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Human–environment interactions in medieval Poland: a perspective from the analysis of faunal stable isotope ratios

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ABSTRACT

Stable isotope analyses of faunal remains provide valuable information about human–environment interactions in the past, including insights into past animal husbandry and land management strategies. Here, we report stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope values of collagen and carbonate from archaeological fauna from Kałdus, a medieval settlement in North-Central Poland, to better understand human–environment interactions during a period of increasing urbanism and marketization. Wild and domestic animals can be separated on the basis of their isotopic values. The mean $\delta^{15}N$ value for 12 domesticated animals is 7.6 ± 1.2‰ and for 5 wild animals is 4.3 ± 0.5‰ ($p = 0.002$). The mean collagen $\delta^{13}C$ value for domesticated animals is −20.6 ± 1.1‰ and for wild animals is −22.0 ± 0.5‰ ($p = 0.004$). The mean carbonate $\delta^{13}C$ value for domesticated animals is −13.14 ± 1.3‰ and for wild animals is −14.14 ± 0.9‰ ($p = 0.034$). The "canopy effect" and anthropogenic effects that alter stable isotope ratios of plants (manuring, swidden agriculture and ploughing) are discussed in relation to these differences. Fish are isotopically variable, which suggests broad-spectrum fishing strategies and/or trade, and increases our awareness of the difficulties in interpreting human paleodiet when freshwater fish were on the menu.

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1. Introduction

A comprehensive understanding of past human behavior and biology begins with knowledge of humans' subsistence strategies and relationships to the environment. Food is a critical link between human culture, biology and the environment and for this reason, investigations of plant and animal remains at archaeological sites are commonplace in anthropology. Faunal assemblages provide information about whether animals were used for primary or for secondary products, the relative importance of different species to humans, whether certain foods advertised high or low status, and how animals were cared for and managed (Bartosiewicz, 1995; Makowiecki, 2010). As a complement to morphological analyses, stable isotope analysis of faunal remains provides another view into the interactions between humans and animals. Stable carbon and nitrogen isotope ratios ($\delta^{13}C$ and $\delta^{15}N$, respectively) provide information about the diets and environmental niches of animals, because isotopic signatures in bone reflect niche-specific differences in the isotopic signatures of foods consumed (for a review, see Schoeninger, 2011). Stable isotope analysis of archaeological human bone collagen and carbonate is widely-used for studying past food-webs.

A principal reason for studying stable isotope signatures of animal bones from archaeological sites is to provide the critical faunal baseline required for interpreting human stable isotope signatures; thus, faunal stable isotope analyses often accompany isotopic human paleodiet reconstructions. Beyond this supplemental use in reconstructing human diets, stable isotope analyses of animal bones also reveal valuable information about the animals themselves, such as their specific ecological niches within an environment (Barberena et al., 2011; Finucane et al., 2006; Noe-Nygaard et al., 2005; Stevens et al., 2013). Because stable isotope ratios of plants and animals are sensitive to anthropogenic effects, they also offer insights into human–environment interactions. For time periods from which human skeletal remains are scarce, such as the period preceding Christianization in Europe when cremation was a prevailing mortuary custom, or in cases where destructive analyses of human remains is impossible, isotopic information on human–

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environment interactions from animal remains at archaeological sites is especially important.

1.1. Goals

Here, we apply stable carbon and nitrogen isotope analysis to bone collagen and carbonate of animals recovered from an early medieval site (12–13th c. AD) at Kałdus in North-Central Poland. The sample is small ($n = 32$), but representative of the overall species diversity from the sites archaeozoological assemblages (Makowiecki, 2010). The goal of this study is to use isotopic analyses of terrestrial animals as a gauge of anthropogenic land modification and ecological niche-splitting in Poland. Studying such issues helps shed light on the economic foundations of the Polish state after its inception and consolidation in the 10–11th c. AD, and has potential to inform on other demographic transitions including transitions to agriculture, settlement aggregation and population mobility. We also investigate stable isotope ratios of freshwater fish recovered from Kałdus to better characterize isotopic variability of the aquatic environments in and around the Vistula River, and to better understand human fishing strategies at this time. This work contributes to a growing interest in the extent and significance of isotopic variation in animal communities in Europe (Fuller et al., 2012a; Fuller et al., 2012b; Grupe et al., 1999; Müldner and Richards, 2007a,b; Pearson et al., 2007; Stevens et al., 2013; Vika, 2011), and in the potential for stable isotope data to illuminate animal husbandry and soil improvement strategies in the past (Bogaard et al., 2007; Commisso and Nelson, 2008; Finucane, 2007; Fiorentino et al., 2012; Fraser et al., 2011; Kanstrup et al., 2012; Szpak et al., 2012).

2. Stable isotope analysis with a focus on fauna

2.1. Stable isotopes in terrestrial foodwebs

Stable isotope values are reported as a per mil (‰) value according to the following equation, which compares the ratio of two isotopes from a sample to the same ratio from a laboratory reference standard, and referred to using a delta (δ) symbol: $\delta = (([^{13}C/^{12}C \text{ sample} - {}^{13}C/^{12}C \text{ standard}]/[^{13}C/^{12}C \text{ standard}] - 1) \times 1000)$. In isotopic studies of human paleodiet, $\delta^{13}C$ values often are used to identify types of plants consumed. This is possible because different classes of plant (e.g., C_3 and C_4 plants; Smith and Epstein, 1971) exhibit systematically different $\delta^{13}C$ values depending on which strategy of photosynthesis they employ, and these differences are passed up the food chain to human consumers (Smith, 1972; van der Merwe and Vogel, 1978; Vogel and van der Merwe, 1977). $\delta^{13}C$ values also help to distinguish between aquatic and terrestrial foods, because the source carbon in freshwater, marine and terrestrial environments differs isotopically (Chisholm et al., 1982; Schoeninger and DeNiro, 1984). Commonly, $\delta^{15}N$ values are used to investigate animal protein consumption among humans. This is possible because in-vivo fractionation of nitrogen isotopes causes $\delta^{15}N$ signatures of consumer tissues to be higher than those of the diet (DeNiro and Epstein, 1981; Schoeninger and DeNiro, 1984; Steele and Daniel, 1978). Both $\delta^{13}C$ and $\delta^{15}N$ values from collagen primarily reflect protein sources in diet, rather than all macronutrients equally (Ambrose and Norr, 1993; Tieszen and Fagre, 1993).

The information sought from $\delta^{13}C$ and $\delta^{15}N$ analyses is slightly different for animals. For example, $\delta^{13}C$ values have been studied to estimate whether animals foraged in dense forests or open fields (Bocherens et al., 1995; Cerling and Harris, 1999; Fizet et al., 1995; Krigbaum, 2003; Lynch et al., 2008; Rodiere et al., 1996). This is possible because of the so-called "canopy effect" (van der Merwe and Medina, 1989; van der Merwe and Medina, 1991) in which ^{13}C-depleted CO_2 is recycled in closed-canopy forests, causing $\delta^{13}C$ values of plants and animals occupying closed-canopy habitats to be less ^{13}C-enriched than those outside the canopy. Low light intensities and water surfeit also contribute to low $\delta^{13}C$ values of plants in closed forests (Farquhar et al., 1982; Lynch et al., 2008). The canopy effect appears to be most pronounced in tropical and mid-latitude forests, where foliar $\delta^{13}C$ show lower minimum values (Kohn, 2010; van der Merwe and Medina, 1991), but also has been reported for temperate and boreal forests (Drucker, 2008; Drucker et al., 2010; but see Stevens et al., 2006). It has been possible to distinguish between wild and domestic species on this basis (Lynch et al., 2008; Rodiere et al., 1996; Vogel, 1978). Stable nitrogen isotope data can reveal whether animals consumed plant foods exclusively, or if scraps of meat, offal or dairy from among human foods and/or human and animal waste also were eaten by animals, which is especially likely in sedentary or agglomerated contexts in which animals and humans share close quarters (c.f. Fuller et al., 2012b; Müldner and Richards, 2007a,b). Stable nitrogen isotope signatures of plants and the animals eating them also indicate when humans used fertilizers in their pasturelands, and when swidden agriculture was used in the past, providing nuanced information about land management strategies (Bogaard et al., 2007; Commisso and Nelson, 2008; Grogan et al., 2000). Grazing intensity also has been shown to influence $\delta^{15}N$ variation in plants (c.f. Han et al., 2008). Because of such variations, stable isotope data have been used to assess the economic role of animals, such as the importation of domesticated animals by urban settlements from rural outskirts (Berger et al., 2010; Stevens et al., 2013). Used together, $\delta^{13}C$ and $\delta^{15}N$ values from different domestic taxa help identify whether care for animals was specialized (dissimilar isotopic profiles among species) or generalized (similar isotopic profiles among species) (c.f. Finucane et al., 2006).

2.2. Stable isotopes in aquatic foodwebs

Whereas CO_2 is the only source of carbon in terrestrial foodwebs, there are several, isotopically variable sources of carbon in aquatic foodwebs, including CO_2, bicarbonate, dissolved inorganic carbon and decomposing plant matter (Hoefs, 2004). Along with differences due to water temperature and pH, the relative contributions of these different carbon sources in various aquatic zones (e.g., littoral vs. pelagic) creates a considerable range of $\delta^{13}C$ variation among fish (Hecky and Hesslein, 1995), even from the same species (Barrett et al., 2011; Orton et al., 2011). In brackish waters, $\delta^{13}C$ values vary with salinity moving inland from the ocean. It is often possible to distinguish marine from freshwater fish (Fuller et al., 2012a; Grupe et al., 1999), because marine fish typically exhibit ^{13}C-enriched values due to weathering of ^{13}C-enriched limestone. However, $\delta^{13}C$ ranges of marine and freshwater fish do overlap (Katzenberg et al., 2010). Anadromous and brackish water fish can exhibit intermediate bone $\delta^{13}C$ values in comparison to freshwater and marine fish (Fuller et al., 2012a; Grupe et al., 1999; Schoeninger and DeNiro, 1984), although it is worth noting that muscle tissue, with its more rapid turnover rate, may more closely reflect the environmental values at the specific place of capture.

Partly because aquatic foodwebs are longer than terrestrial foodwebs, fish $\delta^{15}N$ values are quite variable (Fuller et al., 2012a). This helps distinguish between phytoplanktivorous, zooplanktivorous, and piscivorous species, for example. Additionally, as predatory fish grow larger with age, they may catch a wider variety of prey (other fish, amphibians, molluscs, and even small mammals) which can increase $\delta^{15}N$ values of older, larger fish compared to younger fish of the same species (Sweeting et al., 2007). This, along with other sources of $\delta^{15}N$ variation in water bodies (c.f. France,