

Diet and society in Poland before the state: stable isotope evidence from a Wielbark population (2nd c. AD)

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ABSTRACT: The 1st–4th c. AD Wielbark culture of Eastern Europe is relatively understudied bioarchaeologically due to the fragmentary nature of its cemeteries. Here, we report the first stable isotope analysis of Wielbark diet using stable carbon and nitrogen isotope signatures from both collagen and carbonate of 30 individuals from Rogowo, a 2nd c. Wielbark cemetery in North-Central Poland. Diet at Rogowo was primarily based on terrestrial foods and included millet, a C₄ plant cultivated by many Slavic populations in Europe. Anadromous fish likely supplemented the diet, which is clarified when considering collagen and carbonate data in tandem. Stable isotope differences between the sexes indicate that men and women may have consumed different foods, although there is a possibility that women immigrated to Rogowo from an isotopically different region of Europe. No significant differences are noted in $\delta^{13}\text{C}$ or $\delta^{15}\text{N}$ of women with and without grave goods, suggesting little social differentiation within the Wielbark culture, at least in terms of daily food access. Reconstructing human diet in Europe through stable isotope analysis is problematic because of the relative isotopic homogeneity in this region of the world. This study further demonstrates the utility of using both carbonate and collagen stable isotope data in tandem to reconstruct past European diet.

KEY WORDS: paleodiet, Roman era, Wielbark culture, isotopes, Poland

Introduction

The archaeological culture known as the Wielbark occupied regions of North-Central Europe between the 1st and 4th centuries AD (Barford 2001). This time period is referred to as the pe-

riod of Roman influence or the Roman era by archaeologists, although the geographic regions of modern-day Poland were never incorporated into the Roman Empire. Initially settled in the areas surrounding the Vistula River in Pomera-

nia (Wołgiewicz 1981, Godłowski and Kozłowski 1985), the Wielbark culture expanded during the first half of the 2nd c. AD to Southeast Poland and Wielkopolska (Kozak-Zychman 1996). Origins of the Wielbark culture are uncertain. It may have developed indigenously from the Oksywie culture in and around the Vistula River basin (e.g., Godłowski and Kozłowski 1985; Dąbrowski 2006), but some believe it may represent immigrant populations of Germanic Goths and Gepids from Scandinavia (Czekanowski 1955; Godłowski and Kozłowski 1985; Heather 1996; Kozak-Zychman 1996; Wołgiewicz 1981). The issue of Wielbark origins and relationships with other Roman era European populations remains unresolved. After their appearance in North-Central Poland, Wielbark settlements eventually shift further south, replacing the Przeworsk culture in Southern Poland, and apparently developing into the Černjachov culture in modern-day Ukraine and surrounding areas. The relationship between the Wielbark culture and later, medieval Slavic populations from the Oder and the Vistula rivers basins is also incompletely defined (c.f., Kozak-Zychman 1996; Dąbrowski 2006). Anthropological examinations of skull and tooth morphology suggest biological continuity between Antiquity and the early medieval period (Piontek et al. 2008). Recent preliminary aDNA analyses of a small number of Iron Age and medieval skeletons from Poland suggest genetic discontinuity between these times (Juras 2012). Although inconclusive thus far, contributions from biological anthropology, such as these recent examples, are desirable to clarify the Wielbark culture's relationship to other European populations.

Two archaeological trademarks of the Wielbark culture are bi-ritual cemeteries that include both inhumation and cremation burials, and a characteristic lack of weapons and tools as grave goods (Godłowski and Kozłowski 1985). Wielbark settlements are generally open and unfortified. A degree of social differentiation is manifest in the facts that some graves are cremations whereas some are inhumations, and that ornaments and jewelry grave goods are present in burials. However, in general, Wielbark populations appear to have been relatively egalitarian (Gieysztor et al. 1979). Although linked to the Roman world by trade, Slavic populations in Antiquity are scarcely described in written records; thus, it falls to archaeology to illuminate the daily lives of modern-day Poland's populations in the early centuries AD.

In terms of the subsistence economy, wheat, millet, rye and barley were the most commonly grown crops by the Wielbark culture (Pyrgała 1975). Cattle were the most common domesticated animal in Roman era Poland, comprising approximately 50 to 80% of the total archaeozoological assemblages (Gładkowska-Rzeczycka et al. 1997; Makowiecki 2006; Reitsema et al. 2013). Land was tilled on a household level but was probably collectively owned during the tribal period (Gieysztor et al. 1979). For this reason, little within-group dietary differentiation based on status may be expected at this time.

Because most Wielbark cemeteries comprise cremains and fragmented skeletal remains, only a limited number of bioarchaeological investigations contribute to our understanding of these peoples (e.g., Dąbrowski 2006; Kozak-Zychman 1996, Krenz-Niedbala and Kozłowski 2013; Piontek et al. 2006; Segeda et al.

2007; Smrčka et al. 2000). Here we present the first stable isotope evidence of Wielbark diet from Rogowo, a cemetery with unusually complete skeletal materials, in Kujavian-Pomeranian Voivodeship of North-Central Poland. In addition to reconstructing diet of this Wielbark population, we consider relationships between diet and sex, age, and presence/absence of grave goods to better understand the dual influences of cultural and biological variables in influencing diet of this tribal population.

Stable Isotope Background

Analysis of stable carbon and nitrogen isotopes from human bones is an effective tool in archaeology for reconstructing individual diets of past populations (c.f., Katzenberg 2008; Schoeninger 2011). Plants and animals exhibit systematic isotopic variation due to differences in their environments, physiologies and diets (Ambrose 2000; Park and Epstein 1961; Schoeninger and Moore 1992; van Klinken et al. 2000). Stable isotope signatures are incorporated into consumer tissues, including bones, which come to represent a composite of the stable isotope signatures of foods eaten in life. By measuring stable isotope ratios of ancient bones and comparing the signatures to known ratios of various food types, it is possible to estimate the types of foods a person typically consumed on a daily basis. Stable isotope values are expressed as a permil (‰) ratio of one of an element's isotopes to another in relation to a standard of known abundance: Vienna Pee Dee Belemnite (VPDB) for $\delta^{13}\text{C}$ and the Ambient Inhalable Reservoir (AIR) for $\delta^{15}\text{N}$. Both stable carbon isotope ratios ($\delta^{13}\text{C}$) and stable nitrogen isotope ra-

tios ($\delta^{15}\text{N}$) are reported according to the equation

$$[\delta = (R_{\text{sample}} - R_{\text{standard}}) / R_{\text{standard}} \times 1000].$$

Stable carbon and nitrogen isotope ratios provide differing information about human diet. $\delta^{13}\text{C}$ variation in the plant kingdom exists due to differences in photosynthetic pathways used to metabolize atmospheric carbon (Park and Epstein 1960; Smith and Epstein 1971). $\delta^{13}\text{C}$ ratios in human tissues therefore reflect the local ecosystem, identifying which types of plants were consumed and the influence of environmental parameters on plant $\delta^{13}\text{C}$ values (DeNiro and Epstein 1978; Heaton 1999). The $\delta^{13}\text{C}$ values of fish often (though not always) fall outside the typical ranges of terrestrial foods, and can in many cases be identified isotopically in diet as a result (Chisholm et al. 1982; Dufour et al. 1999; Grupe et al. 1999; Schoeninger and DeNiro 1984).

Stable carbon isotope ratios can be measured from either bone collagen or apatite (referred to henceforth as $\delta^{13}\text{C}_{\text{coll}}$ and $\delta^{13}\text{C}_{\text{ap}}$, respectively). Because collagen is formed from amino acids, it primarily reflects protein in the diet (Ambrose and Norr 1993; Tieszen and Fagre 1993). Apatite is formed from dissolved bicarbonate in the bloodstream which contains carbon from all macronutrients; thus, carbonate from apatite better reflects energy sources in diet (i.e., carbohydrates). Collagen and carbonate provide different and complementary information about foods consumed and when used together, have been shown to be highly effective for reconstructing diet (e.g., Kellner and Schoeninger 2007).

The $\delta^{13}\text{C}$ values of consumers are not identical to the values of foods. Rather, there are systematic diet-tissue spacing relationships that can be considered in

order to backtrack from the stable isotope ratios of a consumer to those of its foods. In general, collagen $\delta^{13}\text{C}_{\text{coll}}$ is approximately 5‰ higher in consumers than in the bulk protein diet (van der Merwe and Vogel 1978). The relationship between $\delta^{13}\text{C}_{\text{ap}}$ and diet is less well-established. Controlled laboratory experiments reveal the diet-to-apatite space for $\delta^{13}\text{C}$ to be approximately 9.5‰ among small mammals (Ambrose and Norr 1993; Tieszen and Fagre 1993), but a review by Garvie-Lok (2001) of published studies suggests a larger value of approximately 12.0‰ may be more appropriate for humans.

Stable nitrogen isotopes reflect the trophic level of a consumer, with carnivores systematically exhibiting higher $\delta^{15}\text{N}$ signatures than herbivores due to physiological and chemical processes during metabolism (DeNiro and Epstein 1981). The diet-tissue space for $\delta^{15}\text{N}$ is generally on the order of 3–5‰ (Drucker and Bocherens 2004). $\delta^{15}\text{N}$ values in collagen can thus be used to estimate the amounts and types of animal products consumed, with higher values in consumers suggesting greater animal protein intake. However, $\delta^{15}\text{N}$ values also vary with respect to local climate (Ambrose 1991; Drucker et al. 2003), soil nitrogen composition (Britton et al. 2008; Grogan et al. 2000), production systems (Bogaard et al. 2007; Commisso and Nelson 2008) and consumer physiology (Ambrose 1991; Fuller et al. 2005; Hobson et al. 1993), complicating their interpretation. Isotopic evidence from animal bones in this region of Poland dating to the medieval period shows a 3.3‰ difference in $\delta^{15}\text{N}$ values and a 1.4‰ difference in $\delta^{13}\text{C}$ values of wild and domestic animals (Reitsema et al. 2013). Higher $\delta^{15}\text{N}$ values among domestic animals likely reflects

the use of manure or other methods used to improve soils (ploughing; burning) on which domestic animals were grazed. For $\delta^{13}\text{C}$, the wild/domestic animal difference likely represents variations in canopy cover on forage lands, with forest plants and animals exhibiting lower values due to the “canopy effect” (for more information on the canopy effect in Europe, see Bocherens and Drucker (2003)).

The value of stable isotope analysis in historic archaeology is that, unlike written records, stable isotope signatures are unaffected by record biases in the prevailing sociopolitical milieu, making them more direct indicators of an individual’s diet. Historical documentation of the Roman era in Northern Europe is limited by the fact that most inhabitants and travelers were illiterate, leaving many populations fragmentarily or subjectively represented in records. Interpretations of archaeozoological and paeobotanical data are limited in that they represent a bulk average of *overall* diet among the entire population, rather than differential food access among sub-populations. Stable isotope analysis has proven invaluable in anthropology not just for understanding subsistence behaviors, but also for recognizing sex-, age- and status-based differences in food access (Katzenberg 1993; Larsen 1997; Polet and Katzenberg 2003; Privat et al. 2002; Reitsema et al. 2010; Reitsema and Vercellotti 2012).

Materials and Methods

Rogowo is a Roman era cemetery discovered in 1984 that dates to the 2nd c. AD (Fig. 1). It was excavated in 1999 and 2000, and is associated with a nearby settlement that covers approximately 6 ha (Krenz-Niedbala and Kozłowski 2013).

The cemetery includes 137 inhumation and 151 cremation burials (Chudziak 2000). Skeletons were interred in a flexed position, many with copper-alloy jewelry that has left green stains on skeletal elements (Fig. 2). One of Eastern Europe's most important trade routes, the Amber Road, connected Rogowo with the Baltic Sea to the North, and the Roman Empire to the South (Buko 2008). Interregional trade and iron smelting, in addition to animal husbandry and agriculture, structured the economy of this Wielbark population (Piontek et al. 2006).

From the cemetery, small pieces of rib approximately 1–2 cm in length from 15 adult males and 15 adult females were

sampled. No animal bones were found at the site, and so an interpretive faunal baseline was established using animals from Denmark which were contemporaneous with Rogowo, previously reported by Jørkov et al. (2010), and animals from medieval Poland, reported here and in more detail by Reitsema et al. (2013).

Collagen was purified from bone using a modified Longin method (Ambrose 1990; Ambrose et al. 1997). Briefly, approximately 0.25–0.50 g of bone was crushed to a coarse powder, demineralized for 3 to 7 days in 0.2 M HCl, soaked in 0.125 M NaOH for 20 hours to remove other contaminants, solubilized at 90°C in HCl of pH=3, filtered and freeze dried. Three human samples were analyzed in duplicate, and one sample was both prepared and analyzed in duplicate. These repeat analyses show replicability to be within 0.1‰ for $\delta^{15}\text{N}$ and 0.2‰ for $\delta^{13}\text{C}$.

Of the 30 human samples analyzed for collagen isotope data, 29 were also analyzed for carbonate data. Carbonate was prepared according to protocol detailed in Garvie-Lok et al. (2004). Bone was powdered in a steel mortar and pestle, deproteinized in bleach for 48 hours, soaked in 0.1 M acetic acid for 4 hours to remove more soluble adsorbed carbonates, dried, and homogenized in an agate mortar and pestle. Two samples were run in duplicate. The mineral composition of all 29 apatite samples was examined using Fourier transform infrared spectroscopy (FTIR) to check for diagenesis, a technique described in greater detail by Wright and Schwarcz (1996). The two FTIR measurements used to evaluate preservation of carbonate are crystallinity index (CI), and carbonate content as estimated by a carbonate-phosphate ratio (C/P). We also consider peaks or shoulders at wavelength 1096 cm^{-1} , in-



Fig. 1. Map of Poland showing the location of Rogowo (geographic coordinates: $53^{\circ} 4' 41''$ N, $18^{\circ} 44' 18''$ E)



Fig. 2. Burial 59 from Rogowo, referred to as a "princess" on account of her rich jewelry. Photographed by Adam Szwarc

dicative of recrystallization to francolite, as a window into post-mortem alteration of bone (Wright and Schwarcz 1996). CI and C/P values far outside the range of modern bone suggest either that contaminating substances are present in the sample, or that the sample has recrystallized during deposition or sample preparation, both of which may shift the isotope signatures in carbonate away from biogenic values (Berna et al. 2004; Nagy et al. 2008; Szostek 2009; Szostek et al. 2011; Yoder and Bartelink 2010). We also examine the stable oxygen isotope ratios ($\delta^{18}\text{O}$) of all apatite samples as a complementary proxy indicator of diagenetic alteration, after Wright and Schwarcz (1996) and Garvie-Lok (2001). The rationale behind using $\delta^{18}\text{O}$ values as indicators of diagenesis rather than as biogenic paleodiet indicators is that $\delta^{18}\text{O}$ values in bone apatite are more affected than $\delta^{13}\text{C}$ values by fractionation that occurs during changes between different species of carbonate in bone during sample treatment or diagenesis (Wright and Schwarcz 1996). Whereas the ranges of FTIR values alone do not necessarily indicate diagenesis *per se* (considerable scatter has been documented in both modern and “well-preserved” archaeological bone; see for example Wright and Schwarcz [1996] and Garvie-Lok et al. [2004]), correlations between $\delta^{18}\text{O}$ and FTIR values cannot parsimoniously be explained otherwise (Wright and Schwarcz 1996; Garvie-Lok 2001). Animal bones from medieval Poland were prepared in the same manner as human bones (for more details on the animal bones used in this study, see Reitsema et al. 2013).

All stable isotope analyses were conducted in the Stable Isotope Biogeochemistry Laboratory at the Ohio State Uni-

versity. Collagen samples were 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. Stable carbon and nitrogen measurements were made where the average standard deviation of repeated measurements of the USGS24 and IAEA-N1 standards were between 0.04‰ and 0.07‰ for $\delta^{13}\text{C}_{\text{coll}}$ and between 0.07‰ and 0.18‰ for $\delta^{15}\text{N}$. We report $\delta^{13}\text{C}_{\text{coll}}$ values to the nearest 0.1‰.

For carbonate, a 1.0–1.2 mg subsample was analyzed for $\delta^{13}\text{C}_{\text{ap}}$ relative to the Vienna Pee Dee Belemnite Limestone standard using an automated Carbonate Kiel device coupled to the mass spectrometer. Samples were acidified under vacuum with 100% ortho-phosphoric acid, the resulting CO_2 cryogenically purified, and delivered to the mass spectrometer. Three samples were run in duplicate and replicability was within 0.20‰ for $\delta^{13}\text{C}$. The standard deviation of repeated measurements of limestone internal standard (NBS-19) for $\delta^{13}\text{C}_{\text{ap}}$ was ± 0.03 ‰. Because of high precision for carbonate measurements, we report $\delta^{13}\text{C}_{\text{ap}}$ values to the nearest 0.01‰.

Results

The preservation quality of collagen samples was assessed using C:N ratios, %C and %N following criteria outlined in DeNiro (1985) (Table 1). All collagen samples, including humans and animals, exhibit C:N ratios of between 3.2 and 3.4, %C values of between 19.2% and 43.6%, and %N values of between 6.9% and 15.7%. Some of these carbon and nitrogen concentrations are lower than the ranges for modern collagen, but these samples nevertheless exhibit acceptable

C:N ratios, and their stable isotope signatures are not anomalous.

The use of FTIR to detect diagenesis is currently limited because there is no consensus as to acceptable cutoff points. We report FTIR results to contribute to a growing body of literature in this area and compare them to previous studies, while recognizing that FTIR does not provide the same kind of assurance of sample “quality” as do collagen quality indicators. FTIR results of the present study (Table 1) suggest that carbonate from Rogowo is reasonably well-preserved and likely retains biogenic $\delta^{13}\text{C}_{\text{ap}}$ signatures. CI values range from 2.7 to 4.2 (mean = 3.6 ± 0.4) and C/P ratios range from 0.10 to 0.41 (mean 0.18 ± 0.07). These values resemble ranges of acetic-treated archaeological carbonate estimated to be well-preserved elsewhere (e.g., Katzenberg et al. 2009). For comparison, modern bones treated with acetic acid to mimic archaeological sample preparation exhibit CI values of between 2.7 and 3.6 (Nielsen-Marsh and Hedges 2000b; Wright and Schwarcz 1996). Shemesh (1990) advocates considering 3.8 a maximum value for archaeological, acid-treated samples, above which samples should no longer be considered well-preserved. This is relatively conservative, as de la Cruz Baltazar (2001) reports a CI range of 2.8–4.0 in a well-preserved archaeological sample, Katzenberg et al. (2009) consider a cut-off of 4.0, and Wright and Schwarcz (1996) report well-preserved values above 4.0. In terms of C/P, modern bones treated with acetic acid exhibit values of 0.10–0.24 (Wright and Schwarcz 1996). Acetic-treated archaeological C/P values tend to be slightly lower (c.f., Katzenberg et al. 2009). Although several samples from 2nd c. Rogowo exhibit higher CI and

lower C/P than modern bones, there is no relationship between either FTIR CI or C/P and either $\delta^{18}\text{O}$ or $\delta^{13}\text{C}$, which has been used elsewhere as a guideline for identifying diagenetically altered samples (c.f., Garvie-Lok 2001) (Fig. 3). Ten of the apatite samples exhibit distinct peaks at wavenumber 1096 cm^{-1} indicating francolite in the apatite matrix, meaning they are more likely than other samples to have been diagenetically altered (c.f., Katzenberg et al. 2009; Wright and Schwarcz 1996). Nevertheless, throughout the sample, peaks are not consistently associated with anomalous CI, C/P or stable isotope ratios (Fig. 3). In keeping with the recommendations of previous researchers (Garvie-Lok 2001; Nielsen-Marsh and Hedges 2003a; Wright and Schwarcz 1996), rather than considering FTIR indices as isolated and finite exclusion criteria, we consider them alongside other indicators of diagenetic alteration, including correlations between the the FTIR data and stable isotope values. In the following discussion we report statistical results of the overall apatite sample ($n=29$) as well as a more conservative restricted sample ($n=13$; values italicized in Table 1) comprising only those individuals with CI values of 3.6 or lower, and CI values between 0.15 and 0.70 (Berna et al. 2004; Szostek et al. 2011).

In addition to medieval Polish fauna, Roman era faunal data from Denmark are included for comparison to the human values from Rogowo in the absence of directly associated animal bones (Table 2). Jørkov et al. (2010) report that 3 cows exhibit a mean $\delta^{13}\text{C}$ of $-21.6 \pm 0.7\text{‰}$ and a mean $\delta^{15}\text{N}$ of $5.7 \pm 0.5\text{‰}$, and 4 pigs exhibit a mean $\delta^{13}\text{C}$ of $-22.1 \pm 0.8\text{‰}$ and a mean $\delta^{15}\text{N}$ of $8.6 \pm 0.9\text{‰}$.

Stable isotope data for humans are presented in Table 1. Rogowo $\delta^{13}\text{C}_{\text{coll}}$

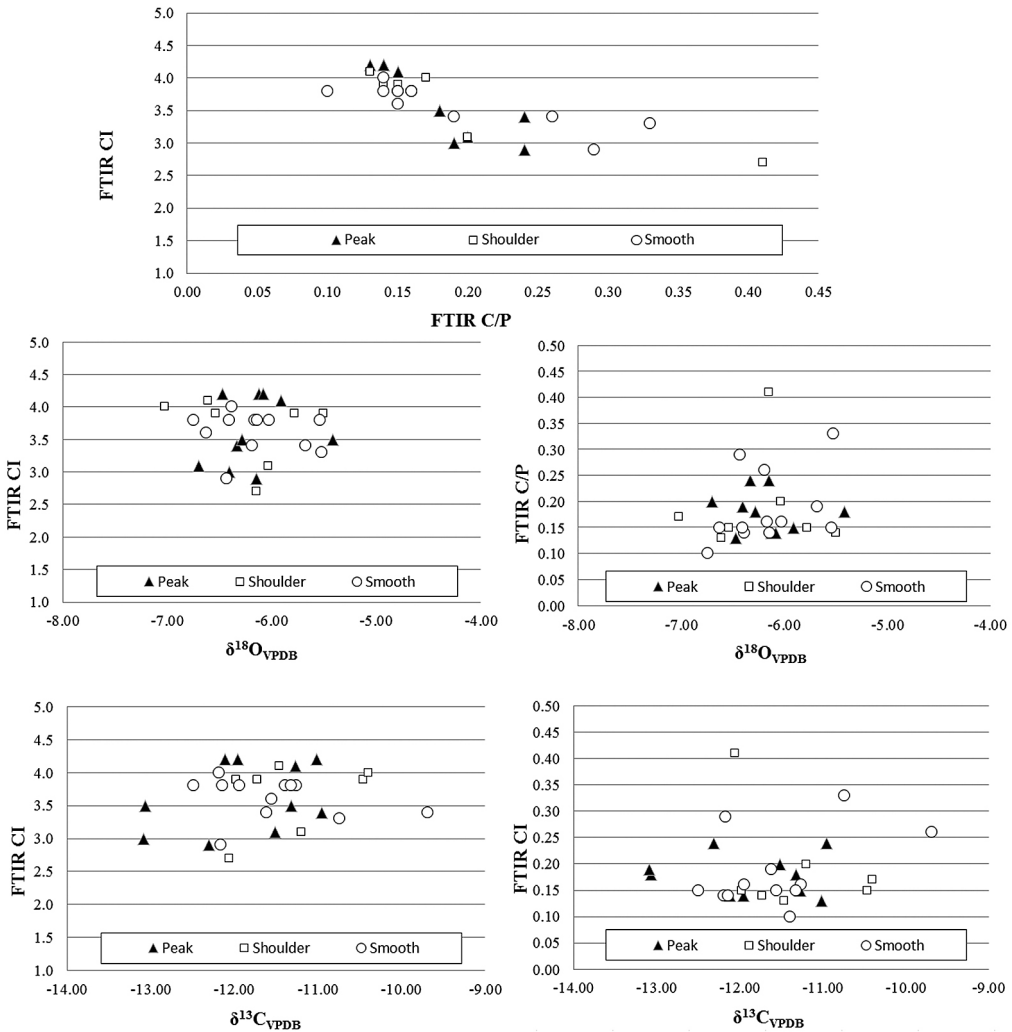


Fig. 3. Indicators of bone mineral diagenesis considered in the present study include (1) the crystallinity index (FTIR CI), (2) carbonate content in bone, estimated through Fourier transform infrared spectroscopy (FTIR C/P), (3) the presence of a peak at FTIR wavelength 1096 cm^{-1} , and (4) any relationship between FTIR indices and stable carbon ($\delta^{13}\text{C}$) or oxygen isotope ($\delta^{18}\text{O}$) values from apatite. FTIR CI and C/P are correlated, as expected for bone apatite. Although some absolute FTIR indices are questionable, the fact that no correlations exist among FTIR and stable isotope values suggests the samples may be reasonably well-preserved

values range widely from -19.5‰ to -16.4‰ (mean $= -17.9 \pm 0.7\text{‰}$) and $\delta^{15}\text{N}$ values range from 8.6‰ to 10.9‰ (mean $= 9.7 \pm 0.5\text{‰}$) (Fig. 4). There is no correlation between $\delta^{13}\text{C}_{\text{coll}}$ and $\delta^{15}\text{N}$

values ($R^2 = 0.1463$), which could occur when ^{13}C -enriched fish (marine or anadromous) are a major source of protein in the diet (e.g., Ambrose et al. 1997). $\delta^{13}\text{C}_{\text{ap}}$ values range from -13.09‰ to -9.69‰

Table 2. Comparative faunal baseline

ID	Species	%N	%C	C:N	$\delta^{15}\text{N}_{\text{Air}}$ (‰)	$\delta^{13}\text{C}_{\text{coll}}$ (‰)	$\delta^{13}\text{C}_{\text{ap}}$ (‰)	Reference
816-02	Cow <i>Bos primigenius taurus</i>	14.6	40.4	3.2	7.8	-20.7	-11.41	Present study
834-02	Cow <i>Bos primigenius taurus</i>	13.4	38.0	3.3	7.9	-21.0	–	Present study
839-02	Cow <i>Bos primigenius taurus</i>	13.1	36.7	3.3	7.6	-21.5	–	Present study
200	Cow <i>Bos primigenius taurus</i>	15.7	43.6	3.2	6.4	-21.0	–	Present study
810-02	Cow <i>Bos primigenius taurus</i>	14.4	40.2	3.2	6.4	-21.3	-13.80	Present study
100	Pig <i>Sus scrofa domesticus</i>	16.1	44.5	3.2	7.9	-21.6	-14.89	Present study
119-05	Pig <i>Sus scrofa domesticus</i>	12.9	35.6	3.2	5.9	-21.6	-14.71	Present study
816-02	Pig <i>Sus scrofa domesticus</i>	13.2	37.6	3.3	6.8	-19.8	-12.66	Present study
	Pig <i>Sus scrofa domesticus</i> (n=4)				8.6±0.9	-22.1±0.8		Jørkov et al. (2010)
	Cow <i>Bos primigenius taurus</i> (n=7)				5.7±0.5	-21.6±0.7		Jørkov et al. (2010)

(mean=-11.60±0.76‰). When only of 3.6 or lower and C/P values of be-
apatite samples with FTIR CI values between 0.15 and 0.70 are considered

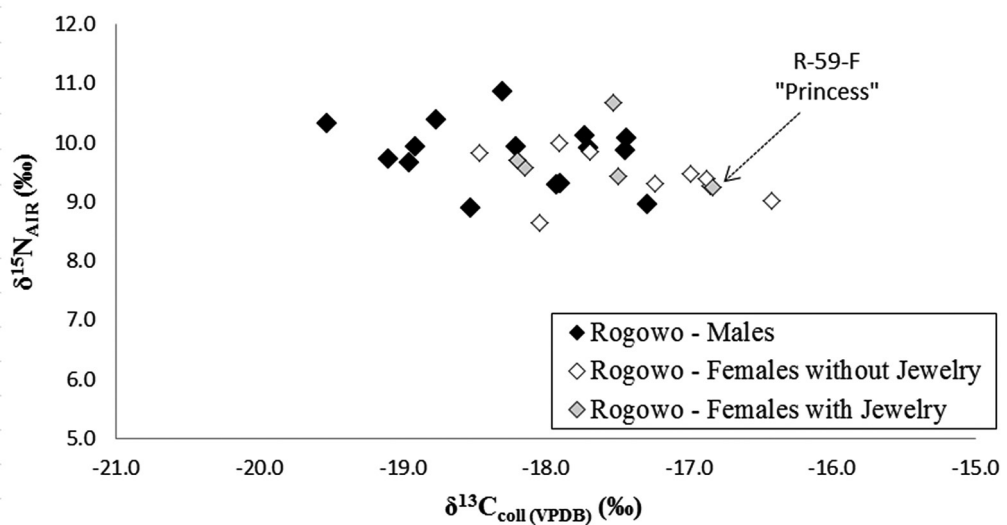


Fig. 4. Stable carbon ($\delta^{13}\text{C}_{\text{coll}}$) and nitrogen ($\delta^{15}\text{N}$) isotope data from collagen from Rogowo, including 15 males, 5 females buried with jewelry, and 10 females buried without jewelry

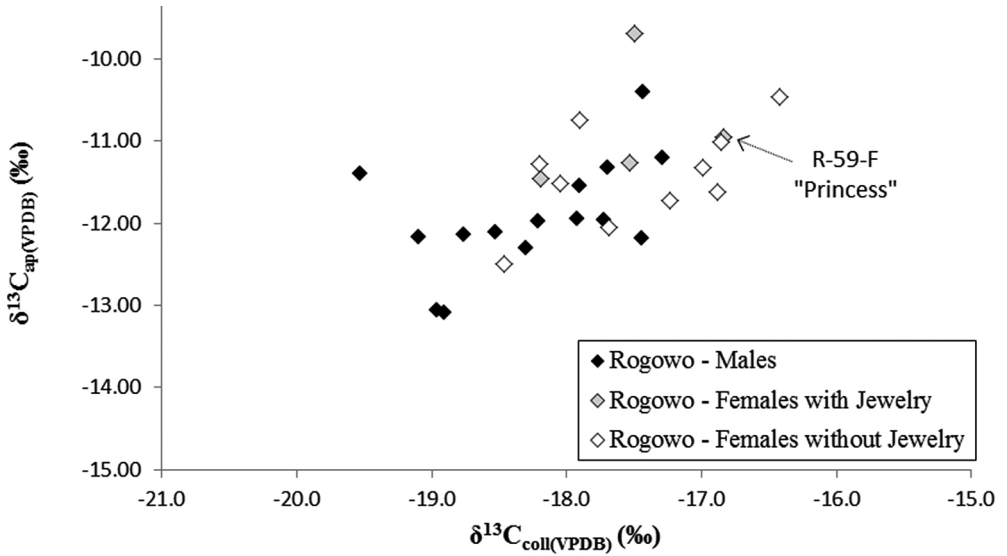


Fig. 5. Stable carbon isotope data from carbonate ($\delta^{13}\text{C}_{\text{ap}}$) and collagen ($\delta^{13}\text{C}_{\text{coll}}$) from Rogowo ($n=29$)

($n=13$), the mean $\delta^{13}\text{C}_{\text{ap}}$ value is similar (-11.64 ± 0.93). $\delta^{13}\text{C}_{\text{coll}}$ and $\delta^{13}\text{C}_{\text{ap}}$ values are modestly positively correlated at Rogowo ($R^2=0.3439$) (Fig. 5). When the restricted $\delta^{13}\text{C}_{\text{ap}}$ sample of just 13 individuals is used, $\delta^{13}\text{C}_{\text{coll}}$ and $\delta^{13}\text{C}_{\text{ap}}$ values remain modestly positively correlated ($R^2=0.4482$). $\Delta^{13}\text{C}_{(\text{ap-coll})}$ values range from 5.3‰ to 8.1‰ (mean $=6.3 \pm 0.7\text{‰}$).

The $\delta^{13}\text{C}$ values of men and women are significantly different: both the $\delta^{13}\text{C}_{\text{coll}}$ and $\delta^{13}\text{C}_{\text{ap}}$ values of females are higher (Kruskal-Wallis Test, $p=0.014$ and $p=0.015$, respectively). When only apatite samples with FTIR CI values of 3.6 and are considered ($n=13$, 7 females and 6 males) this $\delta^{13}\text{C}_{\text{ap}}$ difference remains (Kruskal-Wallis Test, $p=0.032$). Women exhibit lower mean $\delta^{15}\text{N}$ than men (Kruskal-Wallis Test, $p=0.078$).

Five female skeletons buried with jewelry were analyzed. The $\delta^{13}\text{C}_{\text{coll}}$, $\delta^{13}\text{C}_{\text{ap}}$ and $\delta^{15}\text{N}$ values of women with and without jewelry are similar, although $\delta^{13}\text{C}_{\text{ap}}$ of women without jewelry is generally low-

er, albeit not significantly so (all 15 females, $p=0.157$; 7 females with CI ≤ 3.6 , $p=0.121$). The richest grave at Rogowo is skeleton R-59-F, a woman buried with substantial quantities of jewelry (Fig. 2), which we consider in more detail on account of her unusual mortuary context. This individual exhibits relatively high $\delta^{13}\text{C}_{\text{coll}}$ value (-16.8‰) compared to mean values, but the value is similar to several other females (R-705-F, R-56-F, R-688N-F, R-104-F). Furthermore, her $\delta^{13}\text{C}_{\text{ap}}$ (-10.95‰), $\Delta^{13}\text{C}_{(\text{ap-coll})}$ (5.9‰), and $\delta^{15}\text{N}$ values (9.3‰) are unremarkable.

Discussion

Diet Reconstruction

$\delta^{15}\text{N}$ values suggest a predominantly terrestrial diet at Rogowo. $\delta^{13}\text{C}$ values indicate a mixed diet of C_3 plants, C_4 plants, and fish. If a diet-collagen spacing relationship of $+5\text{‰}$ is assumed, the pro-

tein diet of individuals at Rogowo can be inferred to have a $\delta^{13}\text{C}$ value of -21.4‰ to -24.5‰ . In agreement with this, if a $+12\text{‰}$ diet-carbonate fractionation factor is applied (c.f., Garvie-Lok 2001: 125–128; Prowse et al. 2005), the $\delta^{13}\text{C}$ values of bulk diets at Rogowo ranged between -21.7‰ and -25.0‰ . The expected isotopic “space” of a C_3 diet is at the lower end of this range, -23.0‰ to -25.0‰ (Garvie-Lok 2001). Thus, C_3 foods appear to have dominated diet at Rogowo, but foods with a higher $\delta^{13}\text{C}$ signature also contributed to both the energy and protein sources of the diet (namely, millet and marine and/or anadromous fish).

A C_4 signal could have contributed to diet in two ways: through direct consumption of millet by humans, or indirectly through consumption of animals foddered on millet. Sampling local animals is the most straightforward way to resolve this, but it is also possible to explore whether C_4 -foddered animals contributed to human diet by checking for a correlation between $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values. A closer look at Figure 4 shows that individuals with $\delta^{13}\text{C}$ values of greater than -18.0‰ exhibited the entire range of $\delta^{15}\text{N}$ values. The fact that $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values are not positively correlated at Rogowo ($R^2 = 0.1463$) supports an interpretation of direct millet consumption, rather than C_4 -foddered animal consumption. The $\delta^{13}\text{C}_{\text{ca}}$ values from Rogowo suggest millet contributed between 0% and 35% to overall diet, depending on the individual. This corroborates archaeobotanical evidence for a broad-spectrum agricultural strategy including millet, barley, rye, oats and wheat (Wasylikowa et al. 1991).

The lack of a correlation between $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values would seem to caution against an interpretation of marine or

anadromous fish consumption. $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values from both marine and anadromous fish bones tend to be higher than those of terrestrial animals, and humans eating such fish exhibit a correlation between the two isotopes (e.g., Ambrose et al. 1997). However, a growing number of studies reveal that stable isotope ratios of fish bones are highly variable (c.f., Dürrewächter et al. 2006; Fuller et al. 2012; Katzenberg et al. 2009; Müldner and Richards 2005; Redfern et al. 2010; Reitsema et al. 2013). Consequently, a straightforward correlation between $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ among fish-eating humans may not always exist.

To further explore the issue of fish in diet, we consider Rogowo in relation to other European samples. In Figure 6, collagen data from Rogowo ($\text{mean} \pm 1\sigma$) are shown alongside 9 previously reported European historical populations. Four of these are reported to have consumed a predominantly or exclusively terrestrial diet with only C_3 foods: a 4th c. AD Late Roman sample from England (Richards et al. 1998), a 5th–2nd c. BC Greek colonial sample from Bulgaria (Keenleyside et al. 2006), a 2nd c. sample from England (Chenery et al. 2010), and a 1st–4th c. AD Roman Iron Age sample from Denmark (Jørkov et al. 2010). Three comparative samples consumed predominantly or exclusively terrestrial diets that also included C_4 foods: several Hallstatt groups from Austria (Le Huray and Schutkowski 2005), a 9th–5th c. Iron Age sample from Slovenia (Murray and Schoeninger 1988) and an 11th–12th c. AD early medieval population from Poland (Reitsema et al. 2010). Finally, two comparative samples reportedly consumed marine foods in addition to C_3 terrestrial foods: 2nd–5th c. skeletons from Roman Tunisia (Keenleyside et al. 2009) and a Roman

era sample from Sweden (Eriksson et al. 2008).

$\delta^{15}\text{N}$ values place Rogowo near other populations with terrestrial diets. Although the $\delta^{15}\text{N}$ values at Rogowo are not the highest among the terrestrial diets displayed in Figure 6, cautioning against an interpretation of a high-fish diet, they are high in comparison to the lower cluster of populations. For example, the mean $\delta^{15}\text{N}$ value from another Polish sample dating to the 11th–12th c. is $9.2 \pm 0.6\text{‰}$ (approximately 3‰ higher than its faunal baseline) (Reitsema et al. 2010). $\delta^{15}\text{N}$ values at Rogowo ($9.7 \pm 0.5\text{‰}$) are higher than the Giecz sample. Interestingly, humans' $\delta^{15}\text{N}$ values at Rogowo are still just 2.5‰ higher than domestic animal values reported by Reitsema et al. (2013) from nearby Kałdus, a medieval settlement approximately 1000 years younger than Rogowo. A diet-tissue difference of 2.5‰ is a reasonable expectation for consumers of terrestrial animal protein. As previously discussed, the medieval animals from Kałdus exhibit unusually high $\delta^{15}\text{N}$ values likely due to land management practices (e.g., manuring, ploughing, fire-clearing, etc.). At some point in antiquity, the local baseline $\delta^{15}\text{N}$ in this region of Poland may have been raised by human land management strategies such as burning or fertilizing fields (Bogaard et al. 2007; Commisso and Nelson 2008; Grogan et al. 2000), and it is possible this occurred as early as the Roman era. A grain of wheat sampled from a nearby modern field yielded a high $\delta^{15}\text{N}$ value of 7.2‰, which could be due to the influence of either modern or past land management strategies on soil nitrogen (c.f., Commisso and Nelson 2008). Compared to the Roman era animals from Denmark reported by Jørkov et al. (2010) which in

general exhibit lower stable isotope values, humans' $\delta^{15}\text{N}$ values at Rogowo are 4‰ higher than cows and 2‰ higher than pigs. Accepting either the Polish or the Danish faunal baseline would still indicate a predominantly terrestrial diet, if a diet-tissue spacing of 3–5‰ is accepted for $\delta^{15}\text{N}$ (Drucker and Bocherens 2004).

In terms of $\delta^{13}\text{C}$ values in Figure 6, Rogowo overlaps with Hallstatt populations in Austria that consumed a C_4 plant, millet. However, C_3 plants still predominated in the diet: Rogowo $\delta^{13}\text{C}_{\text{coll}}$ values are considerably lower than those of a Slovenian population that consumed large amounts of millet (or millet-foddered animals). Millet has also been detected isotopically in human remains in early medieval Poland (Reitsema 2012; Reitsema et al. 2010), Bronze Age Italy (Tafuri et al. 2009), Iron Age Austria and Slovenia (Le Huray and Schutkowski 2005; Murray and Schoeninger 1988), and possibly as early as the Neolithic in Poland (Kozłowski et al. 2013). Unlike in Eastern and Southern Europe, millet is not widespread in Western Europe. With its occurrence following cultural distribution patterns rather than geography or climate, millet appears to characterize diets of Slavic populations. In her book documenting the history of Polish cuisine, Maria Dembińska posits that "... the Polish preference for millet was cultural and that millet must have arrived with the earliest Slavic migrants" (104). That millet might be used as a proxy for Slavic migrations is an interesting possibility, given the controversy surrounding the relationship between the Wielbark culture and the issue of Slavic ethnogenesis (c.f., Dąbrowski 2006). Millet consumption among Wielbark and early medieval Polish populations represents a potentially significant continuity be-

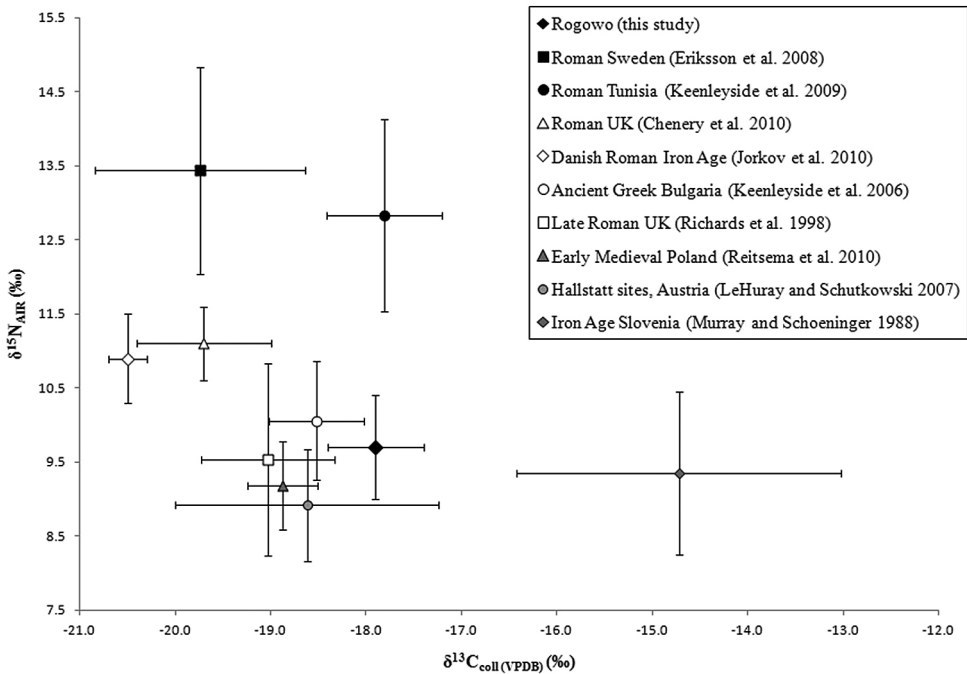


Fig. 6. Collagen stable isotope data (carbon: $\delta^{13}\text{C}_{\text{coll}}$; nitrogen: $\delta^{15}\text{N}$) from Rogowo ($n=30$) compared to other European populations

tween the Roman era and the medieval period in Poland.

A model for using both $\delta^{13}\text{C}$ from carbonate and collagen was developed by Kellner and Schoeninger (2007) to provide a clearer idea of protein and energy in diet. The model consists of three regression lines that were derived from controlled feeding experiments with animals. Each line represents a particular diet: one based on C_3 protein, one based on marine protein, and one based on C_4 protein. The end points of each line represent either 100% C_3 energy (bottom) or 100% C_4 energy (top). Using this model, it is possible to tease apart sources of stable isotope variation from small amounts of fish or millet. In Figure 7, both types of $\delta^{13}\text{C}$ data from Rogowo are displayed in comparison to several other Europe-

an populations after shifting the regression lines by $+1.5\text{‰}$ for both $\delta^{13}\text{C}_{\text{coll}}$ and $\delta^{13}\text{C}_{\text{ap}}$ to account for the Suess effect, by which the modern-day atmospheric $\delta^{13}\text{C}$ value is lower than in the past due to recent fossil fuel emissions (Marino and McElroy 1991). All 29 apatite samples are included but the 16 samples whose FTIR CI values exceed 3.6 and C/P values are below 0.15 are demarcated with an "X". The importance of millet in diet is supported by Rogowo's location at the middle of the C_3 protein line, rather than towards the base where " C_3 -only" populations would plot. The fact that Rogowo plots to the right of the C_3 protein line indicates that dietary protein came from primarily C_3 terrestrial fauna, but with supplemental input from marine or anadromous fish.

Few comparative populations are available for use in Figure 7 because collagen and carbonate are not yet commonly analyzed together in stable isotope studies of Europe. Pictured are: six populations from Neolithic Greece including three from coastal areas and three from further inland (Papathanasiou 2003), a medieval Polish population (Reitsema et al. 2010), Roman populations from Tunisia (Keenleyside et al. 2009) and Italy (Prowse et al. 2005), and humans from Viking era and medieval Sweden (Kosiba et al. 2007). Populations consuming fish plot to the right of the C_3 protein line in this figure with one exception: the Roman Italian sample from Prowse et al. (2005) reportedly consumed some marine foods, but plots left of the C_3 pro-

tein line. Also to the left of the line are populations from inland Greece where marine foods were negligible. Rogowo appears very similar to Roman era Tunisia, where fish made significant contributions to diet (Keenleyside et al. 2009). Interestingly, the $\delta^{15}N$ values from Rogowo are considerably lower than those from the Tunisian sample ($9.7 \pm 0.5\text{‰}$ vs. $12.8 \pm 1.3\text{‰}$). We conclude that anadromous or marine fish were consumed in supplemental amounts at Rogowo, and that they probably had relatively low $\delta^{15}N$ values. A “fish signal” thus emerges only when using the model from Kellner and Schoeninger (2007), and is not apparent when examining collagen data alone. The nearby Vistula River, along with its tributaries and oxbow lakes, would have

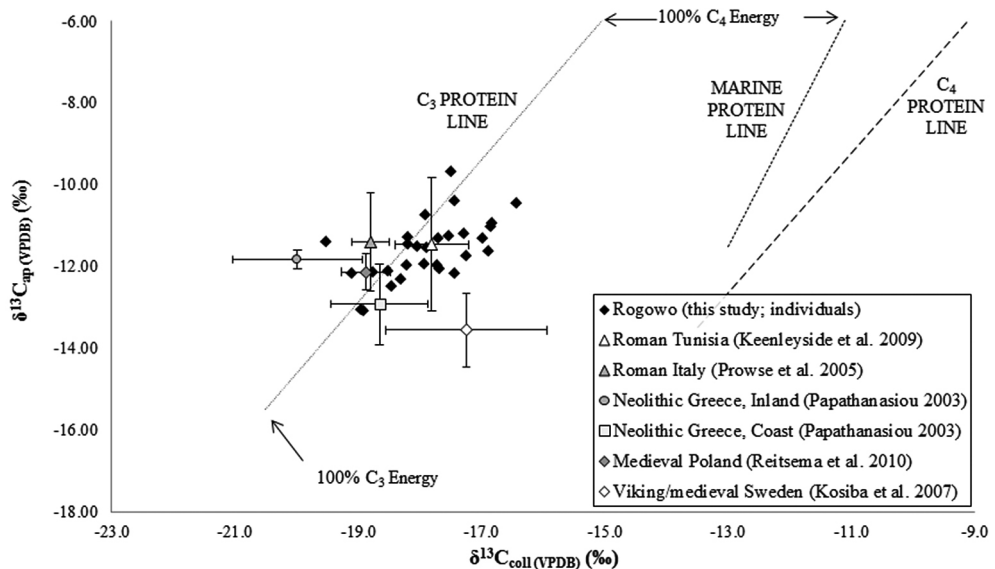


Fig. 7. Stable carbon isotope data from carbonate ($\delta^{13}C_{ap}$) and collagen ($\delta^{13}C_{coll}$) from Rogowo ($n=29$) compared to other European populations. Regression lines are from Kellner and Schoeninger (2007). Because the regression lines were developed using modern animal bones, which will exhibit systematically lower $\delta^{13}C$ values due to differences between modern and pre-industrial atmospheric CO_2 values stemming from fossil fuel emissions (Marino and McElroy 1991), regression lines are shifted to be 1.5‰ higher to make them comparable with the archaeological human samples. Sixteen samples exhibiting crystallinity indices (FTIR CI) in excess of 3.6, and carbonate content (FTIR C/P) below 0.15 are demarcated with a white “X” through the data symbol

provided the population at Rogowo with freshwater (carp, bream, roach) and anadromous (sturgeon) fish. Oxbow lakes composed of shallow, still water were also present in the region which may contain fish with very low $\delta^{15}\text{N}$ values and relatively high $\delta^{13}\text{C}$ values (Hecky and Hesslein 1995). Three anadromous fish (sturgeon) from another nearby medieval settlement, Kałdus, show $\delta^{13}\text{C}$ values of -15.6‰ to -17.1‰ and of 9.9‰ to 11.3‰ (Reitsema et al. 2013). Consumption of these fish would be fairly consistent with the human stable isotope data we have reported. However, their contribution to diet was probably supplemental. Other isotopic paleodietary research has demonstrated that European populations in the first centuries AD were not exploiting aquatic resources though they presumably had the means (e.g., Chenery et al. 2010; Jørkov et al. 2010; Richards et al. 1998). Like these other populations, the subsistence economy at Rogowo was based on animal husbandry and agriculture.

Intrapopulation Variation

Sex-based differences in stable isotope ratios at Rogowo suggest that diets of women included more millet, and possibly less animal protein (meat or dairy) than diets of men. Sex-based social differentiation is a characteristic of many tribal societies and at Rogowo, appears to have translated into differential food consumption. Sex-based differences in diet from this time period are reported by other stable isotope and trace element studies from this time period in Europe (e.g., Fuller et al. 2006; Redfern et al. 2010; Richards et al. 1998; Smrčka et al. 2000). However, such differences do not necessarily implicate sex-based inequali-

ties among the population. Women and men may have performed different subsistence tasks throughout the day, simply exposing women and men to different foods. Increased consumption of plants in general would augment a “millet signal” in bones of women at Rogowo, because it would no longer be so strongly masked the available C_3 protein from terrestrial animals.

It is also possible that the $\delta^{13}\text{C}$ differences between men and women are non-dietary. Plants from warm climates have been shown to exhibit higher $\delta^{13}\text{C}$ values than the same plants in colder climates due to temperature-dependent fractionation of CO_2 (van Klinken et al. 2000). Richards et al. (1998) identified possible immigrants at the Poundbury site in England based on the individuals’ elevated $\delta^{13}\text{C}$ values. Perhaps some women with higher $\delta^{13}\text{C}$ values migrated to Rogowo from a warmer climate. Using morphometrics, Gładkowska-Rzeczycka et al. (1997) report that females buried in another Wielbark cemetery in Pruszcz Gdański were an “autochthonic population of Balts” whereas males had “traces characteristic for Goths-German tribes that [moved into] the East Pomerania region” (Gładkowska-Rzeczycka et al. 1997:92), suggesting sex-biased residency patterns. However, contra the evidence from Pruszcz Gdański, if migration underlies the stable isotope differences in the present study it would suggest *women* were the immigrants at Rogowo. Analyses of strontium and oxygen isotope values of tooth enamel and bone from Rogowo are intended to further explore questions of mobility.

Stable isotope differences were not associated with differences in grave goods (jewelry) in women’s burials (Fig. 4). This accords with an interpretation of

Wielbark populations as relatively egalitarian, with biological variables (e.g., sex) playing a more influential role in structuring diet than cultural variables (e.g., status).

Conclusion

Diet at Rogowo was based on terrestrial foods (meat, milk, and plants), but with supplemental input from fish (likely low- $\delta^{15}\text{N}$ anadromous or littoral fish), indicating an overall broad-spectrum subsistence economy. Millet was consumed at Rogowo, and in greater amounts than during the medieval period to follow (c.f., Fig. 6; Reitsema et al. 2010; Reitsema 2012). Stable isotope differences between the sexes indicate that men and women may have consumed different foods, although there is a possibility that women migrated to Rogowo from an isotopically different region of Europe. No significant differences are noted in $\delta^{13}\text{C}$ or $\delta^{15}\text{N}$ of burials with and without jewelry, suggesting low status-based social differentiation among the Wielbark culture, at least in terms of daily food access.

A significant obstacle to paleodiet studies in Europe using stable isotope evidence is that most foods are isotopically indistinguishable. Consumption of the same foods is not necessarily implicated when individuals exhibit similar stable isotope signatures. In some Eastern and Southern European regions, millet creates isotopic heterogeneity that may highlight differential access within the population. This is the case at Rogowo, but not in Western Europe where agriculture was entirely based on isotopically homogeneous C_3 plants. A second problem with diet reconstruction in Europe is that stable isotope ratios of fish

and terrestrial animals are not always discrete. The stable isotope ratios of fish and terrestrial foods frequently overlap, rendering fish isotopically invisible in human diet. Even more complications arise when past land management strategies such as manuring, ploughing and burning fields raise $\delta^{15}\text{N}$ values at the base of the human food web, or when human consumption of legumes such as peas lowers $\delta^{15}\text{N}$ values. Because of these obstacles it is helpful to consider relationships between different stable isotope ratios ($\delta^{15}\text{N}$, and $\delta^{13}\text{C}$ from both collagen and apatite) and other patterns in the data, rather than simply comparing stable isotope ratios obtained from human bones to expected ranges. Considerations such as these have permitted the identification of millet and anadromous or marine fish consumption at Rogowo. Stable carbon and nitrogen isotope data accord with paleobotanical and archaeozoological evidence for a mixed subsistence economy of agriculture and animal husbandry, and contribute new information regarding the roles of biology and culture in structuring diet and possibly social structure of the relatively unknown Wielbark culture.

Author contribution

LJR prepared and analysed bone samples isotopically, obtained grant sponsorship, and wrote the manuscript; TK contributed bone material for the study, provided archaeological and contextual information about the site, and edited drafts of the manuscript.

Conflict of interests

The authors declare that there is no conflict of interests.

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