3.3	3.2	0.20
G2-1604	M	nd	8.0	25.0	9.2	–20.5	nd	3.2	3.6	nd	nd
G2-1606	M	nd	8.7	26.4	10.6	–20.8	–14.48	12.0	3.6	3.7	0.14
G2-1607	F	20–30	9.0	27.5	10.0	–20.7	–14.90	3.4	3.5	3.2	0.20
G2-1643	M	nd	9.7	28.7	9.6	–20.7	–13.50	6.0	3.5	2.9	0.28
G2-1645	M	nd	12.7	35.0	10.2	–20.0	–13.16	20.0	3.2	3.3	0.20
G2-1646	M	nd	9.7	27.0	9.2	–19.9	–13.66	27.3	3.2	2.9	0.27
G2-1662	M	nd	10.3	28.6	9.0	–19.5	–12.82	20.0	3.2	3.1	0.24
G2-1703	M	nd	9.5	28.5	10.0	–20.7	nd	4.2	3.5	nd	nd

Data from all samples are given including demographic information, collagen quality indicators including nitrogen and carbon content in bone (%N; %C), the atomic carbon-nitrogen ratios of bone (C:N), and the collagen content in bone (%coll), carbonate quality indicators including the crystallinity index (CI) and the carbon content in bone (C/P) as measured through Fourier-transform infrared spectroscopy, and the stable carbon and nitrogen isotope results from collagen ( $\delta^{13}\text{C}_{\text{coll}}$ ,  $\delta^{15}\text{N}$ ) and the stable carbon isotope results from apatite ( $\delta^{13}\text{C}_{\text{ap}}$ ). Asterisks demarcate samples run in duplicate, as described in the text. Values appearing in italics were excluded from analyses on the basis of their collagen or carbonate quality indicators. Samples demarcated with asterisks (\*) were buried with grave goods; most commonly, these included knives and temporal rings.

individuals, recorded according to the Global History of Health Codebook (Steckel et al., 2005), is given in Table 1. Collagen was analyzed from all 133 individuals, and bone apatite was analyzed from 118 of these.

The collagen fraction of bone was prepared according to Ambrose (1990) and Ambrose et al. (1997). Approximately 0.2–0.7 g of coarsely ground bone were demineralized in 0.2 M HCl for several days. Demineralized particles were rinsed to neutrality

and soaked in 0.125 M NaOH for 20 h. After rinsing to neutrality, particles were gelatinized in pH  $\approx$  3 HCl overnight, drawn through a coarse glass filter, and freeze-dried. Freeze-dried collagen was homogenized in an agate mortar and pestle. Approximately 600–700  $\mu$ g of purified collagen powder were weighed into tin capsules in the Stable Isotope Biogeochemistry Laboratory at the Department of Earth Sciences at The Ohio State University. Collagen was analyzed on a Costech Elemental Analyzer coupled to a Finnigan Delta IV Plus stable isotope ratio mass spectrometer under continuous flow using a CONFLO III interface in the Stable Isotope Biogeochemistry Laboratory at The Ohio State University. Stable carbon ( $\delta^{13}\text{C}$  = permil deviation of the ratio of  $^{13}\text{C}/^{12}\text{C}$  relative to the Vienna Pee Dee Belemnite Limestone standard) and stable nitrogen ( $\delta^{15}\text{N}$  = permil deviation of  $^{15}\text{N}/^{14}\text{N}$  relative to AIR) measurements were made where repeated measurements of the USGS24 and IAEA1 standards were  $\pm 0.06\%$  for  $\delta^{13}\text{C}$  and  $\pm 0.17\%$  for  $\delta^{15}\text{N}$ .

Apatite was extracted according to Garvie-Lok et al. (2004). Briefly, bone powder was soaked for 48 h in 10 mL 2% NaOCl solution, replacing solutions every 12 h with centrifugation. Deproteinized powders were centrifuged and rinsed two times using distilled, deionized water. After rinsing, powders were dried in a 70–90 °C oven for at least 12 h. Diagenetic carbonates were removed by soaking deproteinized powders in 50 mL 0.1 M acetic acid for four hours. 1.0–1.2 mg of purified apatite was analyzed for  $\delta^{18}\text{O}$  ( $\delta^{18}\text{O}$  = permil deviation of  $^{18}\text{O}/^{16}\text{O}$  relative to Vienna Pee Dee Belemnite Limestone standard (VPDB) using an automated Carbonate Kiel device coupled to a Finnigan Delta IV Plus stable isotope ratio mass spectrometer in the Stable Isotope Biogeochemistry Laboratory at The Ohio State University. Samples were acidified under vacuum with 100% *ortho*-phosphoric acid, the resulting  $\text{CO}_2$  cryogenically purified, and delivered to the mass spectrometer. Approximately 5% of all samples were run in duplicate. The mean standard deviation of all analytical duplicates was 0.05‰ for  $\delta^{13}\text{C}$  and 0.17‰ for  $\delta^{18}\text{O}$ . The standard deviation of repeated measurements of limestone internal standard (NBS-19) for  $\delta^{13}\text{C}$  was  $\pm 0.03\%$  (values will be reported to the nearest 0.01‰ accordingly), and of a biogenic calcite standard (sclerosponge skeleton) for  $\delta^{18}\text{O}$  was  $\pm 0.06\%$ .

Bone apatite treated for analysis of carbonate also was analyzed using Fourier transform infrared spectroscopy to characterize degree of crystallinity of apatite to test for diagenesis (Shemesh, 1990; Wright and Schwarcz, 1996). FTIR-grade potassium bromide (KBr) crystals weighing  $0.3 \pm 0.05$  g were weighed into plastic vials. Approximately 1.5–2.0 mg of purified, homogenized apatite was added to the vials and mixed in a shaker mill for 30 s. A pure sample of 0.3 g KBr was also weighed to serve as a background baseline for analyses. Sample and KBr mixtures were compressed into thin transparent discs using a die and a Carver lab press under 20,000 lb of pressure for two minutes. KBr “pellets” were scanned 16 times between 4000 and 400  $\text{cm}^{-1}$  at a resolution of 4  $\text{cm}^{-1}$  using a Perkin Elmer IR 16PC FTIR spectrometer housed at The Ohio State University’s Department of Chemistry. Each day, a separate KBr baseline pellet was prepared and scanned initially to provide a baseline which was subtracted automatically from each sample scan by the computer using Spectra<sup>®</sup> software. Spectrum heights were measured at 565, 590, 605, 1035 and 1415  $\text{cm}^{-1}$ .

Criteria for collagen preservation quality used in this study include atomic C:N ratios (C:N), percent carbon (%C) and percent nitrogen (%N) from the purified collagen sample, and in approximately half the cases, where measurements were made, collagen yields (%coll) from the overall bone sample. These criteria are based on previously reported studies of archaeological and modern bones (Ambrose, 1990; DeNiro, 1985; Garvie-Lok, 2001; van Klinken, 1999). We use FTIR-derived crystallinity indices (CI), carbonate-phosphate ratios (C/P), and presence/absence of a

francolite peak at 1091  $\text{cm}^{-1}$ , and relationships between  $\delta^{13}\text{C}_{\text{ap}}$  and  $\delta^{18}\text{O}$  ratios, as indicators of possible diagenetic alteration of bone mineral (de la Cruz Baltazar, 2001; Garvie-Lok et al., 2004; Wright and Schwarcz, 1996).

In the following sections, p values are from Kruskal-Wallis tests unless otherwise noted and are considered significant when  $p \leq 0.05$ .

## 5. Results

### 5.1. Evaluation of collagen and apatite preservation

Collagen is generally well-preserved. From Kałdus, one sample falls outside the desirable range for C:N, with a value of 3.6. Another sample falls outside the desirable range for %N and %C, with values of 3.5% and 9.9%, respectively. However, neither of these exhibit any other evidence of being poorly preserved, and both are included in the following discussion. Two samples from Gruczno site 1 exhibited C:N values of 3.9, and also exhibit the lowest %N and %C values from the sample. Eight samples from Gruczno site 2 exhibited C:N ratios above 3.5, low %N values under 10% and low %C values between 25% and 32%. Unlike the two suspect samples at Kałdus, at Gruczno, multiple collagen quality indicators from the same samples agree with each other and point to diagenetic alteration. Thus, ten suspect samples from Gruczno are excluded from subsequent analyses and appear in italics in Table 1. A total of 123 individuals are included in the final collagen sample.

While FTIR indices offer some insight on bone mineral diagenesis, clear-cut parameters for carbonate preservation in apatite do not exist. Rather than use absolute cut-off values to evaluate diagenesis, multiple diagenetic indicators are typically considered in tandem (de la Cruz Baltazar, 2001; Garvie-Lok, 2001; Katzenberg et al., 2009; Wright and Schwarcz, 1996). We take this approach and consider FTIR indices and their relationships to each other and to corresponding isotope values (including  $\delta^{13}\text{C}_{\text{ap}}$  and bone  $\delta^{18}\text{O}$ ) in assessing sample quality. Most FTIR values in the present study are in-line with those previously reported for carbonate deemed reasonably well-preserved. CI of 117 individuals from the four sites ranged from 2.1 to 4.4 with a mean value of  $3.4 \pm 0.3$ . C/P ranged from 0.09 to 0.33 with a mean value of  $0.19 \pm 0.05$ . For comparison, modern bones treated with acetic acid exhibit CI values of approximately 3.6 and a C/P range of approximately 0.13–0.19 (Wright and Schwarcz, 1996). Sample G1-347-M had an unusual texture, resembling fine-grained salt, that was notably unlike the other, flour-like powders. The appearance of its overall FTIR spectrum differed considerably from the rest of the sample and from other archaeological samples. Its stable isotope values are likely diagenetically altered and while its collagen values are included in the subsequent discussion, its carbonate values are not.

FTIR data indicate declining bone mineral preservation with increasing antiquity, even despite the small time differences between sites and the fact that all four are relatively young. From youngest to oldest site, CI increases and C/P decreases until Kałdus site 4, where the highest CI, lowest C/P, and greatest variation are observed. Whereas few FTIR peaks at 1096  $\text{cm}^{-1}$  are present in the three youngest sites, 38% of spectra from Kałdus site 4 exhibits this peak. Peaks at this wavenumber indicate recrystallization of apatite into F-apatite (francolite), a feature correlating with poorer preservation (Wright and Schwarcz, 1996, but see also Katzenberg et al., 2009).

At Kałdus site 4, there are slight linear relationships between  $\delta^{13}\text{C}_{\text{ap}}$  and CI ( $R^2 = 0.2010$ ) and between  $\delta^{13}\text{C}_{\text{ap}}$  and C/P ( $R^2 = 0.3192$ ). Relationships are anticipated when recrystallization

has altered biogenic isotopic signatures. When samples with CI of 3.7 and greater are removed ( $n = 12$ ), these relationships are reduced ( $\delta^{13}\text{C}_{\text{ap}}$  and CI:  $R^2 = 0.0389$ ;  $\delta^{13}\text{C}_{\text{ap}}$  and C/P:  $R^2 = 0.1354$ ). Although indicators of diagenetic alteration of apatite are neither clear nor consistent, as a conservative measure, 12 apatite samples from Kałdus site 4 (those with CI of 3.7–4.4) and one sample from Gruczno, previously discussed, are excluded from subsequent analyses and discussion and appear in italics in Table 1. The final apatite sample consisting of 105 individuals exhibits a mean CI of  $3.34 \pm 0.25$  (range: 2.7–3.8) and a mean C/P of  $0.19 \pm 0.04$  (range: 0.12–0.33).

## 5.2. Stable isotope data

Isotopic data from all samples are presented in Table 1. Overall, humans exhibit a mean  $\delta^{15}\text{N}$  value of  $9.8 \pm 0.9\text{‰}$ , a mean  $\delta^{13}\text{C}_{\text{coll}}$  value of  $-19.4 \pm 0.9\text{‰}$ , and a mean  $\delta^{13}\text{C}_{\text{ap}}$  value of  $-12.74 \pm 1.30\text{‰}$ . Collagen data from all samples are shown divided by site in Fig. 3. When each settlement's two cemeteries are pooled, Kałdus differs from Gruczno significantly (Kruskal Wallis test:  $\delta^{15}\text{N}$ :  $p < 0.001$ ;  $\delta^{13}\text{C}_{\text{coll}}$ :  $p < 0.001$ ;  $\delta^{13}\text{C}_{\text{ap}}$ :  $p = 0.004$ ). Overall, Kałdus sites 4 and 1 did not differ in terms of  $\delta^{15}\text{N}$  values ( $p = 0.771$ ) but differed in terms of  $\delta^{13}\text{C}_{\text{coll}}$  and  $\delta^{13}\text{C}_{\text{ap}}$  ( $p < 0.001$  and  $p = 0.002$ , respectively). Gruczno sites 1 and 2 did not differ in terms of  $\delta^{15}\text{N}$  or  $\delta^{13}\text{C}_{\text{coll}}$  ( $p = 0.426$  and  $p = 0.086$ , respectively) but did differ in terms of  $\delta^{13}\text{C}_{\text{ap}}$  ( $p = 0.031$ ). Kałdus (11th c. cemetery) could be sub-divided into five chronological phases. Isotopic data from each phase are depicted in Fig. 4. The only significant difference between phases was for  $\delta^{15}\text{N}$ : between phase 2a and 3 at Kałdus site 4,  $\delta^{15}\text{N}$  values declined significantly ( $p = 0.022$ ).

There are no significant differences between stable isotope ratios of males and females when the entire sample is considered together ( $\delta^{15}\text{N}$ :  $p = 0.423$ ;  $\delta^{13}\text{C}_{\text{coll}}$ :  $p = 0.065$ ;  $\delta^{13}\text{C}_{\text{ap}}$ :  $p = 0.125$ ) (Table 2). When sites are considered separately, males exhibit significantly higher  $\delta^{13}\text{C}_{\text{coll}}$  and  $\delta^{13}\text{C}_{\text{ap}}$  values at Gruczno site 2, the latest cemetery. There are no significant isotopic differences between burials with and without graves goods at any site, neither for  $\delta^{15}\text{N}$  nor  $\delta^{13}\text{C}$  (in all cases,  $p > 0.200$ ).

Kałdus site 4 comprises varied burial styles. Stable isotope values are similar between “Christian” ( $n = 22$ ) and “pagan” ( $n = 7$ ) skeletons, but individuals in graves with Scandinavian elements (bowls and buckets, wooden chambers) are associated with slightly higher  $\delta^{15}\text{N}$ ,  $\delta^{13}\text{C}_{\text{coll}}$  and  $\delta^{13}\text{C}_{\text{ap}}$  values.

Faunal analysis at Kałdus suggests domestic animals formed the bulk of the protein diet, with wild animals contributing considerably less to the diet (Makowiecki, 2010). The faunal baseline for

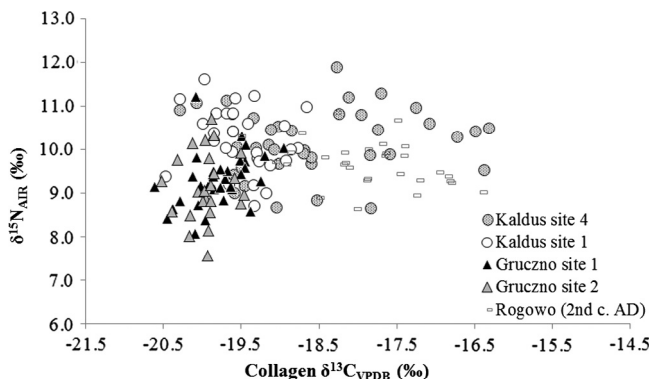


Fig. 3. Carbon stable isotope ( $\delta^{13}\text{C}$ ) and nitrogen stable isotope ( $\delta^{15}\text{N}$ ) data from collagen of skeletons from all four medieval sites, shown in comparison to data from a Roman era population from the same geographic region in Poland (Reitsema and Kozłowski, 2013).

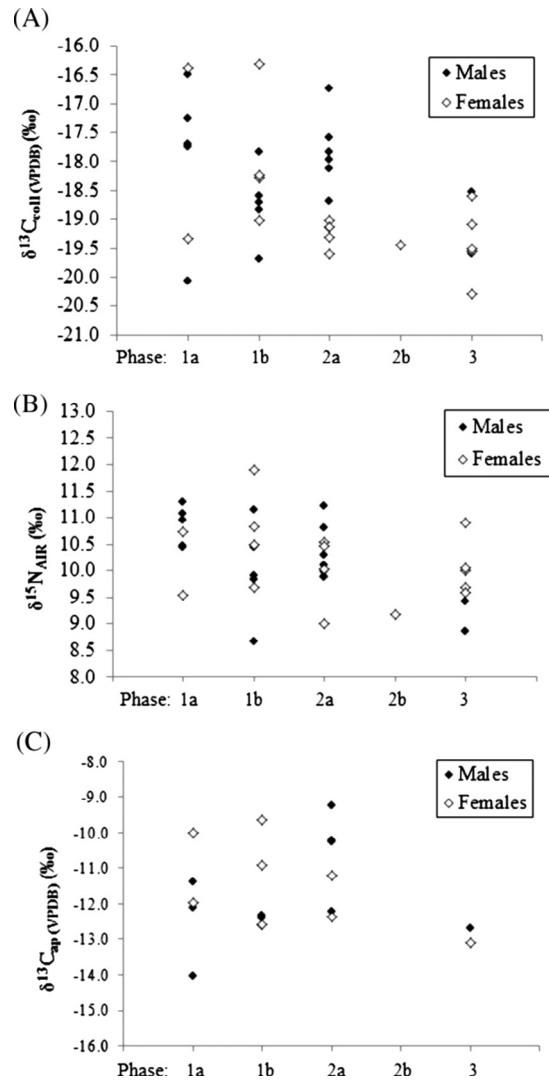


Fig. 4. Kałdus site 4 broken up into relative phases from 975 CE – ca. 1230, showing change in isotope ratios through time. Phases are ordered relatively and are not absolutely dated; each phase lasts approximately 25–50 years.

the present study, described elsewhere in greater detail (Reitsema et al., 2013), comprised domestic animals from Kałdus site 3 ( $n = 11$ ; mean  $\delta^{13}\text{C}_{\text{coll}} = -20.6 \pm 1.2\text{‰}$ ; mean  $\delta^{15}\text{N} = 7.5 \pm 1.1\text{‰}$ ), wild terrestrial animals ( $n = 5$ ; mean  $\delta^{13}\text{C}_{\text{coll}} = -22.0 \pm 0.5\text{‰}$ ; mean  $\delta^{15}\text{N} = 4.3 \pm 0.5\text{‰}$ ), and fish ( $\delta^{13}\text{C}_{\text{coll}}$  range =  $-28.2\text{‰}$  to  $-15.6\text{‰}$ ;  $\delta^{15}\text{N}$  range =  $6.4$ – $12.3\text{‰}$ ) (Table 3). For human bone collagen, the diet-collagen space is expected at approximately  $+3$ – $5\text{‰}$  for  $\delta^{15}\text{N}$  (Drucker and Bocherens, 2004),  $+1\text{‰}$  for  $\delta^{13}\text{C}_{\text{coll}}$  (Fuller et al., 2006; Schoeninger, 1989) and  $+12.0\text{‰}$  for  $\delta^{13}\text{C}_{\text{ap}}$  (e.g., Garvie-Lok, 2001: 125–128; Prowse et al., 2005).

## 6. Discussion

### 6.1. Diet reconstruction

Humans' stable isotope ratios are mostly within an expected diet-collagen offset for consumers of domestic, terrestrial animals. Individuals at Kałdus site 4 exhibit  $\delta^{15}\text{N}$ ,  $\delta^{13}\text{C}_{\text{coll}}$ , and  $\delta^{13}\text{C}_{\text{ap}}$  values in excess of the expected diet-tissue offsets based on domestic fauna. Consumption of  $\text{C}_4$ -foddered animals does not account for humans'  $^{13}\text{C}$ -enrichment: animals are not similarly  $^{13}\text{C}$ -enriched,



**Table 2**  
Inter- and intra-site comparisons.

	$\delta^{13}\text{C}_{\text{coll}}$ (VPDB) (‰)			$\delta^{15}\text{N}_{\text{AIR}}$ (‰)			$\delta^{13}\text{C}_{\text{ap}}$ (VPDB) (‰)		
	Male	Female	p	Male	Female	p	Male	Female	p
Kaldus 4	-18.3 ± 1.0	-18.7 ± 1.1	0.107	10.2 ± 0.7	10.1 ± 0.8	0.523	-11.60 ± 1.42	-11.51 ± 1.33	0.964
Gruczno 1	-19.7 ± 0.2	-19.9 ± 0.5	0.263	9.3 ± 0.5	9.4 ± 0.8	0.904	-12.95 ± 0.69	-13.00 ± 0.72	0.662
Kaldus 1	-19.4 ± 0.5	-19.6 ± 0.3	0.129	10.4 ± 0.7	10.1 ± 0.8	0.129	-12.84 ± 1.60	-12.73 ± 1.84	0.967
Gruczno 2	-19.8 ± 0.2	-20.1 ± 0.3	<b>0.032</b>	9.2 ± 0.9	9.1 ± 0.6	0.772	-13.12 ± 0.70	-13.69 ± 0.59	<b>0.025</b>

Results of Kruskal-Wallis tests comparing males and females at a site. Significant values ( $p \leq 0.05$ ) are emphasized in bold.

**Table 3**  
Fauna.

ID	Species	Nitrogen (%)	Carbon (%)	C:N Ratio	%Coll	$\delta^{15}\text{N}_{\text{AIR}}$ (‰)	$\delta^{13}\text{C}_{\text{VPDB}}$ (‰) bone collagen	$\delta^{13}\text{C}_{\text{VPDB}}$ (‰) bone apatite	
<i>Mammals from Kaldus</i>									
81-05	Elk	<i>Cervus sp.</i>	11.2	32.0	3.3	10.0	3.8	-22.8	-14.94
207-98	Hare	<i>Lepus europeus</i>	12.9	36.6	3.3	5.0	5.0	-21.7	-14.82
140-050A	Aurochs	<i>Bos primigenius</i>	13.2	36.9	3.3	22.2	4.0	-22.2	-14.36
781-02	Deer	<i>Cervus sp.</i>	14.7	41.4	3.3	9.4	4.4	-21.5	-12.95
810-02	Deer	<i>Cervus sp.</i>	11.0	31.6	3.4		4.2	-21.8	-13.61
40-05	Chicken	<i>Gallus gallus</i>	12.9	36.0	3.3		9.1	-18.2	-11.67
639	Chicken	<i>Gallus gallus</i>	15.3	42.7	3.2		9.1	-19.0	-12.44
816-02	Cow	<i>Bos taurus</i>	14.6	40.4	3.2	16.1	7.8	-20.7	-11.41
834-02	Cow	<i>Bos taurus</i>	13.4	38.0	3.3	12.9	7.9	-21.0	
839-02	Cow	<i>Bos taurus</i>	13.1	36.7	3.3	9.5	7.6	-21.5	
200	Cow	<i>Bos taurus</i>	15.7	43.6	3.2		6.4	-21.0	
810-02	Cow	<i>Bos taurus</i>	14.4	40.2	3.2	11.1	6.4	-21.3	-13.80
778-02	Dog	<i>Canis l. familiaris</i>	12.9	36.5	3.3	14.3	9.6	-19.7	-13.56
100	Pig	<i>Sus scrofa</i>	16.1	44.5	3.2		7.9	-21.6	-14.89
119-05	Pig	<i>Sus scrofa</i>	12.9	35.6	3.2		5.9	-21.6	-14.71
816-02	Pig	<i>Sus scrofa</i>	13.2	37.6	3.3		6.8	-19.8	-12.66
841-02	Sheep*	<i>Ovis sp.</i>	10.6 ± 3.2	30.9 ± 9.3	3.4 ± 0.14	10.0	7.1 ± 0.8	-21.5 ± 0.17	
<i>Fish from Kaldus</i>									
75-08	Catfish	<i>Siluris glanis</i>	5.8	16.3	3.3		7.10	-21.5	
547-03	Catfish	<i>Siluris glanis</i>	6.6	19.0	3.3	5.3	12.1	-25.1	-24.1
114-08A	Catfish	<i>Siluris glanis</i>	11.7	32.2	3.2	7.3	9.2	-21.6	
274-03	Carp-bream	<i>Abramis brama</i>	9.4	25.8	3.2	7.7	9.4	-23.0	
64-07	Carp-bream	<i>Abramis brama</i>	10.2	28.1	3.2	3.8	8.6	-27.1	
408-03	Tench	<i>Tinca tinca</i>	11.4	31.2	3.2	3.1	8.9	-28.2	
69-07	Tench	<i>Tinca tinca</i>	11.0	30.0	3.2	10.7	3.8	-5.6	
71-04	Aspe	<i>Aspius aspius</i>	9.1	25.3	3.2	6.3	6.6	-24.0	
161-05	Pike	<i>Esox lucius</i>	10.4	28.8	3.2	4.5	7.3	-23.9	
50-98	Pike	<i>Esox lucius</i>	4.6	12.9	3.3		11.4	-25.6	
100-04	Pike	<i>Esox lucius</i>	11.0	30.3	3.2	5.1	8.9	-25.3	
630-03	Pike-perch	<i>Sander lucioperca</i>	8.4	23.1	3.2	11.8	10.1	-22.3	
4-02	Pike-perch	<i>Sander lucioperca</i>	8.7	24.3	3.3	14.3	12.0	-25.2	
183-98	Sturgeon	<i>Acipenser sp.</i>	12.9	34.9	3.2	7.3	10.6	-15.6	
171-05	Sturgeon	<i>Acipenser sp.</i>	4.1	11.7	3.3	3.7	9.9	-17.1	
114-08	Sturgeon	<i>Acipenser sp.</i>	6.9	19.2	3.3	7.7	11.3	-16.7	
<i>Fish from Giecz†</i>									
F154/03	Fish	<i>Pisces indet.</i>	14.1	39.3	3.3		6.4	-26.5	
F273/03	Fish	<i>Pisces indet.</i>	13.3	38.1	3.3		8.3	-26.4	
F295/05	Fish	<i>Pisces indet.</i>	13.9	39	3.3		12.3	-24.7	
F63/05	Fish	<i>Pisces indet.</i>	14.0	39.3	3.3		11.2	-24.5	

\* Sample run in triplicate.

† Data from nearby medieval Giecz (Reitsema et al., 2010).

and historic evidence suggests domestic animals were foddered on oats, not millet (Dembińska, 1999: 106–107). Instead, greater consumption of millet and fish (freshwater, migratory, or marine) at Kaldus site 4 compared to the other sites is likely. In its earlier phase, Kaldus functioned as a commercial hub for the region. Gruczno, on the other hand, was more a traditional farming village. At Kaldus, some inhabitants acquired, rather than produced, much of their food. Fish were a ready solution to the problem of feeding agglomerated populations detached from farming (Makowiecki, 2001). At Gruczno, more of the population was engaged in farming, rather than tapping into trade and exchange to meet basic subsistence needs. The means by which inhabitants of two neighboring settlements solved their subsistence needs were varied and local,

in spite of their immediate proximity to one another, and in spite of broad national trends toward access to non-local markets (e.g., trade connections to the Baltic Sea) and even Christianization, which may have anticipated increased fish consumption corresponding to fasting directives.

The total diet (including dietary energy) for many individuals, indicated by apatite stable carbon isotope ratios, carries a  $\text{C}_4$  signature. When data are plotted on regression lines devised by Kellner and Schoeninger (2007) based on experimental animal studies (Fig. 5), this  $\text{C}_4$  signature is particularly evident at Kaldus. Two  $\text{C}_4$  plants that may have been eaten in medieval Poland are millet and sown manna. Of these, millet can be considered a major contributor of calories, whereas manna, due to its low yield and

time-intensive harvest, can only be considered supplemental (and likely reserved for the elite). Millet is detected in diet at Kałdus sites 4 and 1, and Grucznno site 1. Little or possibly no millet was eaten at Grucznno site 2, which was not expected. Isotopic evidence of millet consumption in north-central Poland is elsewhere documented dating to the Neolithic (Kozłowski et al., 2013; Osipowicz et al., 2014; Reitsema, 2012), the Roman era (Reitsema and Kozłowski, 2013) and the medieval period (Reitsema et al., 2010). Interestingly, Bronze Age Únětice culture in Silesia, approximately 300 km southwest of the study area and in a milder climate region, does not show evidence for millet consumption (Pokutta, 2013). Elsewhere in Europe, millet has been documented isotopically in human diet in Iron Age and medieval Czech Republic (Halfman and Velemínský, 2015; Le Huray and Schutkowski, 2005), Iron Age Slovenia (Murray and Schoeninger, 1988), medieval Bavaria (Hakenbeck et al., 2010) and Bronze Age and medieval Italy (Ciaffi et al., 2013; Reitsema and Vercellotti, 2012; Tafuri et al., 2009) (see Fig. 5). For a review of isotopic evidence for millet consumption in Eurasia, see Lightfoot et al. (2013).

Data from medieval Poland are compared to other European groups in Fig. 6. Lines are drawn in Fig. 6 to approximately delineate three different diets. These diet “spaces” are estimates based

on the interpretations of authors of the studies from which the data are assembled, for the sake of simplicity. In general, Grucznno resembles other populations whose isotopic data has been previously interpreted as indicative of terrestrial C<sub>3</sub> resource consumption. Kałdus overlaps with all three types of diet, indicating a mixture of C<sub>3</sub> plant, C<sub>4</sub> plant, terrestrial animal, and fish consumption.

Not everyone exposed to Christianity necessarily adopted Christian burial norms, whether fully or partially. The presence of Christian graves at Kałdus retaining pagan elements decades after the Christianization of Poland and seepage of churches into rural areas already reflects a form of resilience and agency in the community. At Kałdus site 4, pagan (n = 7) and Christian (n = 30) graves do not correspond with isotopic differences ( $\delta^{13}\text{C} \text{ p} = 0.938$ ;  $\delta^{15}\text{N} = 0.877$ ). Although the Christian religion called for replacing terrestrial meat with alternate foods, such as fish, on fast days, the regulations did not appreciably affect the amount of fish consumed by those individuals at Kałdus who adhered to Christian burial norms, compared with those individuals who lacked Christian burial elements. Either religion and diet are de-coupled here, religion and burial style are de-coupled, or both, but in all these cases, people in rural communities were electing burial styles and diets the

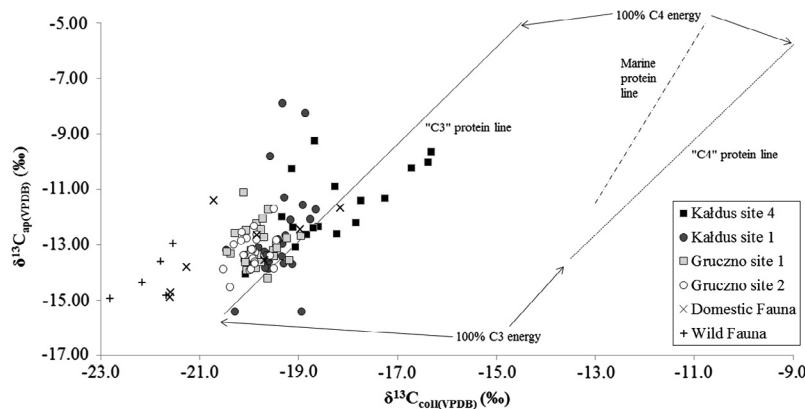


Fig. 5. Bone carbonate data plotted against the regression lines of Kellner and Schoeninger (2007) which are corrected for the Suess effect by adding 1.5‰.

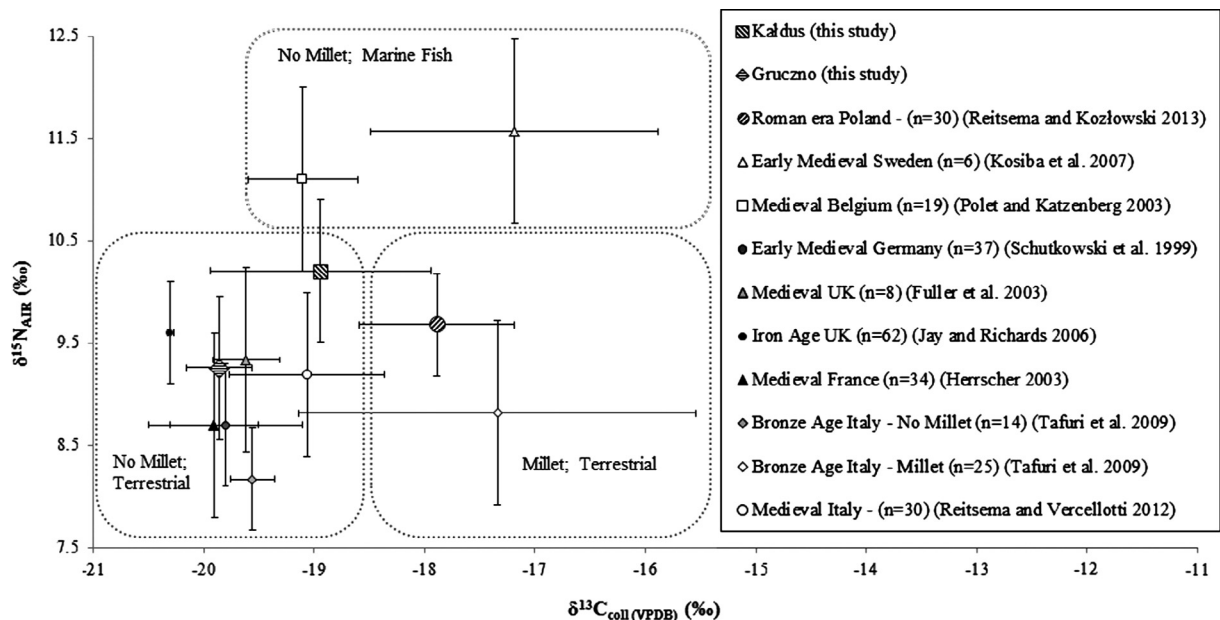


Fig. 6. Comparative collagen data.

state and church would not have prescribed. There is reason to doubt that the peasantry actually adhered to Church doctrines by substituting fish for terrestrial meat on fast days, especially in rural areas. Fish were usually more expensive than terrestrial animal protein, and vegetarianism on fast days would be a more affordable option. The pressures to adhere to Christian customs, including fasts, may have been quite low. Across medieval Europe, few people could read or see a priest regularly (Backman, 2009: 204), and even if they could, sermons were probably delivered unintelligibly in Latin (Backman, 2009; Lynch, 1992). As a final complication, the relationship between diet, stable isotope ratios in human bone tissue, and Christian customs is far from straightforward. People consumed fish before Christianization and had reasons to continue eating fish apart from religious fasts – for example, to solve the problem of feeding urban populations. Additionally, freshwater fish often are difficult to detect isotopically, because they may resemble terrestrial animals and even some plants in terms of stable carbon and nitrogen isotope ratios, and vice versa.

At Gruczno site 2, males consumed more millet than did females. The population at Gruczno site 2 exhibits the least variation overall in  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values, likely reflecting a narrower menu for these people. The existence of sex-based diet differences here is perhaps surprising, as having fewer dietary options would seem to offer fewer opportunities for the manifestation of sex-based differences in diet in the form of differential valuation, daily activities, or daily eating habits in the population. Instead, sex-based differences in diet have appeared where the vegetal (and presumably, cereal) diet is not confounded by other isotopically heterogeneous foods such as fish. It may be the case that sex-based differences in cereal consumption exist at more than just Gruczno site 2, but are masked by other high-protein or isotopi-

cally heterogeneous food items that members of both sexes ate, such as fish. At another medieval site in northern Poland, Giecz (11–12th c. CE), males consume significantly more fish than do females. Overall, isotopic research in Poland demonstrates that sex-differences in diet were small-scale and regionally diverse.

## 6.2. Diet through time

Chronologically, sites and phases leapfrog one another, with a chronological order of Kałdus 4, Gruczno 1, Kałdus 1, Gruczno 2. Rather than phases differing from one another, villages differ from one another. Kałdus sites 1 and 4 exhibit considerable isotopic overlap, although Kałdus site 1 values fall within a more restricted range. Gruczno sites 1 and 2 exhibit isotopic values that are nearly indistinguishable, although Gruczno site 2 values fall within a more restricted range. Stable isotope data are plotted in this sequence in Fig. 7, and include a 2nd c. CE Roman era population from the same geographic region, described elsewhere (Reitsema and Kozłowski, 2013). There is no consistent change through time among the medieval samples.

The most striking change between time periods is between Kałdus site 4 and the rest of the medieval sample. At Kałdus site 4, which is isotopically similar to 2nd century CE Rogowo (Reitsema and Kozłowski, 2013), more fish and millet were consumed, as evidenced by a wider range in isotopic values and comparatively higher  $\delta^{13}\text{C}$  values. A decline in fish consumption was not expected. Rather, our hypothesis was that fish consumption would increase concomitant with the growing foothold of Christianity following Poland's "baptism," following Christian fasting directives. A decline in millet consumption also was not expected in light of broader national changes. However, reduced millet con-

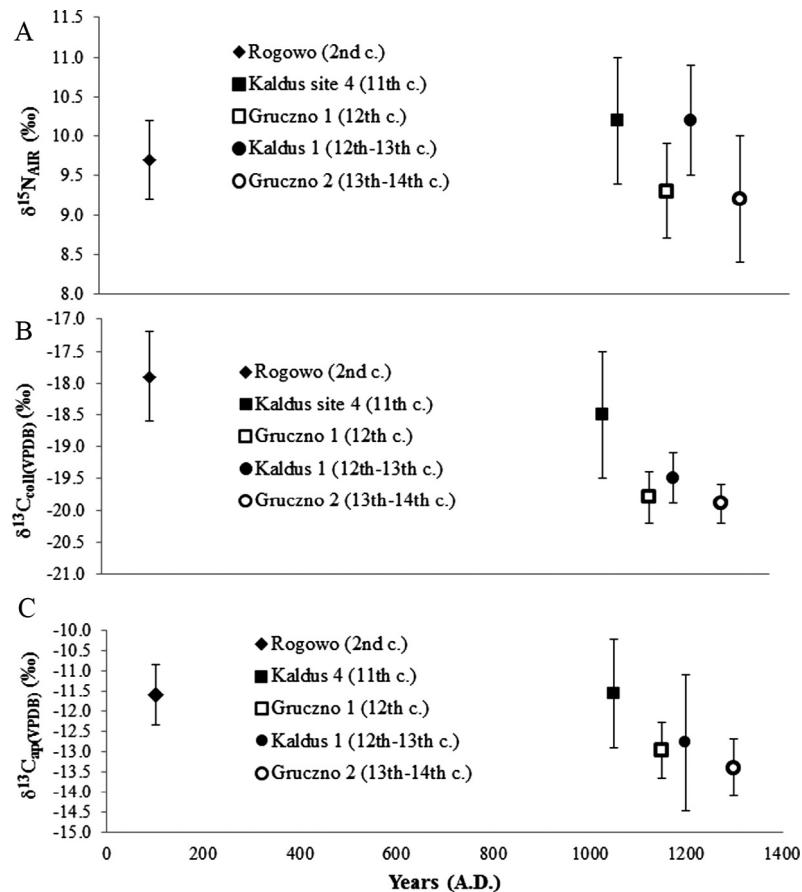


Fig. 7. Change through time; all stable isotope ratios.

sumption and millet farming may be consistent with local sociopolitical conditions, as discussed below.

Differences between diets at Kałdus and Gruczno likely reflect the fact that they were functionally different – both were agricultural, but Kałdus served a more substantive commercial role in the regional settlement structure. Interestingly, at both sites between the two periods represented at each, diet appears to become less varied; in both cases, this is attributable to the removal of the isotopically heterogeneous menu items: millet at both Kałdus and Gruczno, and fish at Kałdus. At a broad national and international scale, fishing and trade increased in the medieval period, in response to economic (markets), technological, demographic (urbanization) and religious (Christian fasting) changes (e.g., Barrett et al., 2004). The rural settlements examined here do not follow these expectations, and instead, appear to follow more localized trends in diet and food access having to do with sites' waxing and waning within a regional settlement system. During the utilization of the site 4 cemetery, Kałdus was an important trade hub linking the economies of the interior with the Baltic. When site 1 was in use, Kałdus had waned in importance, and a "relocalization" of diet may have occurred, with residents continuing to consume animal-derived protein, but from terrestrial animals rather than fish.

Change through time may be investigated on a finer scale at Kałdus site 4. It was possible to assign skeletons at Kałdus site 4 to different relative time slices within the 11th century on the basis of coins and burial location, each representing approximately 50–100 years. These small-scale time differences, depicted in Fig. 4, show gradual changes with no particular time slice representing a major shift. Declining  $\delta^{13}\text{C}_{\text{coll}}$  values at Kałdus reflect a decrease in marine or anadromous fish protein and a relative increase in terrestrial protein in the diet. There is no consistent change through time in  $\delta^{15}\text{N}$  values. In the later phase, millet consumption is less, but the last phase is represented by only two  $\delta^{13}\text{C}_{\text{ap}}$  values, making this a preliminary interpretation.

At Gruczno, millet consumption decreases over time. The drop in millet consumption, also detected at Kałdus, is consistent with a possible "Germanization" of diet. Isotopic, historic and paleobotanical evidence suggests Slavic populations had a cultural preference for millet in ancient and historic times (Barford, 2001; Dembińska, 1999; Hakenbeck et al., 2010: 246; Lightfoot et al., 2013; Rösch, 1998). The borders between Germanic and Slavic territories always were diffuse, with Germanic influences percolating into Poland throughout the medieval period (e.g., the Hanseatic league). Skull and dental morphometric traits in skeletons from West Pomerania underscore gene flow from Germany since the 13th century CE (Mucha and Piontek, 1983). Inhabitants of Gruczno during the 13th century interacted with the Teutonic Order, as attested by Teutonic coins excavated from Gruczno sites 1 and 2 graves. A medieval influx of German immigrants unfamiliar with and possibly uninterested in millet agriculture, combined with the Germanization of preexisting ethnic Poles by their free will or under duress as a non-dominant subpopulation, could be expected to erode agricultural focus on millet, which the isotopic evidence for a shift from  $\text{C}_4$  to  $\text{C}_3$  plants supports. However, millet was not eradicated from Polish diet despite the adoption of serviceable starchy placeholders for millet in many dishes. The Polish word for grain, *kasza*, nearly always refers to millet, but also may be applied equally well to wheat, and today, potatoes substitute for millet in many typical Polish dishes as *kasza* (Dembińska, 1999: 103). Rather than abandoning old ways, humans actively incorporated new menu items into traditional dishes (cf., Weismantel, 1989).

In the medieval period, people at Kałdus and Gruczno were electing burial styles and diets the state and church would not have prescribed, and flexibility in custom allowed them to preserve

fundamental aspects of their daily life. Marked differences in diet existed between Kałdus and Gruczno despite their close geographic proximity: these differences persisted across multiple generations during a period of political, economic, and religious turmoil. However, people were not defying changes entirely: burial style and foodways did change, albeit in unlooked for ways. During the medieval period, at Gruczno, a reliance on agriculture did not change, although the focal crop did, trading millet for  $\text{C}_3$  plants. At Kałdus, animal protein persisted in the diet, although fish were replaced by domesticated animal meat. Overall in these rural communities, small-scale adjustments preserved fundamental aspects of people's foodways. Far from representing either resistance or obeisance to national changes, these changes represent a negotiation between traditions and external pressures that allowed people to preserve aspects of their fundamental ways of life. The mosaic of dietary changes observed at Kałdus and Gruczno could not be termed a "transition" as per the usual bioarchaeological application of the word, because no clear, directional transition occurred or was shared interregionally. Intentionally exploring the related concepts of resilience and agency as explanatory principles for diet change through time at these sites better accommodates the observation of stasis in some aspects of life, and change in others.

### 6.3. Expectations for change in bioarchaeological research frameworks

A tacit assumption in bioarchaeology is that social, political, economic, and demographic upheavals are likely to affect corresponding changes in health, diet, and activity patterns. This expectation is not unfounded, with decades of published bioarchaeological research confirming links between cultural and biological systems (e.g., Cohen and Armelagos, 1984; Cohen and Crane-Kramer, 2007). In medieval Poland, such sociocultural upheavals were, first and foremost, the shift to market economies, Christianization, and urbanization (Betsinger, 2007). However, sociocultural and environmental changes do not always go hand-in-hand with changes in human biology, or with changes in human behavior. This can be attributed to any number of buffering mechanisms associated with human agency, niche construction, geography, and/or phenotypic plasticity (Fuentes, 2016; Smith, 2013). Bioarchaeology is theoretically rooted in evolution, "the essence of [which] is change, a view that admits no constants" (Dunnell, 1996: viii). Human biological response to stressors is well-elaborated, and changes in the human skeleton with sociopolitical and other shifts are well-documented (Larsen, 2015). Yet, sensitive as human physiological adaptation is to shifts in the sociocultural and natural environments, at the population level, issues of episodic resilience, rather than successive change, should also be explored and addressed (e.g., Gregoricka, 2016; Somerville et al., 2013), particularly as they concern diet, which is intertwined with people's social and ethnic identities, historically constrained, and especially resistant to change (Counihan, 1999; Holtzman, 2006; Mintz and Du Bois, 2002; Twiss, 2012). Interpretive frameworks that look for human agency and resiliency offer interpretive power to cases where change is not well-reflected by the human skeleton, because they embrace humans' ability to self-organize and select alternate options rather than depending on exterior forces as causal agents. Large-scale causal agents and evolutionary frameworks may offer incomplete or muddled explanations for human health, organization, and lifestyle, over small time scales. Without a framework for assigning meaning to cases where no change is apparent in the human skeleton, those cases remain underexplored in bioarchaeology. In the present study, human populations appear to be resilient in that they adjusted diets to economic decline by reducing fish consumption, did not increase fish consumption concomitant with official Christianization of the Piast state, and replaced staple grains in daily fare. If Germanic influences are the

source of millet's decline in diet, then this, too, offers an example of resilience: a negotiation between agricultural lifestyle and incoming ideas and norms about diet.

## 7. Conclusion

We examined diet change in medieval rural Poland in relatively refined time slices from 1000 to 1400 CE. Kałdus and Gruczno differ to begin with, with Kałdus being more commercial and Gruczno being more agricultural. Isotopic evidence indicates these differences affected people's relationship with the landscape via food production and diet. Factors affecting diet change at Kałdus and Gruczno appear not to have been broad, national trends such as marketization, Christianization and social differentiation. Rather, they were small-scale influences, reflecting local power dynamics and population interactions. In particular, the economic decline of medieval Kałdus, associated with changes in the regional settlement hierarchy, effected a decrease in fishing or exchange for fish to supplement an agriculturally-based diet. The region has a history of German influence and immigration, including presence of the Teutonic Order in the 13–15th centuries. Germanic influences on subsistence and diet can explain the near abandonment of millet consumption during the 200 years studied at Gruczno.

Christianization affected Kałdus and Gruczno, but not in the form of the populations adhering to Christian fasting directives. Rather, the Teutonic Order came to represent Poland's national religious interests against pagan Prussia, and human populations in a Teutonic sphere of influence may have enacted Germanic culinary preferences. Marketization is not clearly associated with increased dietary heterogeneity or patterned variations in diet reflective of occupational differentiation and enhanced food diversity to diet – at least, not at the scale of the rural settlement. However, this rural area was not immune from changes in Poland's economic climate: the blossoming of other market and urban centers in the regional settlement hierarchy (such as Toruń) sapped commerce from Kałdus and affected consumption of traded fish. Rather than being insulated from broad national trends expected to affect diet, rural settlements absorbed some of the changes going on at a national level, but indirectly, offering a case study in medieval resilience and local adaptation in the face of broad social change.

## Acknowledgments

The authors thank Andréa Grottoli, Yohei Matsui, and the Stable Isotope Biogeochemistry Laboratory at The Ohio State University, as well as Joseph Lanning, Rachel Kopec, Sarah Wehrle, Haagen Klaus, and Daniel Makowiecki. This research was funded by grants from The Ohio State University Graduate School, Department of Anthropology, and Office of International Affairs. We thank the anonymous reviewers for their helpful feedback on the manuscript.

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