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Abstract: In south-eastern Romania, a prominent place was given to pigs in the Gumelnița culture (Late Chalcolithic, second half of 5th millennium BC); as was the highly prized wild boar, one of a variety of species targeted for hunting. The wild boars' ecological niche and the scale of pig husbandry were investigated during a stable isotope study of the Gumelnița A2 occupations at Bordușani-Popină, Hârșova-tell and Vitănești-Măgurice. Results from the bone collagen  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  analysis suggested that the wild boars did not inhabit dense forests, in any of these locations. The emerging picture is of small-scale pig husbandry involving household management: pigs being fed leftovers and/or by-products of human activities. At Vitănești, previous work involving geometric morphometrics on suid molars evidenced, besides the two expected groups of small domestic pigs and large specimens with wild molar shape (i.e. wild boar), the presence of specimens with large size and domestic shape molars, whose relationship with the human community was unclear. Results from the combined geometric morphometric and stable isotope analyses, suggested that the large specimens with domestic molar shape lived in close proximity to the wild ecosystem. They were probably not part of the domestic stock, but belonged to a feral population and were acquired through hunting.



Paris, 18 December 2015

Dear Editor,

Please find enclosed our manuscript titled

**The place of domestic and wild suids in the Late Chalcolithic (5<sup>th</sup> millennium cal BC) Gumelnița communities of Romania: a zooarchaeological approach combining stable isotope and geometric morphometric analyses**

submitted for publication in the *Journal of Anthropological Archaeology*.

We hope it will receive positive attention.

Best regards,

for all co-authors,

Marie Balasse

**The place of domestic and wild suids in the Late Chalcolithic (5<sup>th</sup> millennium cal BC) Gumelnița communities of Romania: a zooarchaeological approach combining stable isotope and geometric morphometric analyses.**

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## Abstract

In south-eastern Romania, a prominent place was given to pigs in the Gumelnița culture (Late Chalcolithic, second half of 5<sup>th</sup> millennium BC); as was the highly prized wild boar, one of a variety of species targeted for hunting. The wild boars' ecological niche and the scale of pig husbandry were investigated during a stable isotope study of the Gumelnița A2 occupations at Bordușani-Popină, Hârșova-tell and Vitănești-Măgurice. Results from the bone collagen  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  analysis suggested that the wild boars did not inhabit dense forests, in any of these locations. The emerging picture is of small-scale pig husbandry involving household management: pigs being fed leftovers and/or by-products of human activities. At Vitănești, previous work involving geometric morphometrics on suid molars evidenced, besides the two expected groups of small domestic pigs and large specimens with wild molar shape (i.e. wild boar), the presence of specimens with large size and domestic shape molars, whose relationship with the human community was unclear. Results from the combined geometric morphometric and stable isotope analyses, suggested that the large specimens with domestic molar shape lived in close proximity to the wild ecosystem. They were probably not part of the domestic stock, but belonged to a feral population and were acquired through hunting.

## Keywords

*Sus scrofa*, Gumelnița, Romania, husbandry practices, stable isotopes, geometric morphometrics.

## Highlights

- Isotopic and geometric morphometric analyses reveal Gumelnița pig husbandry practices.
- Pigs were fed refuse from human activities, suggesting small scale husbandry.
- Large suids with domestic molar shape show close proximity to the wild ecosystem.
- The large suids with domestic molar shape were feral pigs acquired through hunting.

## Introduction

The 5<sup>th</sup> millennium BC in South-East Europe represents a phase of increasing social complexity (Lichardus et al., 1985; Guilaine, 2007; Chapman et al., 2006). In south-eastern Romania, this period witnesses the appearance of numerous tell sites (Marinescu-Bîlcu, 2001). Changes in the subsistence economy of this period have also been observed, particularly in the meat component of the diet (Bréhard & Bălăşescu, 2012). The earliest evidence for animal husbandry in Southern Romania dates from the beginning of the 6<sup>th</sup> millennium cal BC (Dumitrescu et al., 1983), and over one and a half millennia - through early Neolithic to early Chalcolithic times (i.e. Starčevo-Criş, Dudeşti, Vădastra, Boian and Hamangia cultures), pig (*Sus scrofa* f. *domestica*) was sparsely represented in faunal assemblages (Bălăşescu et al., 2005b, Bălăşescu, 2014). A significant change occurred with the Gumelniţa culture (Late Chalcolithic 4600–3900 cal BC), where pig consumption appears to increase in importance - sometimes ranking first or second to cattle or caprines in terms of the number (15 to 25 %) of mammal remains (Bălăşescu et al., 2005a). Wild game procurement through hunting continued as a component of the subsistence economy - acquiring increasing importance at some settlements from Southern Romania compared to previous periods (Bréhard & Bălăşescu, 2012). Within the varied hunted species that were exploited, wild boar, red deer and aurochs remain the main hunted taxa recovered from sites (Bălăşescu et al., 2005a, 2005b).

In this context, defining the ecological niche of wild boar and the scale of pig husbandry at Gumelniţa tell settlements should help with understanding the investment of human society in the management of these related resources. Suids display an opportunistic feeding behaviour within a broad ecological niche, rendering them particularly adaptable to a variety of ecological settings and husbandry systems. The scale of husbandry may vary widely - from household keeping of few individuals to specialized extensive management of large herds – the latter adapted to a wide variety of landscapes (from open areas to woodlands, including seasonal foraging in cultivated fields), involving both highlands and lowlands, and following either sedentary or transhumant pathways (Albarella et al., 2007, 2011; Halstead and Isaakidou, 2011; Hadjikoumis, 2012). As omnivores, pigs can fully exploit different niches within the anthropic ecosystem. Those herded extensively would be expected to have a diet similar to that of their wild counterparts – consisting mostly of plant resources with seasonally variable animal components. In contrast, pigs kept in closer proximity to human settlements (and/or confined and raised for fattening at a household level) would potentially incorporate

in their diet human consumption refuse including by-products of animal exploitation and plant cultivation.

These different dietary components can be detected through analysis of stable carbon ( $\delta^{13}\text{C}$ ) and nitrogen ( $\delta^{15}\text{N}$ ) isotope ratios in archaeological bones. When placed within the local ecosystem (*i.e.* by comparison with values measured against wild and domestic fauna found in association with them),  $\delta^{15}\text{N}$  values measured in pig remains should indicate a positive shift in trophic level induced by the consumption of animal proteins, while  $\delta^{13}\text{C}$  values may be useful, in some instances, to reveal the dietary contribution of  $\text{C}_4$  crops when the surrounding wild environment is dominated by  $\text{C}_3$  plants (Pechenkina et al. 2005; Ervynck et al., 2007; Hamilton et al., 2009; Madgwick et al., 2012; Frémondeau et al., 2013, Chen et al., 2014, 2015). In contrast, lower values of both carbon and nitrogen isotope ratios would be expected for animals under an extensive herding regime, with a diet more focused on wild plants, whereas higher  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values would suggest a closer proximity to (or management by) humans, with a diet higher in protein.

Bone collagen carbon and nitrogen isotope analyses were undertaken on the Gumelnița vertebrate assemblages from Hârșova-tell and Bordușani-Popină, in the Danube River basin, south-eastern Romania. They revealed a high trophic level for domestic pigs, suggesting a significant contribution of animal protein to their diet, which may be partly acquired from the abundant aquatic resources and nesting birds within the surrounding marshland environment. However, a significantly higher trophic level in pigs compared to wild boar, suggested that the former strongly relied on human waste in their diet. Consequently, the scale of husbandry at these sites was thought to more closely resemble household level management than specialised extensive herding (Balasse et al., in press).

In addition to the challenge of disentangling dietary differences between wild and domestic pigs (both being potentially omnivorous and opportunistic), the two forms are also especially difficult to distinguish from their zooarchaeological remains. A decrease in body size is one of the most significant (and traditionally accepted) changes associated with the process of domestication (e.g. Boessneck & von den Driesch 1978; Meadow, 1989; Vigne et al., 2005) and in most previous studies, a size criterion (applied especially to teeth), was used to distinguish the small (domestic) pigs from their (large) wild counterparts (e.g. Albarella et al.

2006; Rowley-Conwy et al., 2012). However, recent studies involving geometric morphometric analyses of teeth have challenged the traditional size criteria used to distinguish domestic pig from wild boar, demonstrating that shape is more powerful in addressing this issue (Cucchi et al. 2011, Evin et al., 2013; 2015a). Moreover, when applied to Romanian Neolithic and Chalcolithic assemblages, geometric morphometric approaches have previously revealed a third group of suids – i.e. large size with ‘domestic’ shape molars - present from the early Neolithic (Evin et al., 2015a).

When combined with ancient DNA sequences from the same specimens, it appears that the majority of small domestic pigs possessed a mitochondrial signature (Y1 haplotype, 17 among 18 specimens) linked with the introduction of pigs from Anatolia during the Neolithic (Ottoni et al., 2013). Based on analyses of teeth, the earliest evidence of these small domestic pigs dates from the Middle Neolithic (Vădastra culture) at the site of Măgura–Buduiasca, though the presence of small pigs had been previously identified during the Early Neolithic from postcranial measurements (Bălăşescu, 2014). So far, the earliest specimen with large and domestic shape molars that was genotyped carried the European haplotype E1-C, suggesting either admixture between the introduced domestic pigs and local wild boar, or local domestication. Furthermore, the presence of large specimens with both a wild and domestic tooth shape, and carrying the Near-Eastern Y1 haplotype during the Gumelnița (Middle Chalcolithic) promotes the admixture hypothesis, at least for this time period (Evin et al. 2015a).

Outstanding questions remain about the status of these large suids with domestic tooth shape - specifically in terms of their relationship to humans – i.e. were they part of the domestic stock or were they hunted (wild or feral) game?

From the two Gumelnița assemblages analysed to date, pigs and wild boar – separated merely by humerus size - showed significantly different stable isotope values (Balasse et al. in press). This distinction suggests that dietary characterisation of the suids with large domestic shape molars may provide clues regarding their role in the anthropic ecosystem and could help confirm their status, if both morphometric and isotopic markers are collected from the same specimens.

In order to resolve the questions surrounding the status of the Gumelnița suids, we first established baseline ecological diversity from a wide spectrum of other animals - at three contemporaneous sites in southern Romania - by measuring their nitrogen and carbon isotope ratios. These included herbivore, omnivore and carnivore taxa from both terrestrial and aquatic food webs. We then contrasted stable isotope compositions obtained from suids (i.e. 'wild' and 'domestic' pigs) from the site of Vitănești- Măgurice with traditional and advanced (geometric morphometric) biometrical approaches, providing a direct dietary characterisation of the three morphological groups (i.e. small domestic, large wild boar, and large specimens with domestic molar shape). These analyses offered a potential new insight into the manner and form of wild and domestic suid exploitation (specialised extensive herding or household management) by the Chalcolithic farming communities of southern Romania.

### **The sites and their subsistence economy**

In total, three archaeological assemblages from south-eastern Romania - dated to the Late Chalcolithic Gumelnița culture (A2 phase) - were included in the study: Bordusani-Popină, Hârșova-tell and Vitănești-Măgurice. Hârșova-tell and Borduşani-Popină (called hereafter Hârșova and Borduşani) are neighbouring sites located approximately 20.5 km apart on the Danube River Plain, south-eastern Romania (Figure 1). At both sites, Gumelnița A2 occupation deposits were radiocarbon dated to the second half of the 5<sup>th</sup> millennium cal BC (Bréhard and Bălăşescu 2012; Gillis et al. 2013). Borduşani is located on the large island of Balta Ialomiței on the Danube River. Hârșova is located on a terrace on the eastern side of the river, protected from seasonal floods by its elevated height. The modern landscape of Balta Ialomiței is a mosaic of riparian poplar and willow forests, coppices, meadows, and marshes, typical of a floodplain and river valley environment. Oak forests, that occupy the most elevated non-floodable riverbanks, may have been more widespread in prehistoric times when anthropogenic pressure was less intense. In spite of significant human-induced alterations to the present day environment, a general continuity in landscape structure - significantly influenced by the river Danube – can be inferred from Chalcolithic to recent times. At Borduşani, wood charcoal assemblages were dominated by hydrophilic species including poplar, willow, and elm, while oak predominated in wood used for construction (Tomescu 2003). Wild mammal and bird remains also reflect this mosaic of lacustrine and forested areas (Moise 1997; Bălăşescu et al. 2003; Gal and Kessler 2003).



Both direct and indirect evidence of agriculture has been recovered from both sites (Popovici and Rialland 1996; Monah 1998-2000; Balasse et al. in press). The spectrum of cultivated plants is very similar and typical of the Chalcolithic period in south-eastern Europe, including varieties of wheat, naked barley, and pulses.

At Hârşova and Borduşani, a substantial part of the subsistence economy derived from aquatic resources - primarily fish and bivalves, in addition to gastropods, crustaceans, amphibians, reptiles, and birds. Fish represent 92% of the archaeozoological remains (NISP) at Hârşova and 33% at Borduşani, with bivalves from 5% to 20% respectively (Bălăşescu et al. 2005a; NISP = 283,492 and 32,893). More than 20 species of fish were identified, with zander and northern pike dominating at Hârşova, whilst common carp and catfish are most common at Borduşani. Painter's and swollen river mussels were the most common shellfish taxa recovered from both sites (Radu 2011), whilst reptiles (especially European pond turtle) and birds were more occasional prey species (Gál and Kessler 2002, 2003; Kessler and Gál 1997).

The importance of animal husbandry for these communities is highlighted by the clear predominance of domestic animals (> 70% of mammal remains determined to species level) in the excavated vertebrate assemblages. At Borduşani, pig remains dominate the domestic animal component (23 % of NR), followed by cattle (20%), and caprines (16%, mostly sheep). At Hârşova, caprines represent the highest number of domestic animal remains (26%, mostly sheep), with pigs a close second (17%), then cattle (11%; Bălăşescu et al. 2005a). Additionally, undetermined suids represent 7% of the remains at Borduşani, and 10% at Hârşova. At both sites, exploitation of milk is suggested from the cattle mortality profiles, while sheep were likely exploited for meat - with a focus on early culling (Bréhard and Bălăşescu 2012). Hunting targeted a variety of wild animals, with wild boar well represented (8.1% and 16.8% of the total mammal remains at Borduşani and Hârşova, respectively), followed by red deer (5.8% and 1.5%), and roe deer (1.7% and 1.2%). Other wild taxa were only occasionally represented amongst the mammal remains (Bălăşescu et al. 2005a).

At Vităneşti-Măgurice (hereafter Vităneşti), two phases of Chalcolithic occupation were identified - separated by an abandonment phase. The first belonged to the early phase of the Gumelniţa culture A1 and the second to Gumelniţa A2 and B1 (Andreescu et al. 2003). The Gumelniţa A2 level is dated to the second half of the 5<sup>th</sup> millennium cal BC (Bréhard and Bălăşescu 2012; Balasse et al. 2013). The tell is located on a floodplain surrounded by

marshlands near to the north-east terrace of the Teleorman Valley. The economy of the site appears to have relied to a significant extent on arable production: besides wild fruits, charred vegetal remains recovered at the site included a number of cereal taxa (i.e. einkorn, emmer, barley and a single find of rye of uncertain status) and a pulse (common pea) (Bogaard 2001). The aquatic resources are represented by various species of bivalves of the genus *Unio*, and are dominated by the thick-shelled river mussel; fish (such as catfish or carp); European pond turtle, and various bird species (Bălăşescu and Radu 2003).

Within the mammal assemblage, wild taxa predominate (68% of identified remains), reflecting the unexpected importance of hunting within this community. Large and very large mammals (red deer 17%, aurochs 16%, wild boar 15%, wild horse 9%) are well represented and (with the exception of beaver, European badger and roe deer) other wild taxa represent less than 1% of the identified remains (Bălăşescu et al. 2005a, 2005b). Pig remains dominate the domestic taxa (14%), followed by cattle (12%), and caprines (4%, mostly sheep).

## **Material and methods**

### *Stable isotope datasets*

At Hârşova and Borduşani, previous stable isotope datasets (Gillis et al. 2013; Balasse et al. in press) included only terrestrial herbivores and omnivores. Given the obvious importance of aquatic resources at both sites (resources which may well also have contributed to the diet of pigs), fish remains were included in the present study (Supplementary material 1). The best-represented fish taxa from the sites were selected, which included catfish (*Silurus glanis*), northern pike (*Esox lucius*), the common carp (*Cyprinus carpio*), and zander (*Sander lucioperca*). Remains of dog were very common at both sites (over 14% of the identified animal bones) compared to other Gumelniţa assemblages (Lazăr et al. in press). They were thus also targeted by our study as typically belonging to the domestic sphere and reflecting access to production and consumption waste (Guiry, 2012) (Supplementary material 2).

Previously published stable isotope values from wild animals (wild boar, aurochs, wild horse, red deer, and roe deer) at Vităneşti provided an important comparative dataset for this study (Balasse et al. 2013). To this was added new data from beaver and fish (i.e. catfish, northern pike, common carp and zander) in order to further characterise the riparian forest vegetation and the aquatic ecosystem). Domestic animals included dogs, cattle, sheep, and pigs

(Supplementary material 2). Humeri of domestic pigs (VIT Sus 1 to 12) were sampled, conforming to previous work performed at Hârşova and Borduşani, by selecting from the smallest and largest specimens (Table 1 and Supplementary material 1). Those mandibles, previously subjected to geometric morphometric analysis (Evin et al. 2015a) were then sampled (VIT Sus morpho 1 to 44) to enable direct comparison of results from all approaches. All specimens analysed were from different individuals, had fully erupted second molars, and were at least 8-10 month of age (i.e. dental stage 10-11; Rowley-Conwy 1993). Since Halstead and Isaakidou (2011) reported broad weaning ages of 45 days to 2-3 months in traditional Greek husbandry systems lacking grain foddering, our sampling strategy thus controlled for the influence of suckling effect on the  $\delta^{15}\text{N}$  values (Fogel et al. 1989).

#### *The geometric morphometrics datasets*

Shape analysis focused on the suid lower second and third molars from Vităneşti. This dataset represented specimens previously published by Evin et al. (2015a). Two dimensional landmark and sliding semi-landmark based geometric morphometric approaches were applied following the protocols published by Evin et al. (2013, 2015a, 2015b), allowing the separate analysis of centroid size and shape for each tooth. In order to measure the association between the log-transformed univariate morphometric data and the isotopic data, a correlation test was computed for each measurement and the regression slope visualised using a biplot. The association between molar shape and isotope values was explored using multivariate regressions.

#### *Collagen extraction and analysis*

Mammal bone collagen was extracted from approximately 300 to 380mg of bone powder, following the procedure described in Bocherens et al. (1991). Fish bone collagen was extracted from approximately 300 to 560mg of bone powder. The fish bone collagen extraction procedure differed from that used for mammal bones only in the NaOH step, which was applied for 15 minutes repeatedly until the solution ran clear, as suggested in Szpak et al. (2013); two to three baths (30 to 45 min) were sufficient.

Coupled measurements of  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  were conducted on 400 to 500 $\mu\text{g}$  of collagen on an elemental analyser Thermo Flash 2000 interfaced to a Thermo DeltaV Advantage IRMS. The analytical precision, determined within each run from analyses of an alanine standard, was 0.1‰ for  $\delta^{13}\text{C}$ , and 0.1 to 0.2‰ for  $\delta^{15}\text{N}$ ; 0.2 to 0.3% for C content, and 0.15% for N content.

Over the course of all analyses, the alanine standard (N=44) gave mean values of  $+0.72 \pm 0.1\text{‰}$  for  $\delta^{15}\text{N}$  (expected value =  $+0.59\text{‰}$ ),  $-22.06 \pm 0.1\text{‰}$  for  $\delta^{13}\text{C}$  (expected value =  $-22.16\text{‰}$ ),  $15.86 \pm 0.26\%$  for N content (expected value =  $15.72\%$ ), and  $40.66 \pm 0.56\%$  for C content (expected value =  $40.44\%$ ).

## Results

### *Quality of collagen extracts*

Following recommendations by DeNiro (1985), Ambrose (1990), and van Klinken (1999), when bone samples yielded less than 2% collagen (20 mg/g) and when collagen extracts contained less than 30% carbon and 11% nitrogen (even though the C:N ratio was between 2.9 and 3.6), they were not considered well preserved and their stable isotope values were not included in the final dataset.

Among the 94 mammal specimens, 91 yielded collagen. All these collagen extracts satisfied the criteria defined for reliable stable carbon and nitrogen isotope compositions: collagen extraction yields varied between 18 and 171 mg/g (mean  $100 \pm 31\text{mg/g}$ ), %C varied between 34.4 and 47.1, %N varied between 12.6 and 17.3, and C:N values were all between 3.1 and 3.3 (Supplementary material 2). Among the fish, only 22/29 specimens yielded collagen, of which only 19 satisfied the criteria defined for reliable stable carbon and nitrogen isotope compositions. Of these reliable extracts, collagen extraction yields varied between 17 and 69 mg/g, %C between 31.3 and 40.2, %N between 11.5 and 14.8, and all C:N were 3.2, except one at 3.1 (Supplementary material 1). Stable isotope values are reported in supplementary materials 1 and 2, and figures 2 and 3. Table 2 presents descriptive statistics for the complete dataset used in the forthcoming discussion, including results from this study and previous works (Gillis et al. 2013; Balasse et al. in press).

### *Beaver*

At Vitănești, the position of beaver in the food web - as defined from the  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  values - showed strong similarities with previous results obtained at Bordușani (Balasse et al. in press, and Figure 2B). Bone collagen  $\delta^{13}\text{C}$  values varied from  $-22.8$  to  $-21.3\text{‰}$ , with an average value of  $-22.1 \pm 0.4\text{‰}$ . These values that characterise the riparian environment, were lower than those measured in large herbivores from the surrounding floodplain and steppe, including red deer ( $-21.4$  to  $-20.2\text{‰}$ , average  $-20.7 \pm 0.3\text{‰}$ ; Balasse et al. 2013) and most

aurochs (average  $-20.9 \pm 0.5\%$ ; Balasse et al. 2013). They varied within a similar range to roe deer ( $-22.7$  to  $-20.2\%$ ; Balasse et al. 2013), exhibiting a more opportunistic feeding behaviour that possibly also included the riparian habitat.

In spite of their exclusively herbivorous diet, beavers yielded higher  $\delta^{15}\text{N}$  values (6.7 to 9.5‰) than other terrestrial herbivores (Figure 2B), which may be related to their particular digestive physiology involving caecotrophy. Indeed, caecal faeces have been shown to be  $^{15}\text{N}$ -enriched compared to diet (by approximately 2‰) in small mammals with hindgut fermentation digestive physiology, while no significant difference was found in  $\delta^{13}\text{C}$  values (Hwang et al. 2007). Re-ingestion of caecal faeces would, therefore, provide a higher source of  $^{15}\text{N}$ -enriched nitrogen compared to nitrogen directly from plants. Consequently, in our study, beavers provided  $\delta^{13}\text{C}$  values comparable to those measured in other herbivores, but their  $\delta^{15}\text{N}$  values should not be used to provide a baseline for a herbivorous dietary regime.

#### *Domestic sheep and cattle from Vitănești*

Domestic sheep and cattle showed significantly higher  $\delta^{13}\text{C}$  values than those measured in wild terrestrial fauna at the site (Wilcoxon rank test,  $W = 44.5$ ,  $p = 4.10^{-6}$ ). A similar observation was made at Hârșova and Bordușani, where this difference was attributed to their feeding on  $\text{C}_4$  ruderal plants available in the vicinity of the settlements and/or in cultivated fields.

#### *Fish*

Fish delivered similar  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  values at Hârșova, Bordușani and Vitănești. Zander and catfish had the highest  $\delta^{15}\text{N}$  values of the whole dataset (10.5 to 11.6‰ and 10.9 to 11.5 ‰, respectively) reflecting their piscivorous diet, and setting them at a super carnivorous level within the aquatic ecosystem. These contrasted with lower  $\delta^{15}\text{N}$  values measured in the common carp (6.0 to 8.3‰), which has an omnivorous diet including molluscs, insects, and plants (Bănărescu 1964). The  $\delta^{15}\text{N}$  values measured in the northern pike (9.7 to 10.3‰) also reflected a reliance on insectivorous fish. The common carp and zander delivered lower  $\delta^{13}\text{C}$  values ( $-25.5$  and  $-23.0\%$ ) than catfish ( $-21.3$  to  $-20.6\%$ ) reflecting their respective dependence on the pelagic and benthic food webs (France 1995). Relatively higher  $\delta^{13}\text{C}$  values measured in the northern pike ( $-22.9$  to  $-22.0\%$ ), compared to the common carp and

zander, may also suggest they were not fished in fast moving waters but in marshes or ponds, where more positive food web  $\delta^{13}\text{C}$  values would be expected (Osmond et al. 1981).

### *Dogs*

Dogs revealed  $\delta^{15}\text{N}$  values averaging  $10 \pm 0.3\text{‰}$  at Hârşova, and  $10.1 \pm 0.6\text{‰}$  at Borduşani. At both sites, the difference in average  $\delta^{15}\text{N}$  values measured in typical terrestrial herbivores (i.e. red deer, roe deer, aurochs, cattle and sheep) was approximately 2.5 to 4.5‰, placing dogs at a carnivorous (but not super carnivorous) level. At Vităneşti,  $\delta^{15}\text{N}$  values for dogs ( $8.6 \pm 0.6\text{‰}$ ) were lower than those at the other two sites (although terrestrial wild and domestic herbivores yielded similar values at Hârşova, Borduşani and Vităneşti), suggesting that the dogs at Vităneşti may have been fed primarily wild game. Across all sites, carnivorous fish (catfish, zander, northern pike) did not seem to have contributed significantly to the diet of dogs otherwise they would have occupied a higher trophic level.

The  $\delta^{13}\text{C}$  values measured in the bone collagen of dogs fell between -22 and -20‰. These values fall well within the range of variation of  $\delta^{13}\text{C}$  values measured in the terrestrial wild fauna at the three sites, except for a single individual with a value of -19.3‰ at Borduşani (Figure 2A). At Hârşova, Borduşani, and Vităneşti, where significantly higher  $\delta^{13}\text{C}$  values were observed in domestic sheep and cattle compared to wild herbivores (Balasse et al. in press and above), dogs show a greater proximity to the wild game within the overall food web. Alternatively, contributions of domestic animal meat (with higher  $\delta^{13}\text{C}$  values) to the dogs' diet may have been counterbalanced by a contribution of fish (with lower  $\delta^{13}\text{C}$  values) - namely the carp with  $\delta^{15}\text{N}$  values comparable to those measured in terrestrial herbivores. Conclusions drawn from observations, on such a limited number of individuals require confirmation with a larger dataset. At Hârşova and Borduşani, the  $\delta^{15}\text{N}$  values from most pigs were higher than those measured in wild and domestic herbivores, and overlapped with the values defined for dogs in the present study (Figure 2A). These data confirm a high trophic status for most domestic pigs.

### *Pigs from Vităneşti: stable isotope measurements on the humerus*

At Vităneşti,  $\delta^{15}\text{N}$  values measured from pig humeri varied from 8.2 to 9.5‰ (average  $8.9 \pm 0.5\text{‰}$ ). These values fall within the range of variation measured in dogs, putting pigs and dogs at a similar trophic level. One pig delivered the highest value of the dataset for

terrestrial fauna (9.5‰). These values are significantly higher than those measured in wild boar (Wilcoxon rank test  $W= 12$ ,  $p= 0.003$ ). The  $\delta^{13}\text{C}$  humeri values for pigs varied from -21.1 to -18.6‰ (average  $-20 \pm 0.9\%$ ). These are significantly higher than those measured in wild boar ( $W= 12.5$ ,  $p= 0.003$ ), supporting previous observations at Hârşova and Borduşani - although no significant differences were found between the  $\delta^{13}\text{C}$  values measured in pigs or wild boars at the last site (Balasse et al. in press).

### **Combining results from GM with stable isotope analysis at Vităneşti**

Among the 41 suid tooth rows analysed through a geometric morphometric approach by Evin et al. (2015a), 26 were classified as “small domestic” (SD), 10 as “large wild” (LW), and five as “large domestic” (LD). Seven of these were also successfully sequenced for mtDNA: two of the LW possessed the European haplotype E1; four of the SD possessed the Y1 haplotype, (assumed to reflect the Neolithic introduction of domestic pigs from the Near East); and one SD possessed the Y2 haplotype (whose origin and dispersal remains unclear but which was already present during the Romanian Mesolithic; Ottoni et al., 2013).

The  $\delta^{13}\text{C}$  values measured in the LW specimens varied from -21.6 to 20.4‰ (average  $-21.1 \pm 0.4\%$ ). These values, similar to those measured in the large humeri (average  $-21 \pm 0.4\%$ ), were within the range defined for red deer and aurochs at the site, and likely reflect foraging in open areas. The  $\delta^{13}\text{C}$  values measured in the SD specimens varied from -22.1 to 19.8‰, encompassing those values also found in wild boar and also enlarging the dataset of humeri with lower values. The difference in  $\delta^{13}\text{C}$  values between the SD and the LW suids was less significant (Wilcoxon rank test,  $W= 68.5$ ,  $p=0.02$ ) than within the dataset based on humeri.

The  $\delta^{15}\text{N}$  values measured in LW specimens (6.3 to 8.7‰) were significantly higher ( $W: 309.5$ ,  $p= 2.10^{-4}$ ) than those measured in other wild herbivores (i.e. red deer, roe deer, aurochs) - the result of an omnivorous diet; and significantly lower ( $W= 48.5$ ,  $p=0.002$ ) than those measured in the SD specimens (7.4 to 9.4‰), in spite of a slight overlap. In the SD specimens, the  $\delta^{15}\text{N}$  values encompass the range of variation defined in dogs, confirming once again a high trophic status for most pigs. Both the  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values measured in the LD specimens were within the range of variation defined for LW suids, suggesting their

greater proximity to a non-anthropogenic ecosystem. All five specimens yielded some of the lowest  $\delta^{15}\text{N}$  values for suids at this site ( $\delta^{15}\text{N} \leq 7.3\text{‰}$ ; Figure 3).

## Discussion

### *Defining the ecological niche of wild boar*

At Hârşova, Borduşani and Vităneşti, wild boar showed  $\delta^{13}\text{C}$  values similar to those measured in red deer, aurochs, and horses: always higher than  $-22\text{‰}$  and in most cases higher than  $-21\text{‰}$ . These values reflect a more open environment and stand apart from those measured in beaver and most roe deer that most likely characterise the riparian environment. This observation confirms previous observations at the site of Cheia (Hamangia, 5<sup>th</sup> millennium cal BC) in the Central Dobruja Plateau (south-eastern Romania), where  $\delta^{13}\text{C}$  values from wild boar, which ranged between  $-21.7$  and  $-19.6\text{‰}$  ( $N=7$ ), were within the range of variation of other large wild herbivores inhabiting open environments (Balasse et al. 2014). From these results, it appears that wild boar cannot be considered a wholly woodland species, unless the woodlands in southern Romania during the Chalcolithic period were open enough for the canopy effect not to apply. At the three sites, a slight (approximately  $1\text{‰}$ ) but significant enrichment in wild boar  $\delta^{15}\text{N}$  values (compared with other wild herbivores) confirmed a more omnivorous diet.

### *The diet of pigs*

The high trophic level for pigs observed at the three sites suggests the contribution of a significant amount of animal protein to their diet. Given that this contribution is considerably higher than in wild boar, it is most likely that it mainly consisted of various human waste. Apart from deliberate provisioning with leftovers, pigs could also benefit from these resources by free-ranging in and around the settlement, adopting the role of refuse disposers. The early consumption of human faeces by pigs has been proposed for the Chinese Neolithic (Pechenkina et al. 2005), although the consequence of such practice on consumers'  $\delta^{15}\text{N}$  values is unclear (Guiry 2012). Waste could also have included the remnants of hunted game, domestic stock or fish, and dairy by-products. Cattle dairying has been strongly suggested at Hârşova and Borduşani from the cattle mortality profiles (Bréhard and Bălăşescu 2012; Gillis et al. 2013), and by-products from e.g. cheese making could also have contributed to the pigs' diet. Feeding pigs with whey, in particular, remains a common practice in many traditional pastoral societies (Dong et al. 2003; Albarella et al. 2011; Halstead and Isaakidou 2011) and



may have constituted an essential component of pig husbandry on a seasonal basis. At the three sites, the significantly higher  $\delta^{13}\text{C}$  values measured in cattle and sheep compared with the remaining fauna could well have been passed up the food chain, and consequently this signal may be used to trace consumption of domestic animal products by pigs. In fact, although a difference does exist between the  $\delta^{13}\text{C}$  values measured in the pigs and wild boar at Hârşova and Vităneşti, the shift in the pigs'  $\delta^{13}\text{C}$  towards higher values is moderate, and no such shift was observed at Borduşani. One possible explanation could be the counterbalancing of this high  $\delta^{13}\text{C}$  signal through the contribution of fish to the diet, whose  $\delta^{13}\text{C}$  values are significantly lower than those measured in terrestrial fauna - especially carp (Figure 2A and 2B). The contribution of northern pike, catfish, and zander would have been moderate, given that their super carnivore diet (and thus considerably increased  $\delta^{15}\text{N}$  values) would have raised the  $\delta^{15}\text{N}$  of their consumers. The range of the pig collagen  $\delta^{13}\text{C}$  values (around average measured values for the spectrum sampled here), and the  $\delta^{15}\text{N}$  values (the highest observed across the sites - comparable to those measured in dogs), would suggest that the pigs consumed all of these products - as is the case in animals fed kitchen scraps. This suggests pigs were living in close proximity to the settlements, and most likely indicates household pig management rather than an extensive herding regime.

High values on average should not obscure the amplitude of variation in pig  $\delta^{15}\text{N}$  values: one trophic level at Borduşani and Hârşova (3.6 ‰ and 3.2‰, respectively), slightly lower at Vităneşti (2.1‰), and a clear overlap with the values measured in wild boar at Hârşova and Borduşani. At Borduşani, the lowest  $\delta^{15}\text{N}$  value for suids was measured in a domestic specimen. This observation is not contradictory with the previous statement of the household management of pigs. If an elevated trophic level is proof of food provisioning by villagers, a lower trophic level (herbivorous pigs) does not rule it out: a household pig may also be allowed to graze in the garden, may be fed cereal by-products or plants collected during weeding, and/or it may occasionally be taken out to graze with cattle and caprines (Halstead and Isaakidou 2011). If also confined for the last months of life for fattening (Halstead and Isaakidou 2011), this would probably not be reflected in the bone collagen due to its long-term renewal rate. The variability in  $\delta^{15}\text{N}$  values and  $\delta^{13}\text{C}$  values may also equally reflect an unspecialized and opportunistic diet, characterizing a system of household management where pigs are fed on available food.

### *Scale of pig husbandry and consequence on production/consumption*

Household pigs naturally require less maintenance compared to extensive herding. At Borduşani in particular, where evidence was provided for local agriculture on the island (Balasse et al. in press), the free-ranging of pigs may have been avoided (at least before harvesting) to limit crop damage. Most importantly, the household management of pigs implies an intense involvement in their feeding. In their ethnoarchaeological study of pig husbandry in Greece, Halstead and Isaakidou (2011) noted that the fattening of a yearling pig is almost equivalent to feeding an adult human. Consequently, most households would only rear one or two such pigs per year. Pig husbandry at the Gumelniţa sites was, therefore, probably practised on a more modest scale. In return, well-fed household pigs not only grew more rapidly than extensively herded animals, but also achieved larger and fatter carcasses. One direct consequence is that they are slaughtered at a younger age, before they reached an unmanageable weight at a household scale (Halstead and Isaakidou 2011). Interestingly, suid mortality profiles at Borduşani, Hârşova (data in Frémondeau 2012), and Vităneşti (Tresset et al. pers. comm. 2015) indicate a specific reliance on animals around 8-10 months in age (based on analyses of the entire assemblage of suid mandibles from the sites). The emphasis on demographic profiles focused on a specific 8-10 month age class - which echoes pig mortality profiles at other Gumelniţa sites (Bălăşescu unpublished) - likely represents the emphasis on the consumption of pork at a household scale.

### *The status of suids with large and domestic shape molars at Vităneşti*

Although this dataset is limited, all five specimens from Vităneşti with large and domestic shape molars showed a greater dietary affinity to other wild mammals in terms of their stable isotope values (Figure 3). This clearly sets them apart from the small domestic pigs based on their diet.

Two hypotheses may explain these results. First, the LD specimens could have been part of the domestic stock (as reflected by their molar shape) but herded in an extensive system (as suggested by their stable isotope values). Such practices would have favoured hybridisation with local wild boar (which would explain their larger size). Alternatively, the LD specimens could have been feral pigs that escaped domestic herding and hybridised with wild boar. To explain the status of the LD specimens in Vităneşti, we must assume that the initial free-ranging hypothesis is unlikely. Within a common pastoral context, such extensively herded pigs would generally outnumber household fattened pigs (Halstead and Isaakidou 2011). Yet,

we found the opposite at Vitănești, where the SD specimens (63% of all suids, 84% of molars with domestic shape) clearly outnumber the LD specimens (12% of all suids; 16% of molars with domestic shape). Therefore, we consider it more likely that the LD specimens reflect a biological history of domestic ancestry, but that their relationship with humans should be considered similar to that of local wild boar.

## **Conclusion**

In this study, stable carbon and nitrogen isotope ratios proved invaluable in identifying wild and domestic suid diets and ecological niches. Distinguishing wild and domestic pigs from stable isotope measurements must be conducted within the framework of a well-characterised ecosystem. In this case study focused on the Chalcolithic of south-eastern Romania, we were able to show that wild boar may not have inhabited a closed forest canopy. Within these contexts, the contrast between open and closed biotopes - as seen through  $\delta^{13}\text{C}$  values - may not be adequate to distinguish wild from domestic pigs. Inter-individual variability in domestic pig  $\delta^{15}\text{N}$  values, establishing the trophic level, was also shown to be important. Nevertheless, the emerging picture of pig husbandry in the Gumelnița culture of southern Romania more closely resembles household management and the feeding of pigs with leftovers and/or by-products of human activities. This would reflect small-scale husbandry, as suggested for cattle and sheep herding at the same sites (Balasse et al. in press).

Regarding the large specimens with domestic molar shape, our data suggests that they belonged to a feral population feeding in the wild, which were likely acquired through hunting. Although their status within the Chalcolithic human niche of southern Romania should not be directly transposed to other geographical and temporal contexts, the evidence presented here clearly supports a long history of hybridisation in the domestication of pigs in Europe (Larson et al. 2007, Ottoni et al. 2013, Larson and Burger 2013, Marshall et al. 2014).

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## Table and figures legends

**Table 1:** Descriptive statistics for measurements of suid humeri from Vitănești (minimal – maximum value, number of specimens). SD = smallest breadth of diaphysis, Bd = (greatest) breadth of the distal end, BT = (greatest) breadth of the trochlea and Dd = depth of the distal end. SD, Bd, and BT after von den Driesch (1976). Dd after Vigne (1988).

**Table 2:** Descriptive statistics (mean  $\pm$  1 $\sigma$ ) for the complete dataset of stable carbon and nitrogen isotope ratios in animal bones from Bordușani, Hârșova and Vitănești, including this study and previous studies by Gillis et al. (2013) and Balasse et al. (in press).

**Figure 1:** Location of study sites in Romania. 1- Bordușani; 2- Hârșova; 3- Vitănești  
(Size 1.5 column)

**Figure 2:** Results from the stable carbon ( $\delta^{13}\text{C}$ ) and nitrogen ( $\delta^{15}\text{N}$ ) isotope analysis of animal bone collagen from Bordușani, Hârșova and Vitănești.  
(Size two columns)

**Figure 3:** Results from the stable carbon ( $\delta^{13}\text{C}$ ) and nitrogen ( $\delta^{15}\text{N}$ ) isotope analysis of suids' teeth row collagen (this study) and concomitant geometric morphometric and DNA analyses (E1, Y1 or Y2 haplotypes) (data Evin et al. 2015).  
(Size 1 column)

**Supplementary material 1:** Results from the stable carbon ( $\delta^{13}\text{C}$ ) and nitrogen ( $\delta^{15}\text{N}$ ) isotope analysis of fish bone collagen from Bordușani (PBORD), Hârșova (HVA), and Vitănești (VIT). Initial amount of bone used for collagen extraction, extraction yield, collagen nitrogen content (%N), carbon content (%C), and carbon:nitrogen ratio (C:N).

**Supplementary material 2:** Results from stable carbon ( $\delta^{13}\text{C}$ ) and nitrogen ( $\delta^{15}\text{N}$ ) isotope analysis of terrestrial mammal bone collagen from Bordușani (PBORD), Hârșova (HVA), and Vitănești (VIT). Initial amount of bone used for collagen extraction, extraction yield, collagen nitrogen content (%N), carbon content (%C), and carbon:nitrogen ratio (C:N). Results from geometric morphometrics (GMM): Small domestic (SD), large wild (LW), large domestic (LD) (data Evin et al. 2015).

**Supplementary material 3:** Measurements (in mm) of suid humeri from Vitănești (minimal – maximum value, number of specimens). SD = smallest breadth of diaphysis, Bd = (greatest) breadth of the distal end, BT = (greatest) breadth of the trochlea, and Dd = depth of the distal end. SD, Bd and, BT after von den Driesch (1976). Dd after Vigne (1988).

Table 1

	SD (mm)	Bd (mm)	BT (mm)	Dd (mm)
small	14.0 - 14.5 (N=3)	34.0 - 39.5 (N=9)	24.5 - 28.6 (N=8)	32.5 - 37.6 (N=7)
large	21.1 - 23.0 (N=5)	50.0 - 59.9 (N=11)	36.5 - 42.6 (N=11)	49.0 - 56.1 (N=10)

Table 2

Site	Species ID	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)	N	Source
Vitânești	<i>Bos primigenius</i>	-20.9 ± 0.5	6.2 ± 0.4	11	Balasse et al. EJA 2013
Vitânești	<i>Cervus elaphus</i>	-20.7 ± 0.3	5.5 ± 0.3	13	Balasse et al. EJA 2013
Vitânești	<i>Capreolus capreolus</i>	-21.7 ± 0.8	6.5 ± 0.5	8	Balasse et al. EJA 2013
Vitânești	<i>Castor fiber</i>	-22.1 ± 0.4	7.8 ± 0.8	14	This study
Vitânești	<i>Equus ferus</i>	-21.4 ± 0.3	3.9 ± 0.3	5	Balasse et al. EJA 2013
Vitânești	<i>Bos taurus</i>	-19.6 ± 1.2	6.9 ± 0.6	6	This study
Vitânești	<i>Ovis aries</i>	-20.1 ± 0.6	7.0 ± 0.3	2	This study
Vitânești	<i>Sus scrofa</i> (humerus)	-21.0 ± 0.4	7.4 ± 1.0	11	Balasse et al. EJA 2013
Vitânești	<i>Sus s. domesticus</i> (humerus)	-20.0 ± 0.9	8.9 ± 0.5	10	This study
Vitânești	<i>Sus scrofa</i> (LW)	-21.1 ± 0.4	7.3 ± 0.7	10	This study
Vitânești	<i>Sus scrofa</i> (LD)	-21.2 ± 0.1	6.5 ± 0.8	5	This study
Vitânești	<i>Sus scrofa</i> (SD)	-20.6 ± 0.6	8.3 ± 0.5	26	This study
Vitânești	<i>Canis familiaris</i>	-20.3 ± 0.2	8.6 ± 0.6	5	This study
Vitânești	<i>Cyprinus carpio</i>	-24.7	7.9	1	This study
Vitânești	<i>Silurus glanis</i>	-20.9 ± 0.4	11.1 ± 0.6	3	This study
Bordușani	<i>Bos primigenius</i>	-20.4 ± 0.1	6.1 ± 0.3	3	Gillis et al. 2013
Bordușani	<i>Cervus elaphus</i>	-20.5 ± 0.2	5.8 ± 0.4	6	Balasse et al., in press
Bordușani	<i>Capreolus capreolus</i>	-22.1 ± 0.7	6.5 ± 0.7	3	Balasse et al., in press
Bordușani	<i>Castor fiber</i>	-21.6 ± 0.1	8.2 ± 0.6	4	Balasse et al., in press
Bordușani	<i>Equus ferus</i>	-21.2	3.8	1	Balasse et al., in press
Bordușani	<i>Bos taurus</i>	-18.5 ± 1.2	7.2 ± 0.6	17	Balasse et al., in press
Bordușani	<i>Ovis aries</i>	-18.7 ± 0.9	7.7 ± 0.6	7	Balasse et al., in press
Bordușani	<i>Sus scrofa</i>	-20.5 ± 0.4	7.9 ± 0.4	8	Balasse et al., in press
Bordușani	<i>Sus s. domesticus</i>	-20.5 ± 0.6	8.8 ± 1.1	13	Balasse et al., in press
Bordușani	<i>Canis familiaris</i>	-20.4 ± 0.7	10.1 ± 0.6	5	This study
Bordușani	<i>Cyprinus carpio</i>	-24.4 ± 0.9	7.7 ± 0.5	5	This study
Bordușani	<i>Esox lucius</i>	-22.9	9.8	1	This study
Bordușani	<i>Silurus glanis</i>	-21.0	11.1	1	This study
Hârșova	<i>Bos primigenius</i>	-20.0 ± 0.4	7.2 ± 0.6	4	Balasse et al., in press
Hârșova	<i>Cervus elaphus</i>	-20.7 ± 0.7	6.3 ± 0.6	7	Balasse et al., in press
Hârșova	<i>Capreolus capreolus</i>	-21.3 ± 0.2	7.0 ± 0.7	3	Balasse et al., in press
Hârșova	<i>Equus ferus</i>	-21.1	4.1	1	Balasse et al., in press
Hârșova	<i>Bos taurus</i>	-19.1 ± 1.6	7.2 ± 1.2	8	Balasse et al., in press
Hârșova	<i>Ovis aries</i>	-19.2 ± 0.6	7.1 ± 0.6	10	Balasse et al., in press
Hârșova	<i>Sus scrofa</i>	-20.7 ± 0.5	7.6 ± 0.8	14	Balasse et al., in press
Hârșova	<i>Sus s. domesticus</i>	-20.2 ± 0.6	8.5 ± 0.8	17	Balasse et al., in press
Hârșova	<i>Canis familiaris</i>	-20.7 ± 0.8	10.0 ± 0.3	5	This study
Hârșova	<i>Cyprinus carpio</i>	-24.6 ± 0.8	6.9 ± 1.0	4	This study
Hârșova	<i>Esox lucius</i>	-22.0	10.3	1	This study
Hârșova	<i>Sander lucioperca</i>	-23.9 ± 0.1	10.9 ± 0.4	2	This study

## Supplementary material 1

specimen ID	species ID	skeleton part	init wt (mg)	yield (mg/g)	% N	% C	C/N	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)
PBORD Cyprinus 1	<i>Cyprinus carpio</i>	dentary	420.8	17	13.4	36.6	3.2	-25.3	7.7
PBORD Cyprinus 2	<i>Cyprinus carpio</i>	dentary	347.9	69	14.9	40.2	3.2	-24.8	7.4
PBORD Cyprinus 3	<i>Cyprinus carpio</i>	dentary	537.9	32	13.5	36.8	3.2	-24.1	8.2
PBORD Cyprinus 4	<i>Cyprinus carpio</i>	dentary	520.9	41	14.8	40.2	3.2	-23.0	7.1
PBORD Cyprinus 5	<i>Cyprinus carpio</i>	pharyngeal bone	540.8	47	14.7	39.8	3.2	-24.7	8.3
HVA Cyprinus 1	<i>Cyprinus carpio</i>	pharyngeal bone	149.4	52	14.1	38.5	3.2	-24.2	6.6
HVA Cyprinus 2	<i>Cyprinus carpio</i>	pharyngeal bone	333.0	73	14.5	39.5	3.2	-25.5	6.5
HVA Cyprinus 3	<i>Cyprinus carpio</i>	pharyngeal bone	360.1	32	14.4	39.6	3.2	-24.9	6.0
HVA Cyprinus 4	<i>Cyprinus carpio</i>	pharyngeal bone	495.0	56	14.1	39.0	3.2	-23.7	8.3
VIT Cyprinus 1	<i>Cyprinus carpio</i>	caudal vertebrae	437.8	31	6.6	18.7	3.3	/	/
VIT Cyprinus 2	<i>Cyprinus carpio</i>	supracleithrum	382.8	44	14.3	39.1	3.2	-24.7	7.9
PBORD Esox 1	<i>Esox lucius</i>	dentary	357.5	/	/	/	/	/	/
PBORD Esox 2	<i>Esox lucius</i>	dentary	354.0	22	13.0	35.7	3.2	-22.9	9.8
HVA Esox 1	<i>Esox lucius</i>	cleithrum	439.1	37	13.7	37.6	3.2	-22.0	10.3
VIT Esox 1	<i>Esox lucius</i>	praecaual vertebrae	307.7	41	7.7	21.7	3.3	/	/
PBORD Sander 1	<i>Sander lucioperca</i>	articular	493.7	/	/	/	/	/	/
HVA Sander 1	<i>Sander lucioperca</i>	dentary	365.3	/	/	/	/	/	/
HVA Sander 2	<i>Sander lucioperca</i>	quadrate	396.4	46	14.1	38.1	3.1	-24.0	11.5
HVA Sander 3	<i>Sander lucioperca</i>	quadrate	288.9	20	11.5	31.3	3.2	-23.8	10.9
PBORD Silurus 1	<i>Silurus glanis</i>	pectoral fin ray	554.4	19	2.1	6.4	3.6	/	/
PBORD Silurus 2	<i>Silurus glanis</i>	pectoral fin ray	400.5	/	/	/	/	/	/
PBORD Silurus 3	<i>Silurus glanis</i>	ceratohyal	470.3	/	/	/	/	/	/
PBORD Silurus 4	<i>Silurus glanis</i>	pectoral fin ray	466.1	/	/	/	/	/	/
PBORD Silurus 5	<i>Silurus glanis</i>	pectoral fin ray	503.1	29	13.9	37.8	3.2	-21.0	11.1
HVA Silurus 1	<i>Silurus glanis</i>	pectoral fin ray	406.4	/	/	/	/	/	/
VIT Silurus 1	<i>Silurus glanis</i>	praecaual vertebrae	453.8	49	10.4	28.9	3.2	/	/
VIT Silurus 2	<i>Silurus glanis</i>	pectoral fin ray	419.7	47	13.3	37.1	3.2	-20.8	10.5
VIT Silurus 3	<i>Silurus glanis</i>	pectoral fin ray	434.0	44	13.6	37.0	3.2	-20.6	11.3
VIT Silurus 4	<i>Silurus glanis</i>	caudal vertebrae	413.6	54	13.5	36.8	3.2	-21.3	11.6

## Supplementary material 2

specimen ID	species ID	skeleton part	init wt (mg)	yield (mg/g)	% N	% C	C/N	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)	GMM
VIT Castor 1	<i>Castor fiber</i>	tibia L	335.3	104	14.7	40.2	3.2	-22.0	7.6	
VIT Castor 2	<i>Castor fiber</i>	tibia L	310.7	68	15.2	41.4	3.2	-22.8	6.7	
VIT Castor 3	<i>Castor fiber</i>	tibia L	304.0	111	15.5	41.8	3.1	-22.0	7.8	
VIT Castor 4	<i>Castor fiber</i>	tibia L	310.3	98	15.2	41.5	3.2	-22.1	7.8	
VIT Castor 5	<i>Castor fiber</i>	tibia L	309.0	107	14.7	40.1	3.2	-21.3	7.3	
VIT Castor 6	<i>Castor fiber</i>	tibia L	327.7	111	15.4	41.7	3.2	-22.1	7.3	
VIT Castor 7	<i>Castor fiber</i>	tibia L	310.1	97	15.7	42.2	3.1	-22.1	8.4	
VIT Castor 9	<i>Castor fiber</i>	tibia L	328.3	118	15.2	41.7	3.2	-22.2	8.7	
VIT Castor 11	<i>Castor fiber</i>	tibia L	302.4	102	15.8	43.6	3.2	-22.3	9.5	
VIT Castor 12	<i>Castor fiber</i>	tibia L	301.1	100	14.8	40.7	3.2	-21.5	7.3	
VIT Castor 13	<i>Castor fiber</i>	tibia L	313.6	124	15.7	43.1	3.2	-21.8	8.0	
VIT Castor 14	<i>Castor fiber</i>	tibia L	313.0	54	15.0	41.2	3.2	-22.1	7.0	
VIT Castor 15	<i>Castor fiber</i>	tibia L	310.3	95	15.0	41.0	3.2	-22.1	8.9	
VIT Castor 16	<i>Castor fiber</i>	tibia L	302.5	112	15.0	41.2	3.2	-22.8	6.6	
VIT Sus 1	<i>Sus s. domesticus</i>	humerus D	304.1	171	14.1	38.6	3.2	-18.7	8.2	
VIT Sus 2	<i>Sus s. domesticus</i>	humerus D	314.5	152	13.8	37.9	3.2	-19.5	8.4	
VIT Sus 3	<i>Sus s. domesticus</i>	humerus D	303.5	147	14.3	39.3	3.2	-19.6	9.4	
VIT Sus 4	<i>Sus s. domesticus</i>	humerus D	339.8	114	13.9	38.3	3.2	-18.6	8.9	
VIT Sus 5	<i>Sus s. domesticus</i>	humerus D	348.7	/	/	/	/	/	/	
VIT Sus 6	<i>Sus s. domesticus</i>	humerus D	305.2	53	14.5	39.4	3.2	-20.3	9.3	
VIT Sus 7	<i>Sus s. domesticus</i>	humerus D	311.8	63	14.1	38.4	3.2	-20.7	9.5	
VIT Sus 8	<i>Sus s. domesticus</i>	humerus D	302.6	88	14.5	39.3	3.2	-20.4	8.7	
VIT Sus 9	<i>Sus s. domesticus</i>	humerus D	321.4	28	12.8	35.0	3.2	-20.5	8.5	
VIT Sus 10	<i>Sus s. domesticus</i>	humerus D	390.8	/	/	/	/	/	/	
VIT Sus 11	<i>Sus s. domesticus</i>	humerus D	309.0	129	14.6	39.8	3.2	-21.1	9.2	
VIT Sus 12	<i>Sus s. domesticus</i>	humerus D	306.7	108	14.7	39.9	3.2	-20.6	8.5	
VIT Sus 13	<i>Sus s. domesticus</i>	humerus D	396.1	/	/	/	/	/	/	
VIT Sus morpho 01	<i>Sus scrofa</i>	hemimandible	357.2	130	14.4	39.8	3.2	-20.4	8.7	SD
VIT Sus morpho 02	<i>Sus scrofa</i>	hemimandible	325.4	127	15.1	40.8	3.2	-20.9	8.4	SD

VIT Sus morpho 03	<i>Sus scrofa</i>	hemimandible	380.0	48	13.8	38.0	3.2	-21.4	7.1	LD
VIT Sus morpho 04	<i>Sus scrofa</i>	hemimandible	364.9	55	13.5	37.5	3.2	-20.5	8.3	SD
VIT Sus morpho 06	<i>Sus scrofa</i>	hemimandible	352.6	65	13.9	38.4	3.2	-20.9	8.6	SD
VIT Sus morpho 07	<i>Sus scrofa</i>	hemimandible	360.1	64	13.9	38.4	3.2	-20.6	6.7	LW
VIT Sus morpho 08	<i>Sus scrofa</i>	hemimandible	340.1	142	15.3	41.9	3.2	-20.4	8.4	SD
VIT Sus morpho 09	<i>Sus scrofa</i>	hemimandible	341.3	124	17.3	47.1	3.2	-20.5	7.9	SD
VIT Sus morpho 10	<i>Sus scrofa</i>	hemimandible	361.3	42	13.1	36.5	3.2	-21.3	6.6	LD
VIT Sus morpho 11	<i>Sus scrofa</i>	hemimandible	351.8	110	14.3	39.1	3.2	-22.1	8.9	SD
VIT Sus morpho 12	<i>Sus scrofa</i>	hemimandible	345.7	106	13.4	38.2	3.3	-21.0	5.3	LD
VIT Sus morpho 13	<i>Sus scrofa</i>	hemimandible	338.4	112	15.2	41.9	3.2	-20.6	8.5	SD
VIT Sus morpho 15	<i>Sus scrofa</i>	hemimandible	340.8	134	15.3	42.0	3.2	-21.0	7.6	LW
VIT Sus morpho 16	<i>Sus scrofa</i>	hemimandible	365.6	94	13.7	37.8	3.2	-20.8	7.4	LW
VIT Sus morpho 17	<i>Sus scrofa</i>	hemimandible	312.4	112	15.1	41.1	3.2	-21.1	8.0	SD
VIT Sus morpho 18	<i>Sus scrofa</i>	hemimandible	308.7	111	15.3	41.7	3.2	-21.3	9.1	SD
VIT Sus morpho 19	<i>Sus scrofa</i>	hemimandible	325.7	141	15.0	41.5	3.2	-21.6	6.3	LW
VIT Sus morpho 20	<i>Sus scrofa</i>	hemimandible	323.2	152	15.0	40.9	3.2	-21.5	7.3	LW
VIT Sus morpho 21	<i>Sus scrofa</i>	hemimandible	312.6	114	14.5	39.9	3.2	-19.8	8.7	SD
VIT Sus morpho 22	<i>Sus scrofa</i>	hemimandible	312.8	74	14.3	39.2	3.2	-20.0	8.3	SD
VIT Sus morpho 23	<i>Sus scrofa</i>	hemimandible	359.4	148	14.6	40.2	3.2	-21.3	7.9	LW
VIT Sus morpho 24	<i>Sus scrofa</i>	hemimandible	330.6	125	14.6	39.7	3.2	-20.5	7.4	SD
VIT Sus morpho 25	<i>Sus scrofa</i>	hemimandible	302.1	105	14.9	40.8	3.2	-21.5	9.4	SD
VIT Sus morpho 26	<i>Sus scrofa</i>	hemimandible	328.8	120	14.8	40.6	3.2	-20.5	8.2	SD
VIT Sus morpho 27	<i>Sus scrofa</i>	hemimandible	304.2	115	14.8	40.4	3.2	-20.9	8.7	LW
VIT Sus morpho 28	<i>Sus scrofa</i>	hemimandible	318.1	111	15.1	41.3	3.2	-21.3	7.3	LD
VIT Sus morpho 29	<i>Sus scrofa</i>	hemimandible	326.0	83	14.9	40.7	3.2	-20.0	7.5	SD
VIT Sus morpho 30	<i>Sus scrofa</i>	hemimandible	316.0	32	14.7	39.4	3.1	-21.6	6.9	LW
VIT Sus morpho 31	<i>Sus scrofa</i>	hemimandible	324.9	136	15.2	41.5	3.2	-19.9	8.6	SD
VIT Sus morpho 32	<i>Sus scrofa</i>	hemimandible	319.6	129	14.5	39.8	3.2	-20.5	8.2	SD
VIT Sus morpho 33	<i>Sus scrofa</i>	hemimandible	302.3	90	14.3	39.3	3.2	-21.5	8.0	SD
VIT Sus morpho 34	<i>Sus scrofa</i>	hemimandible	315.9	135	15.7	43.1	3.2	-20.9	7.2	LW
VIT Sus morpho 35	<i>Sus scrofa</i>	hemimandible	309.3	131	14.3	39.6	3.2	-22.0	7.4	SD
VIT Sus morpho 36	<i>Sus scrofa</i>	hemimandible	300.3	130	14.6	40.2	3.2	-20.5	9.0	SD

VIT Sus morpho 37	<i>Sus scrofa</i>	hemimandible	310.4	103	14.5	39.8	3.2	-20.2	8.7	SD
VIT Sus morpho 38	<i>Sus scrofa</i>	hemimandible	322.4	102	14.3	39.6	3.2	-20.3	7.7	SD
VIT Sus morpho 39	<i>Sus scrofa</i>	hemimandible	331.1	125	14.9	41.1	3.2	-20.1	8.0	SD
VIT Sus morpho 40	<i>Sus scrofa</i>	hemimandible	306.1	100	15.2	41.5	3.2	-20.2	8.6	SD
VIT Sus morpho 41	<i>Sus scrofa</i>	hemimandible	320.3	119	14.5	40.0	3.2	-21.2	6.2	LD
VIT Sus morpho 43	<i>Sus scrofa</i>	hemimandible	309.1	100	14.0	38.5	3.2	-20.4	8.3	SD
VIT Sus morpho 44	<i>Sus scrofa</i>	hemimandible	306.3	128	14.4	39.6	3.2	-21.3	7.2	LW
VIT Canis 1	<i>Canis familiaris</i>	hemimandible R	292.7	30	14.8	41.0	3.2	-20.2	8.3	
VIT Canis 2	<i>Canis familiaris</i>	hemimandible R	291.7	105	15.1	41.6	3.2	-20.2	8.9	
VIT Canis 3	<i>Canis familiaris</i>	hemimandible R	296.6	111	14.8	41.3	3.3	-20.2	7.8	
VIT Canis 4	<i>Canis familiaris</i>	hemimandible R	294.7	72	14.9	41.2	3.2	-20.2	8.6	
VIT Canis 5	<i>Canis familiaris</i>	hemimandible L	296.4	103	15.1	41.6	3.2	-20.5	9.3	
VIT Ovis1	<i>Ovis aries</i>	hemimandible L	317.7	109	14.8	40.9	3.2	-20.5	7.2	
VIT Ovis6	<i>Ovis aries</i>	hemimandible L	307.2	57	14.2	39.5	3.2	-19.7	6.8	
VIT Bt 1	<i>Bos taurus</i>	hemimandible L	317.7	89	14.3	39.8	3.2	-20.5	7.2	
VIT Bt 2	<i>Bos taurus</i>	hemimandible L	307.5	54	14.5	39.6	3.2	-17.2	7.8	
VIT Bt 3	<i>Bos taurus</i>	hemimandible L	319.8	99	15.4	41.8	3.2	-19.6	6.3	
VIT Bt 4	<i>Bos taurus</i>	hemimandible R	321.3	110	15.2	41.6	3.2	-20.1	6.7	
VIT Bt 5	<i>Bos taurus</i>	hemimandible L	312.8	97	14.9	41.3	3.2	-20.1	7.2	
VIT Bt 6	<i>Bos taurus</i>	hemimandible R	319	18	12.6	34.4	3.2	-20.3	6.1	
PBORD Canis1	<i>Canis familiaris</i>	hemimandible L	298.1	114	15.3	42.3	3.2	-20.8	10.4	
PBORD Canis2	<i>Canis familiaris</i>	hemimandible L	294.9	135	15.4	42.6	3.2	-20.2	9.5	
PBORD Canis3	<i>Canis familiaris</i>	hemimandible L	301.6	33	14.4	39.8	3.2	-21.0	10.1	
PBORD Canis4	<i>Canis familiaris</i>	hemimandible L	295.0	77	14.5	40.0	3.2	-19.3	9.4	
PBORD Canis5	<i>Canis familiaris</i>	hemimandible L	305.1	46	15.3	41.7	3.2	-20.6	11.0	
HVA Canis 1	<i>Canis familiaris</i>	hemimandible L	302.3	64	15.4	42.2	3.2	-20.0	10.1	
HVA Canis 2	<i>Canis familiaris</i>	hemimandible L	302.7	110	15.2	41.7	3.2	-22.0	9.5	
HVA Canis 3	<i>Canis familiaris</i>	hemimandible L	306.8	110	15.7	43.0	3.2	-20.0	10.3	
HVA Canis 4	<i>Canis familiaris</i>	hemimandible R	298.9	104	15.5	42.7	3.2	-21.2	10.0	
HVA Canis 5	<i>Canis familiaris</i>	hemimandible R	307.4	77	15.2	42.0	3.2	-20.5	10.0	



## Supplementary material 3

Humerus	specimen	SD	Bd	BT	Dd	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$
small	VIT Sus 1	14.5	37.0	27.5	37	-18.7	8.2
small	VIT Sus 2	/	37.5	27	37.5	-19.5	8.4
small	VIT Sus 3	14.3	34.0	24.5	34.5	-19.6	9.4
small	VIT Sus 4	/	/	/	/	-18.6	8.9
small	VIT Sus 6	/	36.5	27.1	34.8	-20.3	9.3
small	VIT Sus 7	/	36.7	28.6	/	-20.7	9.5
small	VIT Sus 8	/	39.5	28.2	/	-20.4	8.7
small	VIT Sus 9	14	36.0	/	32.5	-20.5	8.5
small	VIT Sus 11	/	36.8	26.7	37.6	-21.1	9.2
small	VIT Sus 12	/	36.0	25.3	34.9	-20.6	8.5
large	VIT Sus 14	23	55.0	40.5	53	-21.4	5.5
large	VIT Sus 15	22	51.0	39.0	51	-20.8	7.4
large	VIT Sus 17	/	59.9	42.6	56.1	-21.1	6.9
large	VIT Sus 18	21.1	50.0	37.9	49.9	-20.8	7.5
large	VIT Sus 19	/	51.2	37.3	53	-20.6	6.4
large	VIT Sus 20	21.2	53.5	38.0	49	-20.6	7.2
large	VIT Sus 21	22.5	53.5	39.0	52.3	-21.9	9.0
large	VIT Sus 22	/	53.0	40.0	50	-20.9	7.0
large	VIT Sus 23	/	50.0	36.5	52	-21.1	9.1
large	VIT Sus 24	/	55.0	42.5	53.5	-21.0	7.5
large	VIT Sus 25	/	51.0	37.0	/	-20.6	8.0

Figure 1  
[Click here to download high resolution image](#)

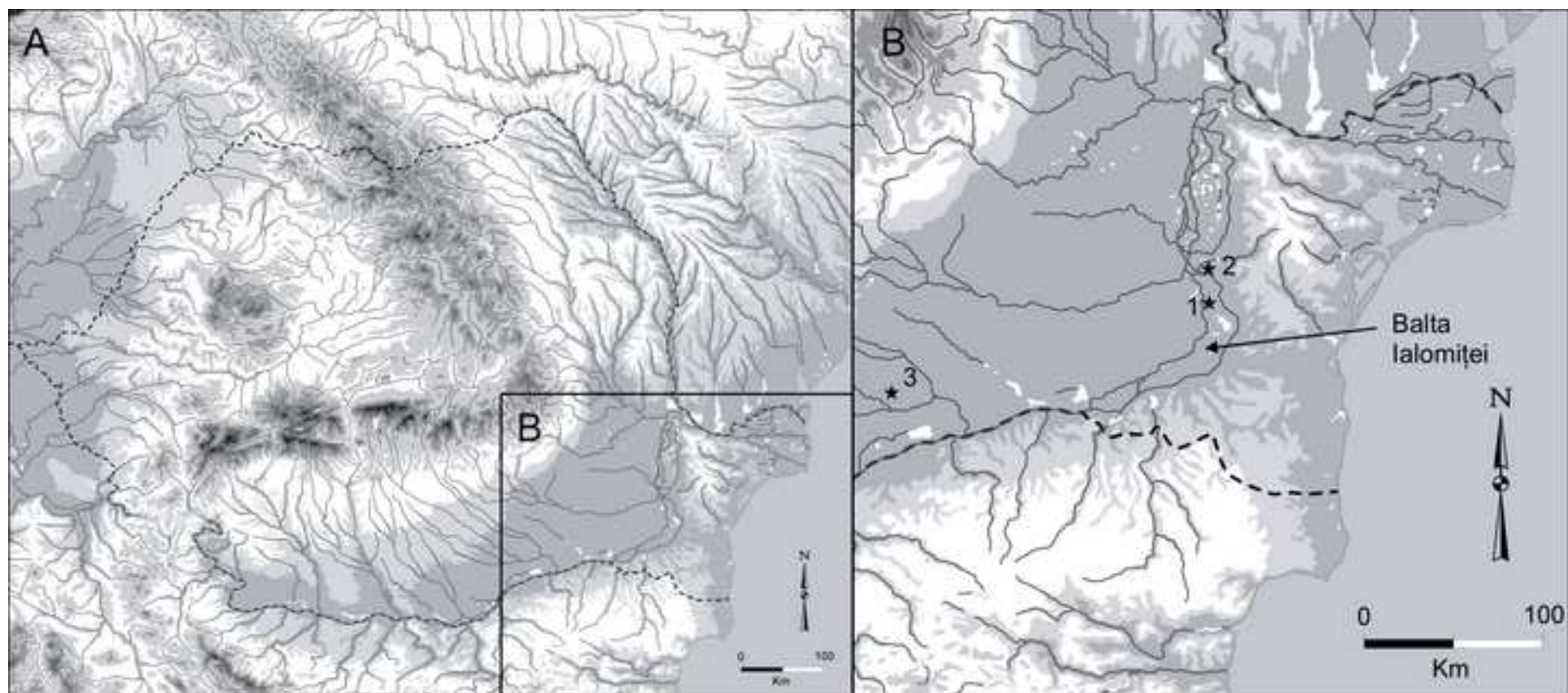


Figure 2

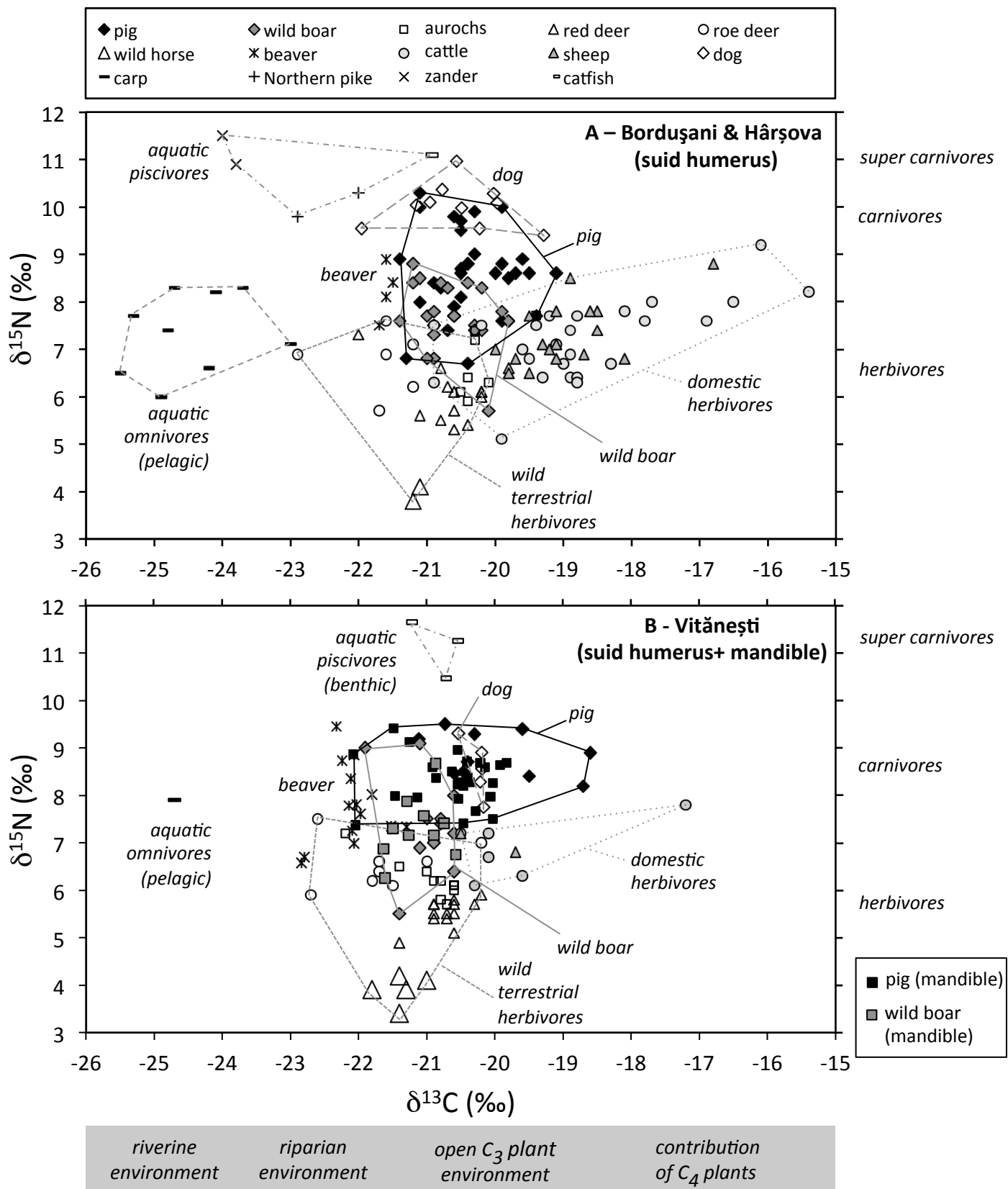
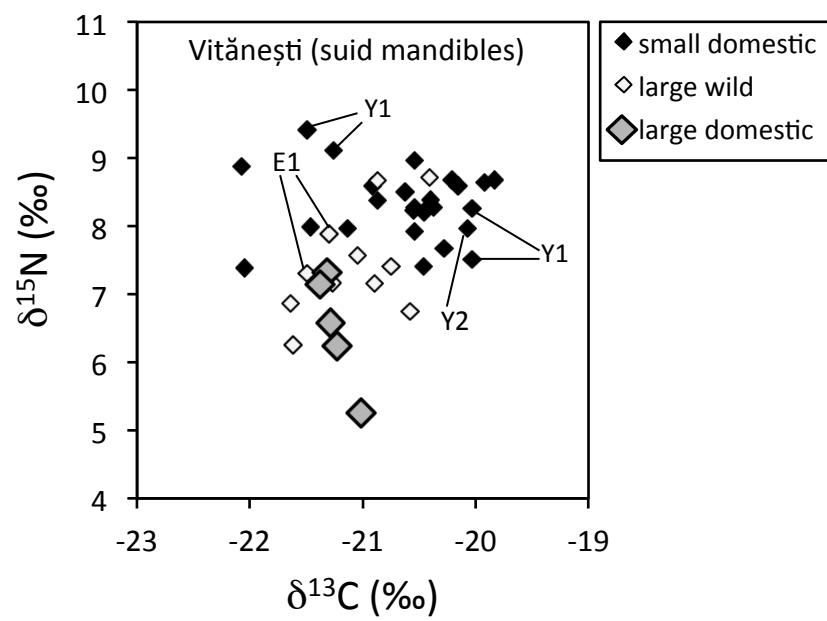


Figure 3





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