INTERPRETING ANCIENT CROP AND ANIMAL MANAGEMENT STRATEGIES AT NEOLITHIC KOUPHOVOUNO, SOUTHERN GREECE: RESULTS OF INTEGRATING CROP AND ANIMAL STABLE ISOTOPES AND DENTAL MICRO- AND MESOWEAR*

Introduction

In this case study, we analyze stable isotope signatures of ancient charred plant and faunal bone remains from Middle-Late Neolithic Kouphovouno in order to investigate the crop cultivation and animal husbandry practices employed by the early farmers. Previous work on the nature of Neolithic agriculture has shed light on the symbiotic relationship in which plant and animal husbandry strategies may function. For example, the by-product of crop cultivation can be used as fodder to feed the animals and the by-product of the animals, dung, can be used to fertilize the soils in which the crops are grown.[1] But just how this inter-dependent strategy was maintained remains to be investigated on a case-by-case basis. Our aim is to use isotopic evidence to address questions of how intensively the cereal and pulse crops were managed, what the diets of the livestock were and how the farmers at Kouphovouno made use of the surrounding landscape for the grazing of animals. These results are interpreted in light of dental micro- and mesowear analysis carried out on the same faunal assemblage. Together, the two strands of information enable us to make inferences about which foods the animals may and which they may not have consumed.[2]

Stable isotope analysis

Stable isotope analysis is based on the principle that all organisms in the ecosystem are made up of tissues - hair, bones, muscles, etc. - which get constantly remodeled during the life times of those organisms. This means that old atoms and molecules which make up the tissues get constantly replaced by new atoms and molecules which come directly from the food that the organisms consume. Food has distinctive chemical signatures depending on what type of environment it is derived from and what biochemical processes it has undergone during digestion. These signatures then get locked into the tissue chemistry of the organisms and when measured, enable us to make inferences about the nature of the organisms' diet.

The chemistry that we are interested in here consists of the ratios of the heavier and lighter stable isotopes of carbon and nitrogen (carbon-13/carbon-12 and nitrogen-15/nitrogen-14). These values, expressed as $\delta^{13}C$ and $\delta^{15}N$, are measured in comparison to internationally set standards in units of parts per mille, ‰.

Plants which grow in soils with a high organic content (such as fields that receive manure) have higher $\delta^{15}N$ than plants which grow in ^{15}N-depleted soils. This is because the organic substrate loses the lighter ^{14}N in the form of ammonia through volatilization, leaving behind a

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1 A. BOGAARD, " 'Garden agriculture' and the nature of early farming in Europe and the Near East", World Archaeology 37 (2005) 177-196.

2 See P. VAIGLOVA, A. BOGAARD, M. COLLINS, W. CAVANAGH, C. MEE, J. RENARD, A. LAMB, A. GARDEISEN and R. FRASER, "An integrated stable isotope study of plants and animals from Kouphovouno, southern Greece: a new look at Neolithic farming," *Journal of Archaeological Science* 42 (2014) 201-215 for a detailed discussion of the isotope study, and F. RIVALS, A. GARDEISEN and J. CANTUEL, "Domestic and wild ungulate dietary traits at Kouphovouno (Sparta, Greece): implications for livestock management and palaeoenvironment in the Neolithic," *Journal of Archaeological Science* 38 (2011) 528-537 for full publication of the dental wear study.

higher concentration of the heavier ^{15}N.[3] Crops cultivated in wetter soils have more negative $\delta^{13}C$ values than crops grown in more arid conditions due to the differing degrees to which the lighter ^{12}C is replenished during photosynthesis.[4] Animal tissues reflect the isotopic composition of their dietary N plus an enrichment factor. The value of this factor is continually debated but generally accepted to be around 3-5‰.[5] In this way, the higher on the food chain that an animal is situated, the higher its $\delta^{15}N$ relative to organisms below it.[6]

Dental wear analysis

Tooth mesowear analysis, first introduced by Fortelius and Solounias[7], is a method of categorizing the gross dental wear of ungulate molars by evaluating the relief and sharpness of cusp apices in ways that are correlated with the relative amounts of attritive and abrasive dental wear. Mesowear is scored macroscopically from the buccal side of upper molars, preferably the paracone of M2.[8] Among taxa with the appropriate masticatory apparatus, a diet with low levels of abrasion maintains sharpened apices on the buccal cusps as the tooth wears. In contrast, high levels of abrasion, associated with a diet of siliceous grass and/or a high rate of soil or dust particle ingestion, results in more rounded and blunted buccal cusp apices. Cusp sharpness is sensitive to ontogenetic age among young individuals and among dentally senescent individuals. However, for intermediate age groups, which typically include the majority of individuals in a fossil collection, mesowear was found to be less sensitive to age and more strongly related to diet.[9] Tooth microwear analysis corresponds to the observation of microscopic scars left by food items on the surfaces of the teeth.

3 R.A. FRASER, A. BOGAARD, T. HEATON, M. CHARLES, G. JONES, B.T. CHRISTENSEN, P. HALSTEAD, I. MERBACH, P.R. POULTON, D. PPARKES and A.K. STYRING, "Manuring and stable nitrogen isotope ratios in cereals and pulses: towards a new archaeobotanical approach to the inference of land use and dietary practices," *Journal of Archaeological Science* 38 (2011) 2790-2804; A. BOGAARD, T.H.E. HEATON, P. POULTON and I. MERBACH, "The impact of manuring on nitrogen isotope ratios in cereals: archaeological implications for reconstruction of diet and crop management practices," *Journal of Archaeological Science* 34 (2007) 335-343.

4 G.D. FARQUHAR, M.H. O'LEARY and J.A. BERRY, "On the Relationship between Carbon Isotope Discrimination and the Intercellular Carbon Dioxide Concentration in Leaves," *Australian Journal of Plant Physiology* 9 (1982) 121-137; G.D. FARQUHAR, J.R. EHLERINGER and K.T. HUBICK, "Carbon Isotope Discrimination and Photosynthesis," *Annual Review of Plant Physiology and Molecular Biology* 40 (1989) 503-537; M. WALLACE, G. JONES, M. CHARLES, R. FRASER, P. HALSTEAD, T. HEATON and A. BOGAARD, "Stable carbon isotope analysis as a direct means of inferring crop water status," *World Archaeology* 45.3 (2013) 388-409.

5 S.H. AMBROSE, "Controlled diet and climate experiments on nitrogen isotope ratios of rats," in S.H. AMBROSE and A.M. KATZENBERG (eds), *Biogeochemical Approaches to Paleodietary Analysis* (2000) 243-259; R.E.M. HEDGES and L. M. REYNARD, "Nitrogen isotopes and the trophic level of humans in archaeology," *Journal of Archaeological Science* 34 (2007) 1240-1251; D.G. DRUCKER. and H. BOCHERENS, "Carbon and nitrogen stable isotopes as tracers of change in diet breadth during Middle and Upper Palaeolithic in Europe," *International Journal of Osteoarchaeology* 14.3-4 (2004) 162-177.

6 For a more comprehensive review of the technique refer to J.A. LEE-THORP, "On Isotopes and old bones," *Archaeometry* 50 (2008) 925-950, H.P. SCHWARCZ and M.J. SCHOENINGER, "Stable isotope analyses in human nutritional ecology," *Yearbook of Physical Anthropology* 34 (1991) 283-321, T.C. O'CONNELL and R.E.M. HEDGES, "Investigations Into the Effect of Diet on Modern Human Hair Isotopic Values," *American Journal of Physical Anthropology* 108 (1999) 409-425 and M.J. SCHOENINGER and K. MOORE, "Stable bone isotope studies in archaeology," *Journal of World Prehistory* 6 (1992) 247-296.

7 M. FORTELIUS AND N. SOLOUNIAS, "Functional characterization of ungulate molars using the abrasion-attrition wear gradient: a new method for reconstructing paleodiets," *American Museum Novitates* 3301 (2000) 1-36.

8 *Supra* n. 7.

9 F. RIVALS, M.C. MIHLBACHLER and N. SOLOUNIAS, "Effect of ontogenetic-age distribution in fossil samples on the interpretation of ungulate paleodiets using the mesowear method," *Journal of Vertebrate Paleontology* 27 (2007) 763-767.

Study site

Kouphovouno is located in the Laconia region of the Peloponnesian peninsula in southern Greece, 3km southwest of Sparta (see Pl. LXXXIa). The time-period of our interest is the Middle Neolithic (c. 5950 - 5450 cal BC) to Late Neolithic (c. 5450 - 4500 cal BC) (following the chronology of southern Greece). Many of the samples chosen for this analysis were AMS radiocarbon dated and place the group of samples into a narrower window between 5800 - 5000 cal BC.[10] The onset of the Late Neolithic brought changes that are reflected in the nature of the architectural features and material remains. The extent of the site remained the same, i.e. the village did not seem to have changed in size, but the structures became more ephemeral, the pottery assemblage became less homogenous (now consisting of coarse ware sherds and more numerous storage vessels) and archaeozoological and archaeobotanical remains became sparser (this is not a result of the excavation/sampling strategy). Given these changes, it is our aim to consider potential chronological shifts in agricultural management strategies. Unfortunately, the Late Neolithic is not very well represented in the present dataset. Out of all the animals and crops analyzed, the only species where chronological comparisons can be made are the sheep and goats.[11]

A key characteristic of the environment surrounding Kouphovouno is that it was well drained.[12] The river Eurotas was located just 2.5km east of the site, and a stream originating in the westerly alluvial fans borders the northern edge of the tell. Agricultural fields may have been established either in floodplain surrounding the site, on the alluvial fans lying 300m to the west of the site or on (unoccupied) parts of the tell site itself.[13] Livestock may have been allowed to graze in the floodplain, in the hills rising up above the basin to the southeast or on the nearby Taygetos mountain range.

Materials and methods

In this study, we analyzed 12 samples of free-threshing wheat grain (*Tricitum aestivum* L./*Triticum durum* Desf.), 7 samples of hulled barley grain (*Hordeum vulgare* L.), 7 samples of common pea (*Pisum sativum* L.), and 1 sample of lentil (*Lens culinaris* Medik.). There was enough lentil sample to get only one carbon measurement and no nitrogen measurement. Animals of both the wild and domestic variety were targeted and include 16 samples of domestic cattle (*Bos taurus* L.), 7 samples of dog (*Canis lupus familiaris* L.), 14 samples of domestic sheep (*Ovis aries* L.), 7 samples of domestic goat (*Capra hircus* L.), 25 samples of domestic pig (*Sus scrofa domesticus* E.), 2 samples of wild boar (*Sus scrofa scrofa* L.), 2 samples of hare (*Lepus europaeus* P.), 1 sample of bear (*Ursus arctos* L.) and 1 sample of wild goat (*Capra aegagrus* E./*Capra ibex* L.). The samples were obtained from areas B, C, G, and H. Sheep and goat bones were differentiated using ZooMS analysis by Matthew Collins at the University of York.[14] To correct for the c.+1‰ "charring effect" observed in experimental studies,[15] 1‰ was subtracted from all δ^{15}N plant measurements.

10 C. MEE, W. CAVANAGH and J. RENARD, "The Middle-Late Neolithic transition at Kouphovouno" (Paper submitted to the *BSA*).

11 See W. CAVANAGH, C. MEE and J. RENARD, "'Sparta before Sparta': Report on the Intensive Survey at Kouphovouno 1999-2000," *BSA* 99 (2004) 49-128, W. CAVANAGH, C. MEE and J. RENARD, "Excavations at Kouphovouno, Laconia: Results from the 2001 and 2002 Seasons," *BSA* 102 (2007) 11-101, and a forthcoming monograph for results of the excavation and survey undertaken between 1999 and 2006.

12 E. FOUACHE, C. COSANDEY, J. RENARD, M. RIBIÈRE and L. CEZ, "Contexte géomorphologique du bassin de Sparte et ressources en eau du site néolithique de Kouphovouno (Péloponnèse, Grèce)," *BCH* 131 (2007) 805-19; P. JAMES and X. KOUSOULAKOU in CAVANAGH 2004 (*supra* n. 11).

13 Peter James, pers. comm.

14 For a description of the technique refer to M. BUCKLEY, S. WHITCHER KANSA, S. HOWARD, S. CAMPBELL, J. THOMAS-OATES and M. COLLINS, "Distinguishing between archaeological sheep and goat bones using a single collagen peptide," *Journal of Archaeological Science* 37 (2010) 13-20.

15 R.A. FRASER, A. BOGAARD, M. CHARLES, A.K. STYRING, M. WALLACE, G. JONES, P. DITCHFIELD and T.H.E. HEATON, "Assessing natural variation and the effects of charring, burial and pre-treatment on the stable carbon and nitrogen isotope values of archaeobotanical cereals and pulses," *Journal of Archaeological Science* 30 (2013) 1-13.

Collagen was extracted from the animal bones using a modified Longin protocol.[16] Plant measurements were taken on bulk samples of homogenized grain and seeds (containing between 3 and 25 items of grain/seed fragments), which underwent acid-base-acid washing pre-treatment.[17] Measurement of the $\delta^{13}C$ and $\delta^{15}N$ of all the samples was performed using a mass spectrometer at the NERC Isotope Geosciences Laboratory at the British Geological Survey.[18]

Microwear features of dental enamel were examined following the protocol developed by Solounias and Semprebon[19] and Semprebon *et al.*[20] Microwear scars (i.e., elongated scratches and rounded pits) were quantified on a taphonomically unaltered enamel region on the enamel of the molars. Scratch and pit densities obtained on the archaeological samples were compared to a database constructed from extant ungulate taxa.[21] Using this information, it was possible to discriminate between the dietary categories of browser (i.e., eating woody and non-woody dicotyledonous plants) versus grazer (i.e., eating grass) using average scratch and pit densities.

Results

The plant and animal isotope results are plotted in Pl. LXXXIb. All the plants have lower $\delta^{13}C$ compared to the animals, which can be explained by carbon enrichment between diet (i.e. plant foods) and whole body isotope composition of the consumers.[22] The plants cluster more tightly by species and there is almost no overlap between the plant species, except for two barley samples which lie in the pea region. The free-threshing wheat samples have considerably higher $\delta^{15}N$ than the barley samples. The peas show a noticeable enrichment over their source of nitrogen – AIR, which is defined as 0‰. The faunal results do not separate out by species as distinctly as the plant results, but there are still statistically significant differences between some of the faunal species clusters. The dog and pig values are more enriched over the rest of the animals in terms of their $\delta^{15}N$, which reflects their more omnivorous dietary adaptation. The diets of the sheep and goats vary isotopically, and this difference shifts between the Middle and Late Neolithic (see Pl. LXXXIV discussed later).

In this paper, we focus on four trends in the stable isotope results: 1) the distinct $\delta^{15}N$ signatures of the free-threshing wheat and the barley, 2) the elevated $\delta^{15}N$ of the peas, 3) the projected values of the crop chaff and 4) diachronic changes in the sheep and goat diets.

Cereals and their growing conditions

Pl. LXXXIb shows that there is a c. 3‰ difference between the average $\delta^{15}N$ of the two cereals (mean free-threshing wheat $\delta^{15}N = 5.9 \pm 0.7$‰; mean hulled barley $\delta^{15}N = 2.7 \pm 1.2$‰). This indicates that the wheat was grown in soils that were markedly more enriched in ^{15}N than the soils in which the barley grew. There are several possible reasons for this contrast. ^{15}N-enrichment in soils can be caused by climatic factors such as aridity, soil salinity and sea-spray effect,[23] but these factors are likely to have affected the landscape around Kouphovouno

16 M.P. RICHARDS and R.E.M. HEDGES, "Stable Isotope Evidence for Similarities in the Types of Marine Foods Used by Late Mesolithic Humans at Sites Along the Atlantic Coast of Europe," *Journal of Archaeological Science* 26 (1999) 717-722.

17 FRASER *et al.* (*supra* n. 3).

18 For a more complete description of the techniques, information about the lab protocols used and measures used to assess the reliability of the data, please refer to VAIGLOVA *et al.* (*supra* n. 2).

19 N. SOLOUNIAS and G. SEMPREBON, "Advances in the reconstruction of ungulate ecomorphology with application to early fossil equids," *American Museum Novitates* 3366 (2002) 1-49.

20 G.M. SEMPREBON, L.R. GODFREY, N. SOLOUNIAS, M.R., SUTHERLAND and W.L. JUNGERS, "Can low-magnification stereomicroscopy reveal diet?" *Journal of Human Evolution* 47 (2004) 115-144.

21 SOLOUNIAS and SEMPREBON (*supra* n. 19).

22 M.J. DENIRO and S. EPSTEIN, "Influence of diet on the distribution of carbon isotopes in animals," *Geochimica et Cosmochimica* 42 (1978) 495-506.

23 T.H.E. HEATON, "The 15N/14N ratios of plants in South Africa and Namibia: relationship to climate and coastal/saline environments," *Oecologia* 74 (1987) 236-246; M.S. LOPES and J. L. ARAUS, "Nitrogen source and water regime effects on durum wheat photosynthesis and stable carbon and nitrogen isotope composition," *Physiologia Plantarum* 126 (2006) 435-445; S.H. AMBROSE, "Effects of Diet, Climate and

because the surrounding soils were well-drained and the site was not situated next to the coast.[24] Anthropogenic causes of soil enrichment involve the addition of organic substances to the soil, in the form of farmyard manure and/or midden material.[25] In experimental studies on the effects of manuring on crop stable isotope ratios, wheats and barleys which were intensively manured had values of around 6‰ or higher, while crops which were manured at lower rates (representing either long-term cultivation with low-level manuring, residual effects after a period of intensive manuring or early years of a new intensive cultivation regime) had values between c. 2.5-6‰; crops grown over a long period of time without manuring had values below 2.5‰.[26] Comparatively, the measurements of Neolithic Kouphovouno cereals ranged from intensively manured to unmanured, with free-threshing wheat exhibiting a distinctly higher manuring signature than hulled barley. This suggests that the Kouphovouno farmers: 1) made a distinction between the two different cereals and did not grow them in one field as maslin (mixed crops) like modern farmers do on the island of Amorgos, for example,[27] and 2) they treated the two cereals at different levels of intensity and did not grow them in rotation on the same piece of land.

Pulses and their growing conditions

The findings show that peas were also being manured intensively. Peas are nitrogen fixers – types of plants that take most of their N straight from the atmosphere,[28] and thus have $\delta^{15}N$ close to 0‰, which is the value of AIR. Based on experimental findings, Fraser *et al.*[29] argue that small amounts of manure cause $\delta^{15}N$ enrichment in pulses which is almost indistinguishable from measurement error, and that when we do see noticeable enrichment, it is likely a result of intensive manuring. Pl. LXXXIb shows that the peas cultivated in Kouphovouno show such a noticeable enrichment over AIR (mean $\delta^{15}N = 1.3 \pm 0.3$‰). A similar example of a small-scale farming situation where pulses are significantly enriched in $\delta^{15}N$ is the modern farming collection in Evvia, Greece.[30]

Crop water status

One of the phenomena that isotopes can help us understand is the watering status of crops. To do this, $\delta^{13}C$ values have to be converted into $\Delta^{13}C$ values; the conversion accounts for the changes in $\delta^{13}C$ of atmospheric CO_2 through time and thus allows us to compare carbon isotopic values across time.[31]

Physiology on Nitrogen Isotope Abundances in Terrestrial Foodwebs," *Journal of Archaeological Science* 18 (1991) 293-317; R.A. VIRGINIA and C.C. DELWICHE, "Natural 15N Abundance of Presumed N2-Fixing and Non-N2-Fixing Plants from Selected Ecosystems," *Oecologia* 54 (1982) 317-325.

24 FOUACHE *et al.* (*supra* n. 12).

25 BOGAARD *et al.* (*supra* n. 3); FRASER *et al.* (*supra* n. 3); R. BOL, N.J. OSTLE, J.J. PETZKE, C. CHENU and J. BALESDENT, "Amino acid ^{15}N in long-term bare fallow soils: influence of annual N fertilizer and manure applications," European Journal of Soil Science 59.4 (2008) 617-625; E.B.A. GUTTMAN, "Midden cultivation in prehistoric Britain: arable crops in gardens," *World Archaeology* 37 (2005) 224-239.

26 FRASER *et al.* (*supra* n. 3).

27 G. JONES and P. HALSTEAD, "Maslins, Mixtures and Monocrops: on the Interpretation of Archaeobotanical Crop Samples of Heterogeneous Composition," *Journal of Archaeological Science* 22 (1995) 103-114.

28 P. HÖGBERG, "Nitrogen-Fixation and Nutrient Relations in Savanna Woodland Trees (Tanzania)," *Journal of Applied Ecology* 23 (1986) 675-688; C.C. DELWICHE, P.J. ZINKE, C.M. JOHNSON and R.A. VIRGINIA, "Nitrogen isotope distribution as a presumptive indicator of nitrogen fixation," *Botanical Gazette* S140 (1979) 65-69.

29 FRASER *et al.* (*supra* n. 3).

30 FRASER *et al.* (*supra* n. 3).

31 M. WALLACE, G. JONES, M. CHARLES, R. FRASER, P. HALSTEAD, T. HEATON and A. BOGAARD, "Stable carbon isotope analysis as a direct means of inferring crop water status," *World Archaeology* 45.3 (2013) 388-409; FARQUHAR *et al.* 1982 (*supra* n. 4); FARQUHAR *et al.* 1989 (*supra* n. 4). Refer to VAIGLOVA *et al.* (*supra* n. 2) for how this conversion was done.

Pl. LXXXIIa shows the $\Delta^{13}C$ of the crop samples in relation to watering 'bands' established by Wallace *et al.*[32] based on crops grown under experimentally controlled watering conditions. The bands show the isotope ranges of "moderately watered" plants representing wheat, barley and peas, with the corresponding "poorly watered" plants lying below the indicated range and "well watered" ones lying above it. The data show that wheat and barley grown at Kouphovouno had similar water status, as they both fall into the moderately watered band. The peas and lentil, on the other hand, are situated in the well-watered region. Pulses have been found to be more sensitive to wetness conditions (i.e. when the conditions are drier, their $\Delta^{13}C$ looks more distinctively dry and when the conditions are wetter, their $\Delta^{13}C$ looks distinctively wet). Therefore, a significant enrichment in the $\Delta^{13}C$ of the pulses suggests that these crops were being artificially watered. The peas also exhibit higher variability in $\Delta^{13}C$ (also see $\delta^{13}C$ in Pl. LXXXIb), which resemble, isotopically, broad beans grown under less standardized, small-scale 'traditional farming' conditions in central Evvia, Greece.[33] It is likely that this variability reflects the practice of hand watering, as has been suggested for the Bronze Age/Early Iron Age site of Assiros Toumba.[34]

Question of fodder use

One of the advantages of measuring the stable isotopes of the actual archaeological remains of crops is that we can use the results to try to infer which plants/parts may have contributed to the animal diets and exclude those which did not.[35]

Dental micro- and mesowear analyses show that the diets of the Neolithic pigs in Kouphovouno were intermediate between mixed feeders, frugivorous ungulates and omnivores. In Pl. LXXXIIb, they lie above the cattle and ovi-caprids, which plot between modern leaf browsers and grazers. The only place where they would be able to obtain this diet was in or around the village.[36] Stable isotopes can help us untangle which of the cultivated crops may have been on the pig menu.

The cereals that were measured in this study were all samples of grain. Experimental studies have shown that there is a consistent offset of about -2.4‰ in nitrogen between the grain and the chaff of cereal plants; for carbon, the offset is -1.9‰ for wheat and -1.7‰ for barley.[37] Using these offsets, Pl. LXXXIIIa shows the projected values of the chaff of the cereals cultivated at Kouphovouno.

The average $\delta^{15}N$ of the pigs is 5.9 ± 0.9‰ and subtracting their trophic level enrichment of 3-5‰ (see above), the $\delta^{15}N$ value of their diet is situated around 0.9-2.9‰. This means that the pigs may have consumed a combination of the free-threshing wheat chaff, hulled barley chaff, hulled barley grain, pulse product and by-product, or other food items with similar isotopic composition. What they could *not* have been consuming in significant amounts is the free-threshing grain. In light of this, it is possible that wheat was grown exclusively for human consumption.

Sheep and goat diets

In the case of sheep and goats, dental micro- and mesowear analysis did not show any significant dietary differences between the two species (see Pl. LXXXIIIb), but the distinction was based on morphological identification of teeth, which may be problematic. Overall, the dental results indicate that all the Middle and Late Neolithic sheep and goats had variable diets.

The stable isotopes can be used to untangle part of this variability. The $\delta^{13}C$ and $\delta^{15}N$ values show differences in the diets of the ovi-caprids, but these differences change between

32 WALLACE *et al.* (*supra* n. 31).
33 WALLACE *et al.* (*supra* n. 31).
34 M. WALLACE, *Crop watering practices in the Neolithic and Bronze Age: the stable carbon isotope appraoch* (unpublished Ph.D. dissertation, Department Archaeology, The University of Sheffield, Sheffield, 2011).
35 BOGAARD *et al.* (*supra* n. 3); FRASER *et al.* (*supra* n. 3).
36 RIVALS *et al.* (*supra* n. 2).
37 BOGAARD *et al.* (*supra* n. 3); FRASER *et al.* (*supra* n. 3); WALLACE *et al.* (*supra* n. 31).

the Middle and the Late Neolithic. In the Middle Neolithic, the distinction lies in the carbon, while in the Late Neolithic, the difference is in the nitrogen (see Pl. LXXXIV). Middle Neolithic sheep have significantly lower $\delta^{13}C$ values compared to the Late Neolithic sheep and all of the goats (mean $\delta^{13}C$ of MN sheep = -20.9 ± 0.3‰; mean $\delta^{13}C$ of LN sheep = -20.3 ± 0.4‰; mean $\delta^{13}C$ of all goats = -20.1 ± 0.2‰). Late Neolithic sheep have the highest $\delta^{15}N$ of all the ovi-caprids in both phases (mean $\delta^{15}N$ of LN sheep = 5.3 ± 0.7‰; mean $\delta^{15}N$ of LN goats = 4.2 ± 0.9‰; mean $\delta^{15}N$ of MN sheep = 4.9 ± 0.5‰; mean $\delta^{15}N$ of MN goats = 5.0 ± 1.0‰). Note that the sample sizes are quite small but the chronological differences are statistically significant (when comparing the $\delta^{13}C$ means of MN sheep and goats, $p = 0.0041$; when comparing the $\delta^{15}N$ means of of LN sheep and goats, $p = 0.0041$).

There are various feeding habits that sheep and goats can adopt that will influence their stable isotopic values. Sheep can be used for preventative grazing, which is a way of controlling excessive growth of cultivated cereals on highly fertile soils.[38] Excessive growth can lead to problems with vulnerability to late frosts and unpredictable spring rains, 'lodging' (when crops grow too tall too quickly and may break under heavy rain) or competition with weeds whose growth is also promoted for the same reasons of higher soil fertility. Foddering (of cultivated crop product/by-product or collected vegetation) is another way of introducing different food items into the animal diets. However, both preventative grazing and foddering are short-term feeding strategies (livestock generally feeds on fodder only during harsh winters and preventative grazing as a one-off event when excessive cereal growth is taking place). For these reasons, it is unlikely that the adoption of these practices would have a significant influence on the stable isotopic values of the animals.

Still, the chronological differences in the carbon and nitrogen remain to be explained and we can consider questions of habitat and forage to try to tease out the dietary distinctions: either the sheep and the goats were grazing/browsing in different parts of the landscape or they were consuming different plants/plant parts in the same landscape. In the Middle Neolithic, the sheep have more depleted $\delta^{13}C$ values, which may be a result of 1) grazing in areas that are wetter[39] or 2) grazing in more forested areas – a result of the so called "canopy effect", which, some argue, causes depleted carbon isotope values.[40] As sheep generally prefer to graze in more open areas than in forests,[41] the former explanation seems more likely.

The nitrogen differences between the Late Neolithic sheep and goats are unlikely to be the result of any of the environmental factors causing $\delta^{15}N$ enrichment in soils (such as aridity, soil salinity and denitrification, discussed above) for the same reasons that the free-threshing wheat is unlikely to have been independently affected by them. Thus, it seems plausible that the higher $\delta^{15}N$ in the LN sheep is a result of anthropogenic causes. Sheep, which are obligate grazers, may have been given access to grazing on arable lands (fallow fields or vegetation growing on the edges of fields), whereas goats may have been left to browse on vegetation or woody parts of plants in unmanaged fields (and therefore would not have been affected by the manuring effect). Regardless of the causes of the distinctions in the diets, what we can comfortably infer is that the sheep and goats were managed in different ways and that their management changed between the Middle and the Late Neolithic. The management revolved around exploitation of different parts of the landscape and may have been linked with issues of land ownership and the social meaning of food.

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38 P. HALSTEAD, "Sheep in the Garden: The Integration of Crop and Livestock Husbandry in Early Farming Regimes of Greece and Southern Europe," in D. SERJEANTSON and D. FIELD (eds), *Animals in the Neolithic of Britain and Europe* (2006) 42-55.

39 As per WALLACE *et al.* (*supra* n. 31).

40 D.G. DRUCKER, A. BRIDAULT, K.A. HOBSON, E. SZUMA and H. BOCHERENS, "Can carbon-13 in large herbivores reflect the canopy effect in temperate and boreal ecosystems? Evidence from modern and ancient ungulates," *Palaeogeography, Palaeoclimatology, Palaeoecology* 266 (2008) 69-82; N. NOE-NYGAARD and M. U. HEDE, "The first appearance of cattle in Denmark occurred 6000 years ago: an effect of cultural or climate and environmental changes," *Geographical Annals* 88 A(2) (2006) 87-96.

41 HALSTEAD (*supra* n. 38).

Discussion

The findings presented herein suggest that, in the Middle and Late Neolithic, Kouphovouno farmers cultivated wheat and pulses at high intensity (probably in relatively close proximity to the settled area) and hulled barley at low intensity (probably at a greater distance from the houses). The labor-intensive cultivation of the wheat and pulses may have been carried out in garden plots on the tell itself, but the archaeology suggests that open spaces inside the village were likely not used for cultivation, but rather for firing pottery, preparing food, waste disposal and as pathways or lanes. Thus, the structure of the settlement seems to be one where the gardens were located adjacent to and not dispersed within the nucleated village. It is possible that the village was organized into neighborhoods, the inhabitants of which made use of adjacent land for gardening, but the extent of archaeology that was uncovered is insufficient to corroborate this claim.

The fact that the farmers were 1) distinguishing between the two different cereals and 2) managing them at different intensities, suggests that from the early stages of the site's occupation, the farmers were already familiar with the growing needs of the different cereal species (such as the fact that barley can survive in more marginal conditions). Pigs, which would have subsisted in or around the village, may have consumed a combination of the hulled barley grain and by-product, by-product of the wheat, any part of the pulses and any other isotopically similar dietary components, which were not measured in this study. They could not have consumed significant amounts of the free-threshing wheat grain. This leads us to believe that the cereal which the farmers consciously selected to grow with higher labor inputs was cultivated for the purpose of human consumption.

The water status of the crops does not enable us to differentiate between the watering management of the two cereals. The most we can say is that these two crops had similar water status, but whether that was a result of natural water being supplied by rain or artificial watering achieved by irrigation is unclear. The high watering signatures of the pulses indicate that these crops received additional water and the wide distribution of their carbon signatures suggests that they were being hand watered, the variability reflecting significant differences between watering strategies of individual farmers, years and/or plots.

The diets of the domestic animals reflect the browsing and grazing nature of sheep, goats and cows, and the more omnivorous nature of the pigs and dogs. The one sample of wild goat fits into the isotopic cluster of the domestic sheep and goats, but has a lower $\delta^{15}N$ than the domestic individuals. The most likely explanation for this is that the wild goat is unlikely to have consumed any types of plants that may have been affected by manuring, such as graze in fallow fields and cereals which have to be preventatively grazed.

The change in the sheep and goat management in the Late Neolithic was accompanied by changes in the handling of, and perhaps the symbolic significance of, food. As opposed to the Middle Neolithic, where the pottery assemblage was quite homogenous, the ceramics from the Late Neolithic represent a wider range of wares and include a greater amount of storage vessels.[42] The fact that the shift in food processing coincided with the change in the sheep and goat management strategy shows just how closely interlinked the spheres of settlement organization and subsistence strategy were.

Conclusions

The stable isotopes of faunal and crop remains from Kouphovouno provide us with critical insight for understanding the nature of the crop and animal management at the Neolithic site of Kouphovouno. They enable us to infer that different types of cereals were grown under distinct growing conditions and that intensive crop cultivation, of both cereals and pulses, was already well established at the start of the Neolithic occupation of the site. Management of the sheep and the goats changed between the Middle and the Late Neolithic, which had an effect on their diets. The nature of the change was most likely exploitation of different

42 MEE *et al.* (*supra* n. 10).

parts of the arable and natural surrounding landscape. Future oxygen isotopic work on sheep teeth planned by the authors may help us track the movement of these animals across the wider (topographically diverse) landscape and thus better understand their seasonal behavior. Other future work will involve the study of other Neolithic sites in Greece, which will enable us to understand more thoroughly how the mechanisms of early farming worked in different settings and shaped communities in different regions.

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Amy BOGAARD
Rebecca FRASER
Armelle GARDEISEN
William CAVANAGH
Christopher MEE
Josette RENARD
Angela LAMB

LIST OF ILLUSTRATIONS

Pl. LXXXIa Map of the Peloponnesian peninsula, southern Greece, indicating the location of Neolithic Kouphovouno (map prepared by Jean Cantuel, from RIVALS *et al*. [*supra* n. 2]).

Pl. LXXXIb δ^{13}C and δ^{13}N of all Neolithic plants and animals analyzed in this study.

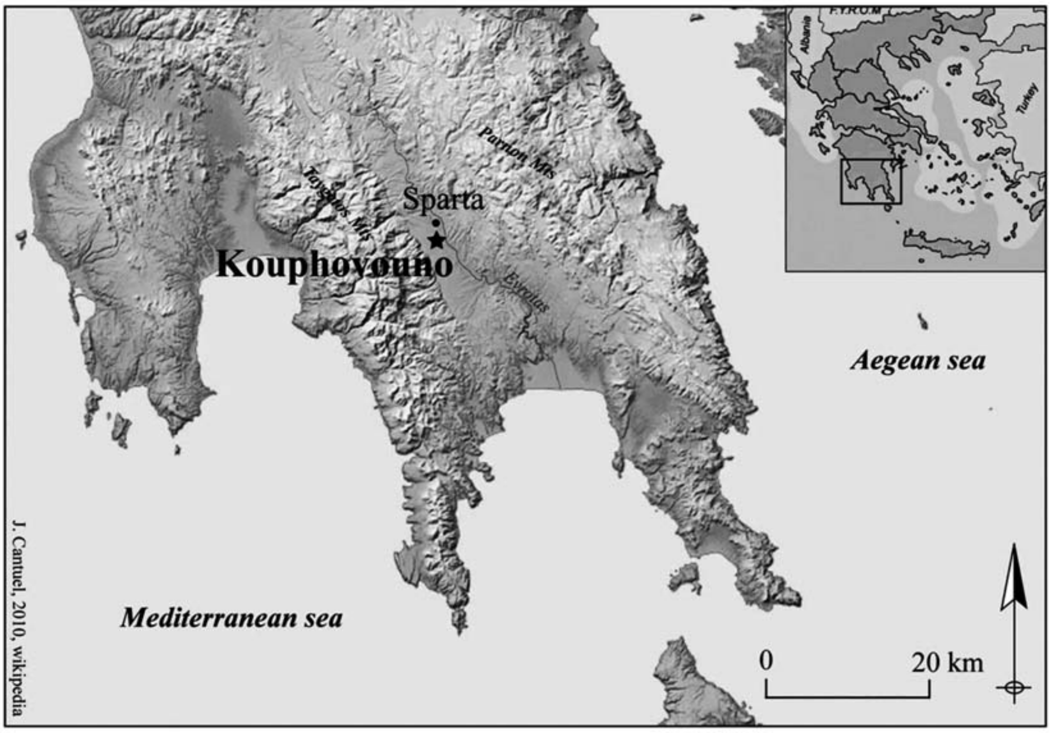
Pl. LXXXIIa Δ^{13}C values of all crops measured in this study compared to watering bands established through experimental studies (WALLACE *et al.* [*supra* n. 4]).

Pl. LXXXIIb Microwear bivariate graph for the domestic ungulates from Kouphovouno. Ellipses indicate Gaussian confidence ellipses (p=0.95) on the centroid of the samples from Kouphovouno and the extant grazer and browser samples adjusted by sample size.

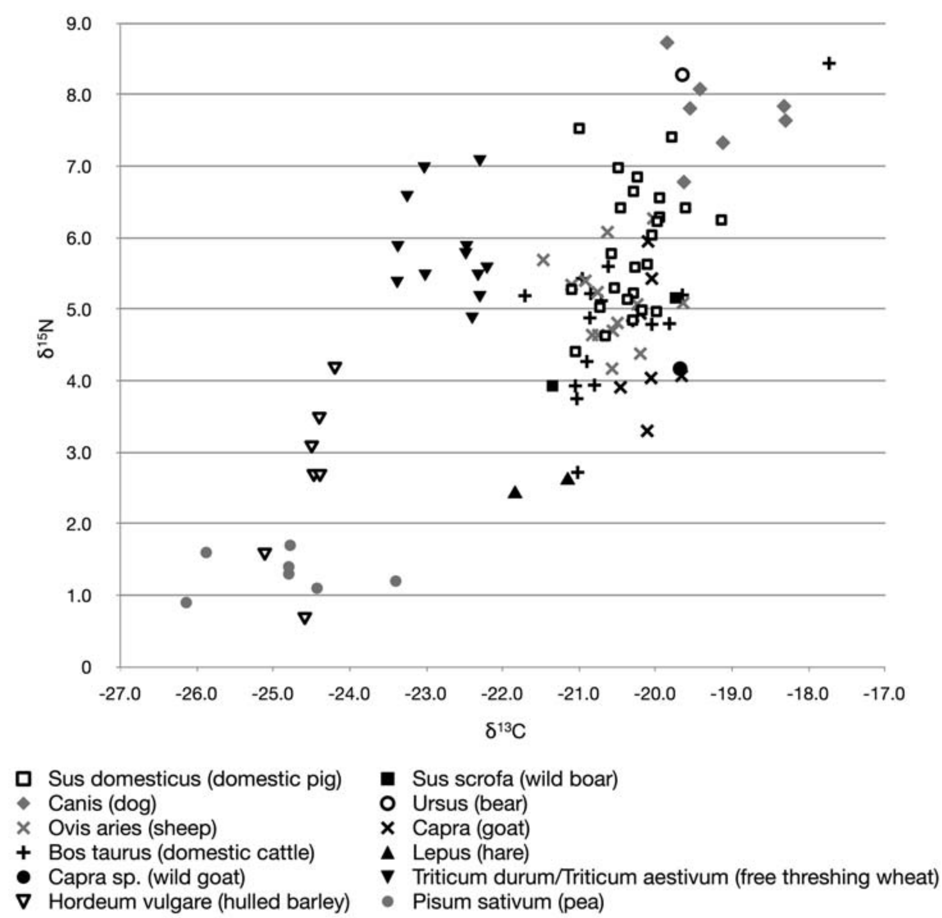
Pl. LXXXIIIa Projected values of cereal chaff (free-threshing wheat and hulled barley) based on the measured values of the archaeological cereal grains from Kouphovouno. The offset used was -2.4‰ for nitrogen (as per FRASER *et al.* [*supra* n. 3]) and -1.9‰ for carbon of wheat and -1.7‰ for carbon of hulled barley (as per WALLACE *et al.* [*supra* n. 4]).

Pl. LXXXIIIb Results of sheep and goat microwear analysis measurements.

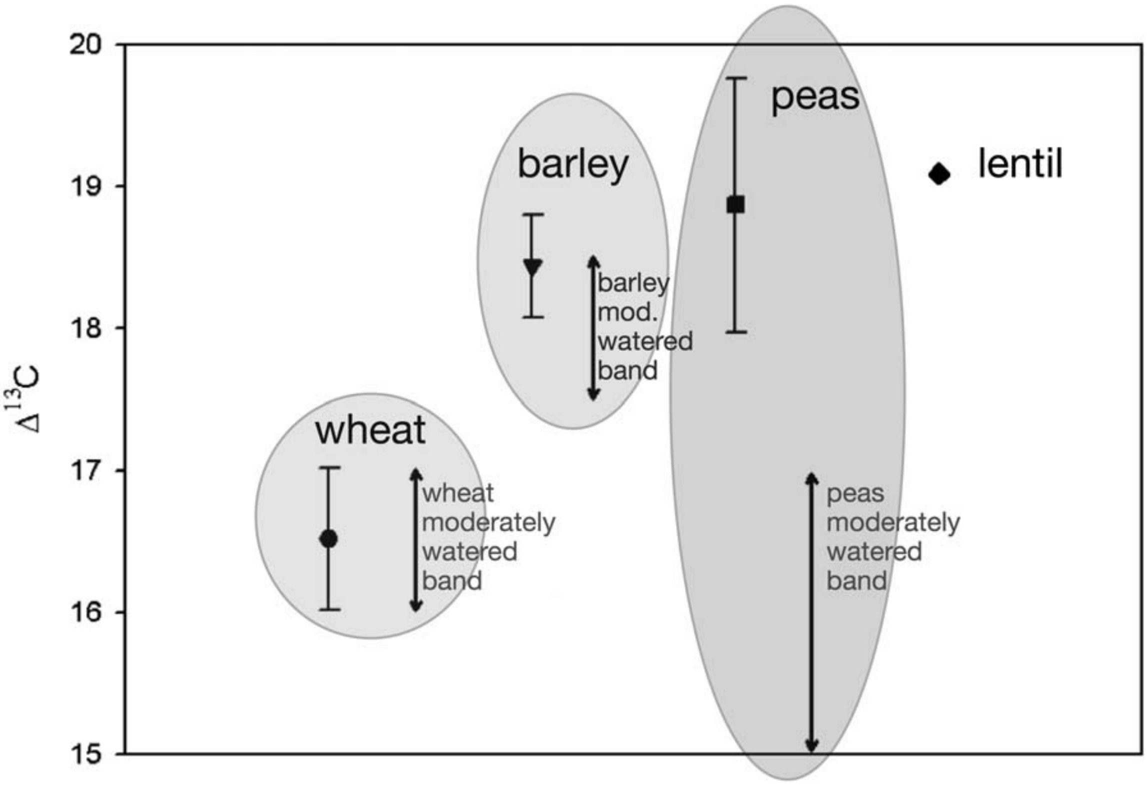
Pl. LXXXIV δ^{13}C and δ^{15}N of Middle Neolithic (MN) and Late Neolithic (LN) sheep and goats from Kouphovouno.


Sparta
Kouphovouno
Parnon Mts
Evrotas
Aegean sea
Mediterranean sea
0
20 km
J. Cantuel, 2010, wikipedia
Albania
F.Y.R.O.M
Turkey

a

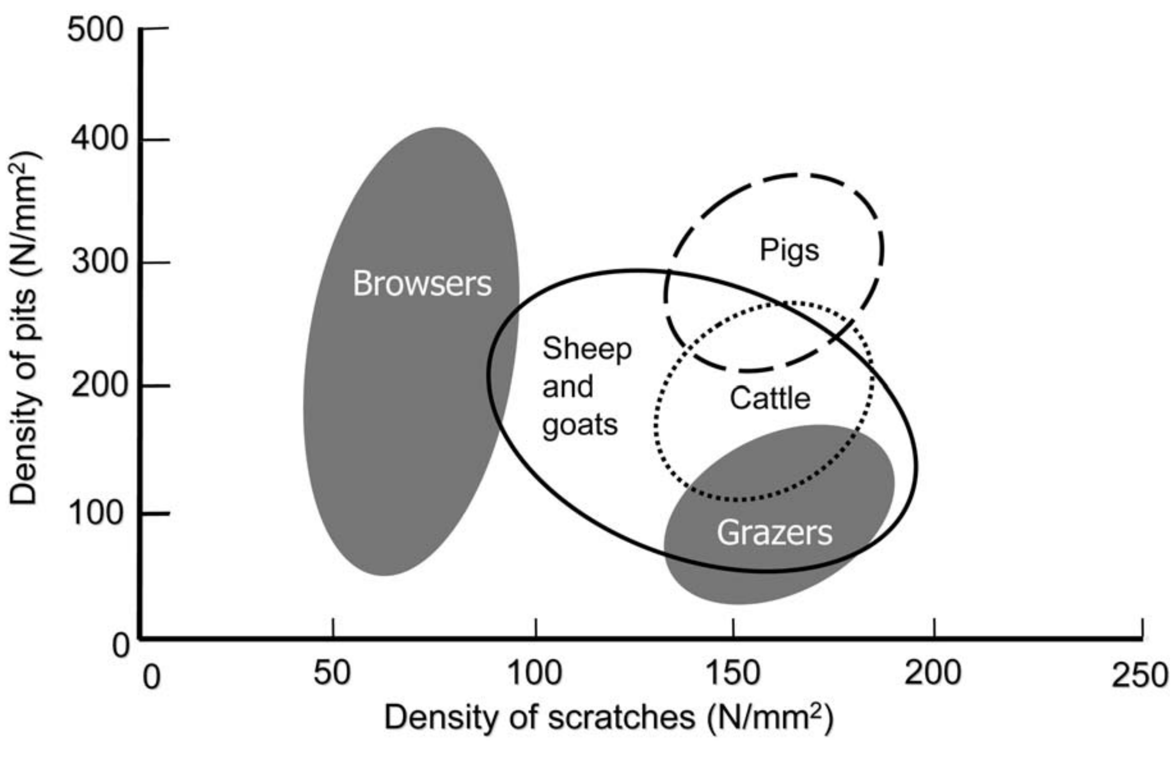

δ15N
δ13C
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
-27.0
-26.0
-25.0
-24.0
-23.0
-22.0
-21.0
-20.0
-19.0
-18.0
-17.0
Sus domesticus (domestic pig)
Canis (dog)
Ovis aries (sheep)
Bos taurus (domestic cattle)
Capra sp. (wild goat)
Hordeum vulgare (hulled barley)
Sus scrofa (wild boar)
Ursus (bear)
Capra (goat)
Lepus (hare)
Triticum durum/Triticum aestivum (free threshing wheat)
Pisum sativum (pea)

b



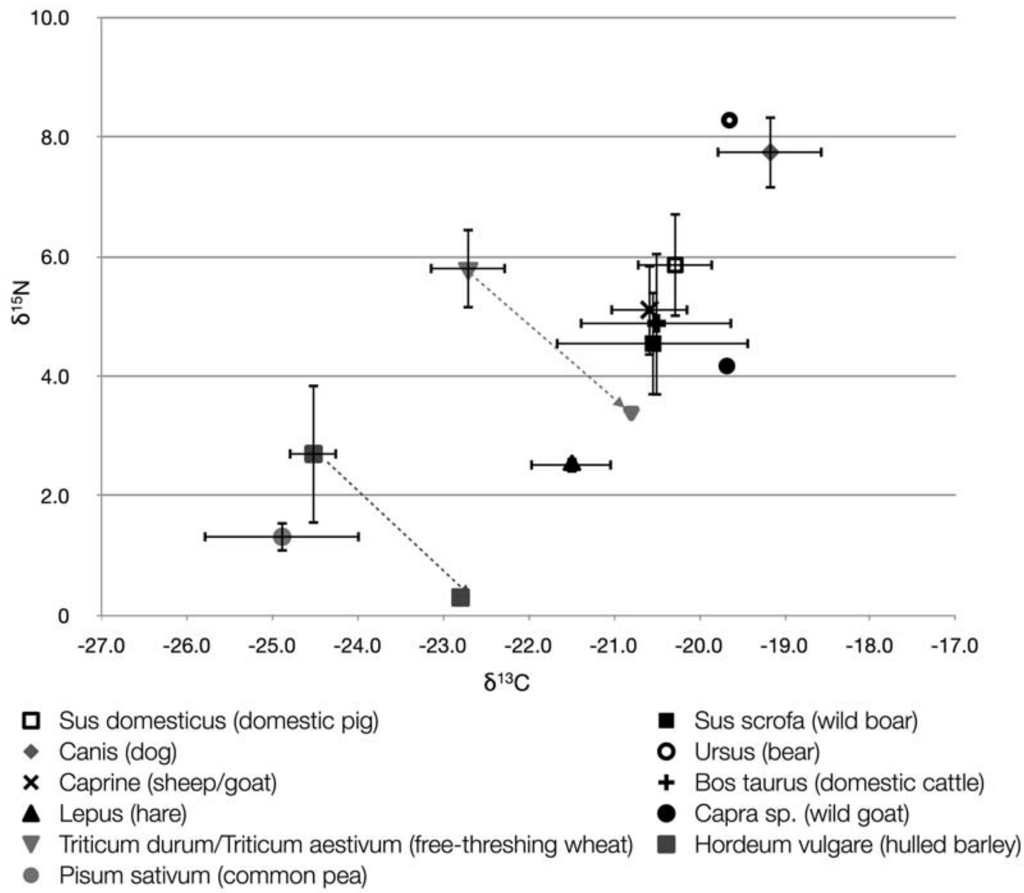
20
19
18
17
16
15
Δ13C
peas
barley
lentil
barley
mod.
watered
band
wheat
wheat
moderately
watered
band
peas
moderately
watered
band

a

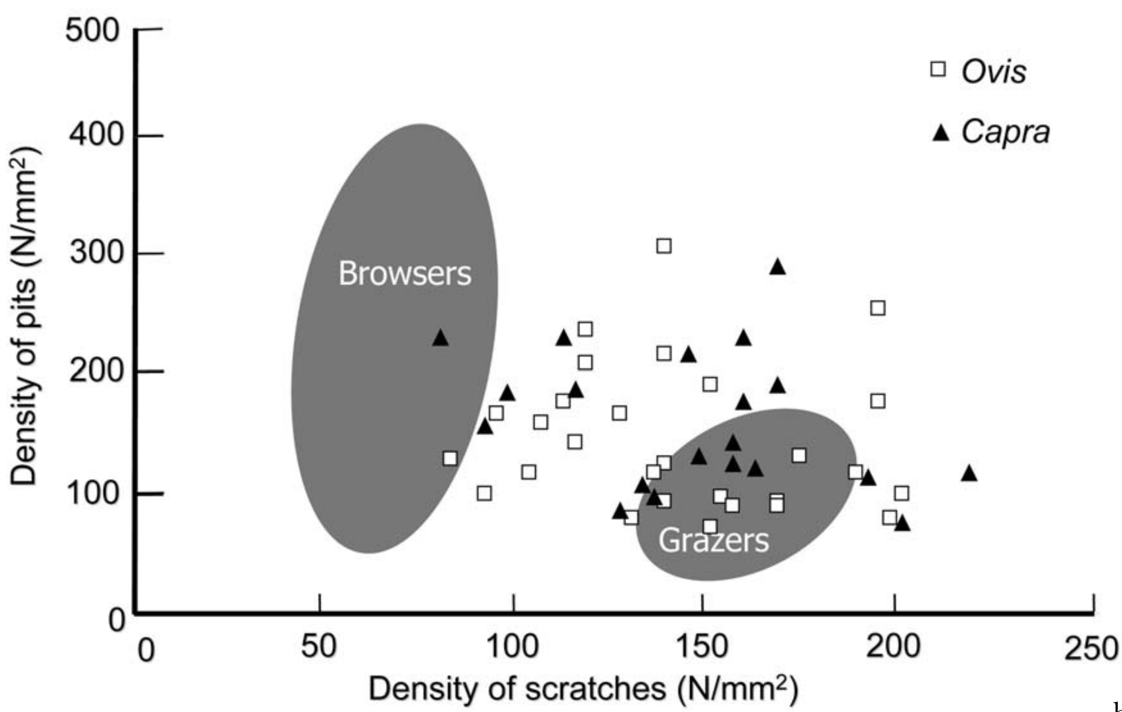


500
400
300
200
100
0
Density of pits (N/mm2)
Browsers
Pigs
Sheep
and
goats
Cattle
Grazers
0
50
100
150
200
250
Density of scratches (N/mm2)

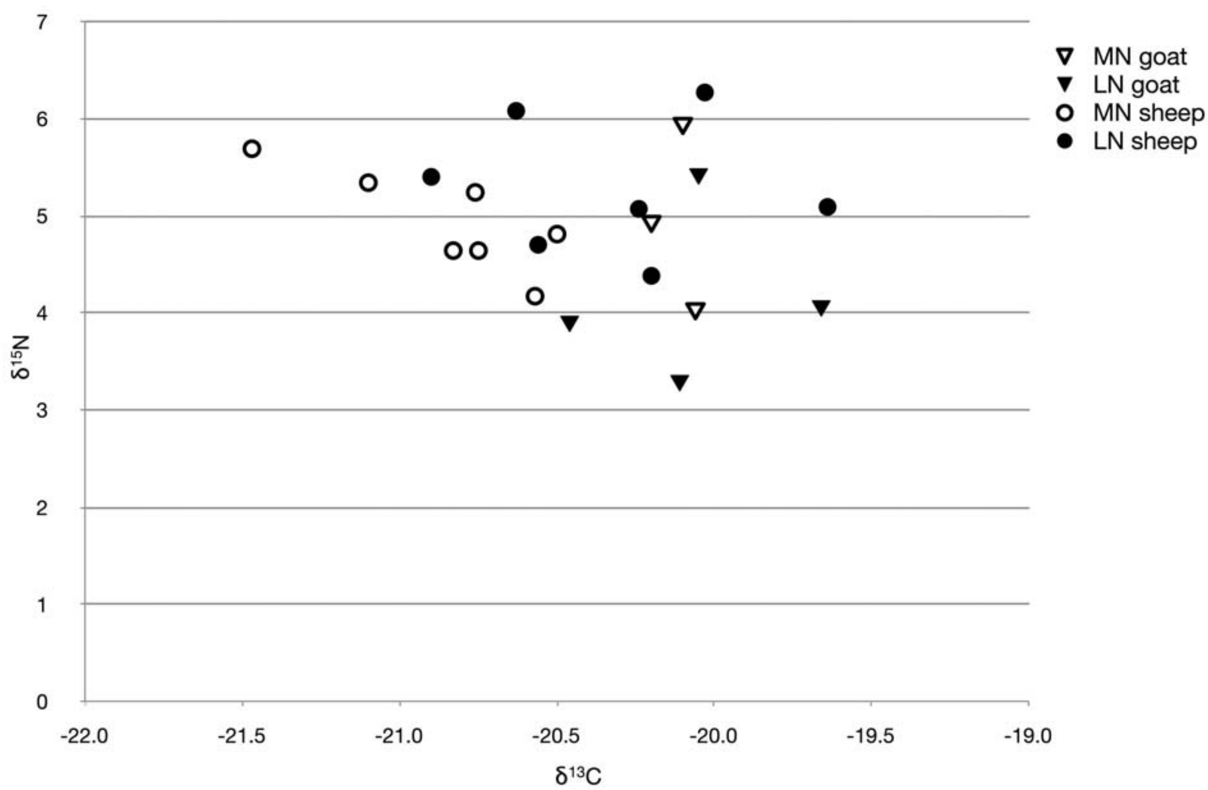
b


10.0
8.0
6.0
4.0
2.0
0
δ15N
-27.0 -26.0 -25.0 -24.0 -23.0 -22.0 -21.0 -20.0 -19.0 -18.0 -17.0
δ13C
Sus domesticus (domestic pig)
Canis (dog)
Caprine (sheep/goat)
Lepus (hare)
Triticum durum/Triticum aestivum (free-threshing wheat)
Pisum sativum (common pea)
Sus scrofa (wild boar)
Ursus (bear)
Bos taurus (domestic cattle)
Capra sp. (wild goat)
Hordeum vulgare (hulled barley)

a


500
400
300
200
100
0
Density of pits (N/mm2)
Ovis
Capra
Browsers
Grazers
0 50 100 150 200 250
Density of scratches (N/mm2)

b


7
6
5
4
3
2
1
0
δ15N
-22.0
-21.5
-21.0
-20.5
-20.0
-19.5
-19.0
δ13C
MN goat
LN goat
MN sheep
LN sheep