

Using stable isotopes and functional weed ecology to explore social differences in early urban contexts: the case of Lattara in mediterranean France

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Abstract

Integrated stable isotope investigation of plant and animal ecology can shed new light on the practicalities and politics of land management. Ecological analysis of archaeobotanical weed flora offers a complementary approach to arable growing conditions. Here we introduce the first combined study of stable isotope compositions (carbon and nitrogen) of plant and faunal remains and functional weed ecology from mediterranean France in order to investigate agricultural strategies under urbanisation and their social implications. Animal bones and charred crops and weeds are investigated from two archaeologically distinct residential areas from 5th century BCE Lattara, zones 1 and 27, during a period characterised by significant urban expansion in the region. Plant carbon and nitrogen isotope composition and functional weed ecology suggest some differences in growing conditions between crops found in the two zones, zone 27 being associated with more intensively cultivated crops than zone 1, where extensive cultivation, which can achieve much greater surplus, was dominant. These findings coincide with archaeological evidence of a 'richer' variety of material culture and foodstuffs in zone 1. Carbon and nitrogen isotopic values of animal bone collagen suggest that the main domesticates from both zones consumed a similar diet; however, rabbits exhibit a difference, with those from zone 1 having significantly higher $\delta^{15}\text{N}$, implying that the two zones sourced this species differently.

1. Introduction

During the Iron Age, the northwestern Mediterranean, as in other regions of Europe, witnessed or consolidated profound changes in several essential socio-economic and cultural domains, three of which we want to emphasize in this work: urbanism, food production and trade.

First, the 6th-5th centuries BCE witnessed the birth of cities and the establishment of urbanism: that is to say, a new organisation of nucleated housing and associated production and consumption activities (Almagro et al., 2001; Buchsenschutz, 2015; Fernández-Götz, 2017; Garcia, 2004; Sanmartí, 2004; Wells, 2011). In fact, this is not an entirely new phenomenon because in certain regions, such as the southern Iberian peninsula, for example, agglomerated settlements with fortification systems, testifying to a rather large diversity of spaces and economic and cultural activities, are already known from the third millennium (Aranda Jiménez et al., 2015; Chapman, 2003). In the mid-first millennium BCE, nucleated settlements generally coexist with dispersed ones composed of farms. However, this distinction between urban and rural is not clearly observed everywhere, especially in mediterranean regions (Almagro et al., 2001; Brun and Ruby, 2008; Garcia, 2004; Py, 2012). The main question that we want to address here is how urban and rural areas interacted in our case study, especially with regard to agropastoral and food practices.

Secondly, it is currently accepted (Alonso, 2000; Ferdière et al., 2006; Reynolds, 2011; Wells, 2011) that food production became more 'efficient' during the Iron Age, enabling larger scale production. The role of livestock is thought to have been increasingly crucial, as much for arid-plowing and the transport of crops as for the fertilisation of the fields. In connection with these new practices, the Iron Age is also associated with major changes in agricultural technology, especially the use of iron. Pulses served an essential role, as did the increasing cultivation of perennial trees, shrubs or climbing plants producing edible fruits (such as vines and olive trees), in addition to the expanded spectrum of backyard animals (e.g. chickens; Columeau, 1997). These are the beginnings of the formation of an agrarian system which blossomed during Roman times, organised in three levels of land exploitation: the *ager*, the *saltus* and the *silva*. However, as we will argue, agropastoral production during the Iron Age was not the exclusive domain of the countryside but was intimately connected to urban life.

Finally, a third feature of this period is thought to be the development of trade and a market economy that goes beyond the local or even the regional scale (Dietler, 2010; Py, 2012; Wells, 2011). This must be examined in connection with two aspects of food production: the level of agricultural yields and the development of speculative production of crops and livestock for trade, and access to these foodstuffs. During the Iron Age, the northwestern Mediterranean also witnessed the accomplishment of a process already underway at least since the Bronze Age in some regions, which is the establishment of long-distance trade with foreign societies (Etruscans, Greeks, Phoenicians, Iberians, Celts, among others) (Sherratt, 1993). This process in some cases takes the form of colonial settlements and in others of *emporia* or trading posts, with greater or lesser degrees of influence from foreign and indigenous communities. In all cases, new animal and plant products, production strategies, food processing and consumption techniques emerged in the northwestern Mediterranean,

particularly from the 6th-5th centuries BCE onwards. Of the many questions that these intercultural contacts raise, we are particularly interested here in how the origin and the quality or diversity of food can reveal the implementation of particular agropastoral production strategies (including some that could be allochthonous), as well as the identity and social status of the people who produce and/or consume them, especially in urban settings.

Here we present an investigation of agricultural strategies under urbanisation in mediterranean France (ca.750-25 BCE), a region which witnessed the development of substantial long distance trade networks, especially after the founding of the Phocaean Greek colony of Massalia in 600 BCE (Dietler, 2010). These mercantile connections are evidenced by the quantity of wine amphorae and other imports at sites across the region. One such site is the coastal city of Lattara (in modern day Lattes), where local agricultural production is believed to have assumed a reciprocal role in this trade (Dietler, 2010; Py, 2009; 2012).

To this end, this study presents the first foray into the stable carbon and nitrogen isotope analysis of plant and faunal remains from the mediterranean French Iron Age. Taking advantage of stable isotopes' ability to elicit subtle spatiotemporal changes in past agricultural systems, we set out to investigate farming practices at 5th century BCE Lattara, complementing crop stable isotope measurements with functional weed ecology to ascertain the intensity of crop cultivation (cf. Bogaard et al., 2016). In particular, we examine the extent to which agricultural production strategies differed between two neighbourhoods that have produced significantly different material culture, architecture and food remains, suggesting that their residents also differed socio-economically and did not have access to the same foodstuffs. Considering that the onset of urbanism in mediterranean France and its rapid growth during this period gave rise to new social classes that were not all involved in subsistence agriculture (Garcia, 2005), we hypothesise that these two distinct neighbourhoods should reveal some divergent attributes in production of the food they consumed.

2. Background

2.1 Lattara during the 5th century BCE

Founded ca. 500 BCE, Lattara was situated on a small headland on the Lez river delta by a large likely freshwater lagoon with access to the sea (fig. 1; Bagan et al., 2010). The area today is characterised by a subhumid mediterranean climate with dry summers, mild winters and rainfall occurring primarily during spring and autumn (Ambert and Chabal, 1992). The botanical, faunal, palynological and dendrological evidence recovered from excavations at Lattara indicate the presence of wetlands, salt marshes, drylands and closed-canopy forests in the vicinity of the city in antiquity (Alonso and Rovira, 2010; Alonso et al., 2008; Chabal, 2005; Gardeisen, 2008; Loublier, 1992; Puertas, 1998; Rovira and Alonso, 2010).

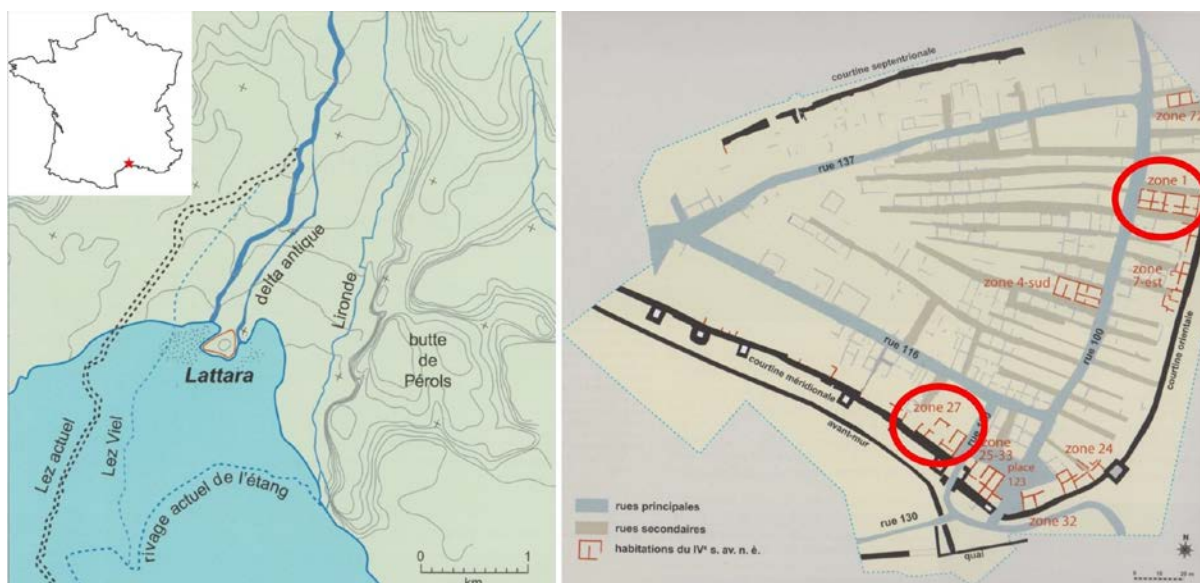


Figure 1 - Location of Lattara and settlement layout with the two zones examined in this paper circled (after Py, 2009).

In addition to a section of its fortification wall, two residential areas within Lattara have been excavated down to 5th century levels, zones 1 and 27, providing the earliest glimpses of urban life here. At the city's foundation these two areas reveal a number of non-local features that have led to the perception that Lattara was not an ordinary indigenous settlement and that at least some foreigners resided here (Gailledrat, 2015; Py, 2009; 2012). Following violent destruction of both areas ca. 475 BCE, however, indigenous wattle-and-daub architecture largely replaced the earlier Mediterranean style mudbrick houses for a brief period (Belarte et al., 2010; Lebeaupin and Séjalon, 2010; Py, 2012).

Beginning around 450 BCE the settlement underwent reorganisation based on an orthogonal street plan. It was at this time that zone 1 re-adopted the exogenous construction methods, while zone 27 retained its indigenous qualities until ca. 425 BCE, when it too followed suit (Belarte et al., 2010; Lebeaupin and Séjalon, 2010). The brief interlude from 450-425 BCE when these zones exhibit distinct differences in architecture and material culture has led to the proposal that these areas may have even belonged to two different social classes during this time (Py, 2009:78).

A difference in the archaeobotanical record between the two zones highlights further distinctions. Zone 1 produced greater taxonomic variety than zone 27, which was dominated by cereals. Of the cereals, there is a predominance of hulled barley over free-threshing wheat in zone 27, while free-threshing wheat dominates in zone 1 (Alonso and Rovira, 2010). The variety of pulses recovered from the two areas is similar with the exception of a concentration of broad beans in zone 27 and of peas in zone 1 (Alonso and Rovira, 2010). Overall zone 1 presents evidence of regular domestic consumption practices while zone 27 reveals a focus on activities associated with cereal processing, especially barley. While these variances could reflect cultural and/or social differences between the residents of the two quarters, they could also be the result of different areas of activity, or a combination of both.

Of the faunal remains from 5th century levels, only the fish have been studied from both zones. Zone 1 exhibits a greater diversity in its aquatic species, including sea bream, eel, sea bass, mullet, meagre and sturgeon and in its paraphernalia such as hooks and net weights. Zone 27 is instead represented almost exclusively by eels and large taxa are absent (Piquès, 2010). Terrestrial species from zone 1 have not yet been fully studied, so no comparisons can be made between the two areas. In zone 27, caprine bones are the most common followed closely by cattle and then pigs, although cattle would have contributed the largest quantity of meat (Gardeisen, 2010).

2.2 Isotopic background

Stable carbon and nitrogen isotope measurements provide quantitative data that can be useful in determining the growing conditions of crops and feeding ecology of animals. The carbon isotope composition ($\delta^{13}\text{C}$) of terrestrial plants in general is primarily a reflection of their photosynthetic pathway and dependant to a large extent on the $\delta^{13}\text{C}$ of local atmospheric CO_2 (Bassham, 1971; Farquhar et al., 1989). Plant photosynthesis results in discrimination against the heavier carbon isotope causing the plant carbon to be depleted in ^{13}C relative to the atmosphere (Farquhar and Richards, 1984). This carbon isotope discrimination independent of atmospheric CO_2 is normally represented by $\Delta^{13}\text{C}$ (Farquhar et al., 1982). For C_3 taxa wetter conditions and greater stomatal opening result in greater discrimination against ^{13}C and higher $\Delta^{13}\text{C}$ values (Farquhar et al., 1982; Farquhar and Richards, 1984). When the $\delta^{13}\text{C}$ value of C_3 species is converted to $\Delta^{13}\text{C}$ it can be compared to modern studies of watering regimes to gauge ancient crop water availability (Araus et al., 1997; Wallace et al., 2013). Marine plants and algae assimilate dissolved CO_2 and bicarbonate from the water, which leads to enriched ^{13}C values compared to land-based C_3 plants (Smith and Epstein, 1971).

Plant stable nitrogen isotope compositions ($\delta^{15}\text{N}$) can be affected by numerous factors, especially the $\delta^{15}\text{N}$ of the soil which is itself a reflection of the nitrogen inputs into the soil and losses due to nitrogen cycling (Högberg, 1997; Robinson, 2001). Soil can be enriched in ^{15}N by both anthropogenic and environmental agents. Waterlogged soil, such as that in wetlands, can have elevated $\delta^{15}\text{N}$ due to denitrification under anaerobic conditions (Kendall, 1998), while soil salinity and marine nitrates from sea spray (the “sea spray effect”) can also increase plant $\delta^{15}\text{N}$ (Heaton, 1987; Virginia and Delwiche, 1982; Wooller et al., 2005), though this apparent salinity effect may also or instead be caused by denitrification under wet conditions (cf. Heaton, 1987; see also Handley et al., 1997 for the observation that salinity can be associated with *lower* $\delta^{15}\text{N}$ in barley). Some organic nitrogen inputs like manure, which is enriched in ^{15}N due to ammonia volatilisation, can increase soil $\delta^{15}\text{N}$ (Bogaard et al., 2007; Riga et al., 1971). Manuring has been shown to significantly increase crop $\delta^{15}\text{N}$ values and even nitrogen-fixing plants (such as certain legumes) have demonstrated enriched values, albeit to a lesser extent (Bogaard et al., 2007; Fraser et al., 2011). Nitrogen-fixing plants are less responsive to soil nitrogen and typically have $\delta^{15}\text{N}$ values close to that of atmospheric nitrogen ($\sim 0\text{‰}$) (Szpak et al., 2014). However, nitrogen-fixing legumes can use soil nitrogen when it is highly available, such as with intensive manuring and/or middening, resulting in increased $\delta^{15}\text{N}$ values (Delwiche and Steyn, 1970; Fraser et al., 2011; Treasure et al., 2016).

The $\delta^{13}\text{C}$ values of animal tissues largely reflects the $\delta^{13}\text{C}$ values of the food consumed with an offset due to fractionation and a small trophic level shift; for bone collagen this offset equates to roughly +5 ‰ (Hedges, 2006; van der Merwe and Vogel, 1978). The $\delta^{13}\text{C}$ value of carnivore collagen has been shown to be around 1 ‰ higher than the collagen of their prey due to this trophic level increase (DeNiro and Epstein, 1978; van Klinken et al., 2002). Collagen is the main organic component in bone and dentine and its $\delta^{13}\text{C}$ values primarily reflect the dietary protein fraction rather than the whole diet including carbohydrates and lipids (Ambrose and Norr, 1993).

The $\delta^{15}\text{N}$ values of animals reflect their trophic level with increases of between 3-5 ‰ with each successive level (Ambrose and DeNiro, 1986; DeNiro and Epstein, 1981; Hedges and Reynard, 2007; Schoeninger and DeNiro, 1984), with values as high as 6 ‰ reported in humans (O'Connell et al., 2012). Due to the greater length of aquatic food chains compared to terrestrial ones, $\delta^{15}\text{N}$ tends to be higher in predatory aquatic species than their land-based counterparts, something also reflected in the isotopic values of terrestrial consumers of aquatic animals (Schoeninger and DeNiro, 1984).

2.3 Functional weed ecology

The biogeographical distribution of weed species has changed through time, making direct comparison of species composition between modern and ancient weed flora problematic. Here we distinguish between farming regimes based on the *functional attributes* of the weeds – i.e. those traits that allow them to flourish under particular conditions. This allows ‘translation’ of present-day cultivation practices to the past, but also provides a means of distinguishing the effects of different regimes, thus allowing identification of combinations of farming practices that have not been observed today (Jones et al., 2000; 2010). Studies of weed flora from modern small-scale/high-intensity cereal plots in Asturias, Spain and large-scale/low-intensity (extensive) fields in Haute Provence, France permitted a model of cultivation intensity to be developed, based on five functional attributes that reflect the response of weed species to soil productivity and/or mechanical disturbance (tillage and weeding; Bogaard et al., 2016: table 3). Discriminant analysis was used to extract a linear equation combining these functional attributes with the aim of maximising the separation between intensive and extensive farming regimes (Bogaard et al., 2016: fig. 7). Cultivated plots containing weeds with functional attributes associated with high soil productivity and high disturbance group to the ‘high-intensity’ end of the spectrum, since these indicate high levels of fertilisation (i.e. manure), tillage, and weeding, which require high labour inputs. Cultivated plots containing weeds with functional attributes associated with low soil productivity and low disturbance group to the ‘low-intensity’ end of the spectrum.

3. Material and methods

3.1 Samples

A total of 71 animal bone and 44 charred crop samples was submitted for isotopic analyses in this study. The archaeobotanical remains were recovered using water flotation of selected soil samples, while the faunal material was recovered both by hand in the trench and from the heavy fraction in the flotation tank. Samples were selected to cover two chronological periods

223 (450-425/425-400 BCE) from both zones excavated to these levels. Stratigraphic unit 51103
 224 from zone 1 covers a broader date range of 450-400 BCE due to the mixed nature of the
 225 deposit.

226 Due to the limited number of samples preserved from some taxa, not all differences between
 227 the two zones or chronologies could be tested statistically. It is also worth emphasising here
 228 that the samples originate from two limited zones within the 3.5 hectare walled area of
 229 Lattara, and do not include the possible further seven hectares of extramural settlement to the
 230 north (Py, 2009). Therefore the results should not be taken as representative of the entire
 231 settlement but rather as a partial comparison from these two quarters only.

232 Where possible, at least five grains/seeds were sampled and homogenised to account for the
 233 variability in isotopic values that exist both between plants and within the same plant,
 234 providing an ‘average’ of growing conditions (cf. Nitsch et al., 2015). Crop taxa include
 235 *Triticum aestivum/durum* (free-threshing wheat), *Hordeum vulgare* (six-row hulled barley),
 236 *Triticum dicoccum* (emmer wheat), *Panicum miliaceum* (broomcorn millet), *Triticum*
 237 *monococcum* (einkorn wheat), *Setaria italica* (foxtail millet), *Hordeum vulgare nudum*
 238 (naked barley), *Lathyrus sativus* (grass pea), *Lens culinaris* (lentil), *Vicia faba* (broad bean),
 239 *Pisum sativum* (common pea) and *Vicia ervilia* (bitter vetch) (table 1).

lab code	taxon	excavation code	stratigraphic unit	Date (BCE)	zone	no. seeds	%C	%N	C:N	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)	$\Delta^{13}\text{C}$ (‰)
LATPR001	Hulled barley	LSS 98 27310	27310	425-400	27	5	62	-	18.2	-23.7	-	17.7
LATPR002	Broad bean	LSS 98 27310	27310	425-400	27	1	49	-	11.2	-22.1	-	16.1
LATPR003	Free threshing wheat	LSS 98 27310	27310	425-400	27	7	61	-	17.0	-22.7	-	16.7
LATPR004	Hulled barley	LSS 98 27293	27293	425-400	27	5	66	-	30.3	-24.6	-	18.7
LATPR009	Free threshing wheat	LSS 98 27293	27293	425-400	27	8	65	-	38.5	-23.2	-	17.2
LATPR011	Hulled barley	LSS 97 27216	27216	425-400	27	8	63	-	29.0	-24.2	-	18.3
LATPR012	Free threshing wheat	LSS 97 27216	27216	425-400	27	7	54	-	26.1	-24.3	-	18.4
LATPR014	Einkorn	LSS 97 27216	27216	425-400	27	6	64	-	24.1	-24.9	-	19.0
LATPR018	Lentil	LSS 98 27300	27300	425-400	27	23	52	-	16.1	-21.9	-	15.8
LATPR021	Hulled barley	LSS 98 27300	27300	425-400	27	5	48	-	35.4	-23.3	-	17.3
LATPR023	Free threshing wheat	LSS 2001 51019	51019	425-400	1	6	50	-	17.4	-23.9	-	17.9
LATPR032	Hulled barley	LSS 2001 51080	51080	425-400	1	8	57	-	23.5	-23.6	-	17.6
LATPR033	Free threshing wheat	LSS 2001 51080	51080	425-400	1	10	50	-	15.5	-23.2	-	17.2
LATPR034	Emmer	LSS 2001 51080	51080	425-400	1	10	54	-	18.0	-23.8	-	17.8
LATPR043	Free threshing wheat	LSS 2002 51103	51103	450-400	1	9	59	-	19.2	-23.7	-	17.7
LATPR045	Emmer	LSS 2002 51103	51103	450-400	1	9	-	3	-	-	5.1	-
LATPR046	Hulled barley	LSS 2002 51103	51103	450-400	1	10	67	3	25.2	-23.4	7.6	17.4
LATPR047	Free threshing wheat	LSS 2001 27495	27495	450-425	27	5	64	4	19.3	-22.4	5.2	16.4
LATPR048	Hulled barley	LSS 2001 27495	27495	450-425	27	3	71	3	29.6	-23.8	7.7	17.8
LATPR050	Broomcorn millet	LSS 2001 27495	27495	450-425	27	6	58	-	22.0	-10.8	-	-
LATPR051	Grass pea	LSS 2001 27463	27463	450-425	27	1	56	6	11.5	-21.9	2.5	15.9
LATPR053	Free threshing wheat	LSS 2001 27463	27463	450-425	27	3	64	3	24.3	-23.0	8.1	17.0
LATPR054	Emmer	LSS 2001 27463	27463	450-425	27	3	55	4	20.4	-23.3	5.4	17.3
LATPR056	Free threshing wheat	LSS 2004 53030	53030	450-425	1	10	60	3	23.7	-23.7	4.1	17.7
LATPR057	Common pea	LSS 2004 53030	53030	450-425	1	11	62	7	13.9	-23.3	2.4	17.3

LATPR058	Lentil	LSS 2004 53030	53030	450-425	1	7	67	7	11.5	−22.4	1.9	16.4
LATPR059	Hulled barley	LSS 2004 53030	53030	450-425	1	10	64	3	21.5	−24.2	6.7	18.2
LATPR060	Emmer	LSS 2004 53030	53030	450-425	1	10	50	4	22.0	−22.6	5.7	16.6
LATPR061	Free threshing wheat	LSS 2004 53030	53030	450-425	1	8	60	3	18.6	−23.2	4.7	17.2
LATPR063	Emmer	LSS 2007 53329	53329	450-425	1	6	60	3	25.4	−23.4	5.8	17.4
LATPR064	Hulled barley	LSS 2007 53329	53329	450-425	1	11	83	3	21.0	−24.6	7.5	18.7
LATPR065	Broomcorn millet	LSS 2007 53329	53329	450-425	1	9	65	4	15.8	−10.9	8.7	-
LATPR067	Free threshing wheat	LSS 2007 53329	53329	450-425	1	9	59	4	20.8	−23.2	4.9	17.2
LATPR070	Common pea	LSS 2007 53329	53329	450-425	1	4	64	5	14.6	−23.7	3.1	17.7
LATPR071	Broad bean	LSS 2007 53329	53329	450-425	1	1	75	8	9.9	−24.2	1.4	18.2
LATPR072	Foxtail millet	LSS 2004 53038	53038	450-425	1	5	58	-	15.3	−10.7	-	-
LATPR073	Hulled barley	LSS 2004 53038	53038	450-425	1	10	64	3	29.2	−24.6	6.2	18.6
LATPR077Y	Bitter vetch	LSS 2004 53038	53038	450-425	1	1	63	5	18.7	−24.3	2.3	18.4
LATPR078	Naked barley	LSS 2003 27631	27631	450-425	27	3	61	3	24.1	−23.6	6.0	17.6
LATPR079	Hulled barley	LSS 2003 27631	27631	450-425	27	10	58	-	18.5	−24.6	-	18.7
LATPR080	Free threshing wheat	LSS 2003 27631	27631	450-425	27	9	67	-	15.8	−22.9	-	16.8
LATPR081	Emmer	LSS 2003 27631	27631	450-425	27	6	55	3	22.8	−22.8	4.4	16.8
LATPR082	Grass pea	LSS 2005 53121	53121	450-425	1	1	64	6	9.8	−22.2	0.8	16.1
LATPR084	Free threshing wheat	LSS 2005 53121	53121	450-425	1	7	66	-	17.1	−23.6	-	17.6

240

241 **Table 1 - List of crop samples analysed in this study. C:N molar ratios calculated using (%C/12)/(%N/14) from the**
242 **plant carbon runs. $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values adjusted for charring (−0.11‰ and −0.31 ‰, respectively) as per Nitsch et al.**
243 **(2015).**

244 It was not possible to ensure sampling of different individuals when selecting bone elements
245 and so, to achieve independence of samples, only one sample was selected per species from
246 each of those stratigraphic units that contained two bones. The decision as to which bone to
247 select was made using the *sample()* function in R (v2.15.1) to generate a random number
248 corresponding to the first or second sample. Species sampled include *Ovis aries/Capra hircus*
249 (sheep/goat - caprine), *Sus domesticus* (pig), *Bos taurus* (cattle), *Canis familiaris* (dog),
250 *Oryctolagus cuniculus* (rabbit), *Equus caballus* (horse), *Capreolus capreolus* (roe deer),
251 *Cervus elaphus* (red deer), *Sus scrofa* (wild boar), *Felis sp.* (cat) and *Lynx sp.* (lynx) (table 2).

lab code	species	element	excavation code	stratigraphic unit	date (BCE)	zone	collagen yield %	%C	%N	C:N	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)	notes	excluded from stats?
*LATFR001	Cattle	Calcaneus	os-27112-102	27112	425-400	27	3.2	6	2	3.7	−21.2	4.1	failed QA	n/a
LATFR002	Cattle	Vertebra	os-27461-15	27461	425-400	27	3.9	27	9	3.4	−19.7	7.7		No
LATFR003	Cattle	Mandible	os-27463-2	27463	450-425	27	3.7	22	7	3.5	−19.6	7.6		No
LATFR004	Cattle	Phalange I	os-27747-22	27747	450-425	27	7.3	25	9	3.4	−20.4	6.6		No
LATFR005	Dog	Tibia	os-27112-34	27112	425-400	27	7.5	36	13	3.2	−19.6	9.4		No
LATFR006	Dog	Radius	os-27461-38	27461	425-400	27	6.4	36	13	3.3	−17.3	11.0		No
LATFR007	Dog	Talus (astragalus)	os-27461-37	27461	425-400	27	6.0	27	9	3.4	−18.6	8.4		Yes
LATFR008	Dog	Metacarpal 3	os-27648-1	27648	425-400	27	4.1	41	15	3.3	−18.8	9.9		No
LATFR009	Dog	Mandible	os-27850-2	27850	450-425	27	6.1	35	13	3.3	−16.1	11.8		No
LATFR010	Roe-deer	Antler	os-27112-36	27112	425-400	27	9.9	39	14	3.3	−21.2	4.8		No
LATFR011	Red-deer	Femur	os-27346-14	27346	425-400	27	13.5	45	16	3.2	−20.8	3.4		No

LATFR012	Horse	Femur	os-27396-3	27396	425-400	27	6.3	35	12	3.3	−21.8	3.6		No
LATFR013	Rabbit	Metatarsal 3	os-27346-37	27346	425-400	27	11.1	45	16	3.2	−21.3	4.5		No
LATFR014	Lynx	Radius	os-27346-35	27346	425-400	27	3.0	43	16	3.3	−19.9	6.1		No
LATFR015	Rabbit	Tibia	os-27850-64	27850	450-425	27	7.1	38	14	3.2	−23.1	5.8		No
LATFR016	Caprine	Radius	os-27112-26	27112	425-400	27	4.6	27	10	3.3	−18.8	7.3		No
LATFR017	Caprine	Radius	os-27461-26	27461	425-400	27	7.9	35	13	3.3	−20.3	7.3		Yes
LATFR018	Caprine	Tibia	os-27461-28	27461	425-400	27	7.6	43	16	3.2	−19.7	7.4		No
LATFR019	Caprine	Humerus	os-27463-35	27463	450-425	27	5.5	38	13	3.3	−21.7	7.2		No
LATFR020	Caprine	Tibia	os-27463-24	27463	450-425	27	12.2	42	15	3.2	−20.0	7.3		Yes
LATFR021	Caprine	Coxal	os-27747-4	27747	450-425	27	6.3	30	10	3.4	−20.0	8.1		No
LATFR022	Caprine	Metatarsal	os-27747-6	27747	450-425	27	9.5	41	15	3.2	−20.6	8.6		Yes
LATFR023	Caprine	Tibia	os-27850-70	27850	450-425	27	4.7	33	12	3.3	−21.7	9.8		No
LATFR024	Pig	Phalange I	os-27112-38	27112	425-400	27	1.2	26	9	3.4	−20.3	5.3		No
LATFR025	Pig	Phalange II	os-27461-36	27461	425-400	27	1.7	41	14	3.4	−20.1	7.4	Juvenile	No
LATFR026	Pig	Humerus	os-27850-57	27850	450-425	27	3.5	27	9	3.4	−20.2	9.8		Yes
LATFR027	Pig	Phalange II	os-27850-60	27850	450-425	27	6.0	35	12	3.3	−19.8	6.1		No
LATFR028	Cattle	Femur	os-50030-80	50030	450-425	1	11.6	43	16	3.2	−18.7	6.2		No
LATFR029	Cattle	Femur	os-50038-2	50038	450-425	1	11.3	39	14	3.3	−20.7	5.0		No
LATFR030	Cattle	Tibia	os-50292-17	50292	425-400	1	12.5	41	15	3.2	−20.1	7.4		No
LATFR031	Cattle	Metatarsal	os-50315-32	50315	425-400	1	13.3	41	15	3.2	−19.6	6.6		No
LATFR032	Cattle	Ulna	os-51104-17	51104	425-400	1	9.2	42	14	3.4	−19.2	6.8		No
LATFR033	Cattle	Femur	os-53229-9	53229	450-425	1	13.1	45	17	3.2	−21.3	8.0		No
LATFR034	Cattle	Tibia	os-53230-2	53230	450-425	1	6.9	40	14	3.2	−20.4	6.4		No
LATFR035	Cattle	Femur	os-53242-2	53242	450-425	1	13.4	42	15	3.2	−19.4	6.8		No
LATFR036	Cattle	Long bone	os-53328-1	53328	450-425	1	13.3	39	14	3.2	−21.8	6.8		No
LATFR037	Dog	Metapodial	os-50332-10	50332	425-400	1	7.5	41	15	3.2	−18.1	10.3		No
LATFR038	Caprine	Radius	os-50315-46	50315	425-400	1	14.0	44	16	3.2	−19.8	6.1		No
LATFR039	Horse	Femur	os-53057-3	53057	450-425	1	7.7	37	13	3.3	−20.9	7.9		No
LATFR040	Rabbit	Humerus	os-50038-3	50038	450-425	1	5.2	44	16	3.3	−23.2	14.2	Juvenile	No
LATFR041	Rabbit	Mandible	os-50292-1	50292	425-400	1	6.5	49	18	3.3	−21.8	14.7		No
LATFR042	Rabbit	Coxal	os-50311-50	50311	425-400	1	9.9	43	15	3.3	−21.5	13.6		No
LATFR043	Caprine	Tibia	os-50030-75	50030	450-425	1	4.4	40	14	3.3	−20.7	6.0		No
LATFR044	Caprine	Tibia	os-50038-4	50038	450-425	1	14.1	43	16	3.2	−19.1	5.4		No
LATFR045	Caprine	Humerus	os-50292-101	50292	425-400	1	9.9	41	15	3.2	−21.1	8.3		Yes
LATFR046	Caprine	Radius	os-50292-103	50292	425-400	1	6.4	39	14	3.3	−20.7	5.3		No
LATFR047	Caprine	Radius	os-50311-29	50311	425-400	1	7.5	44	16	3.2	−20.8	11.2		No
LATFR048	Caprine	Tibia	os-50315-55	50315	425-400	1	7.1	41	14	3.3	−20.2	8.0		Yes
LATFR049	Caprine	Tibia	os-51104-45	51104	425-400	1	10.8	42	15	3.3	−20.4	5.5		Yes
LATFR050	Caprine	Tibia	os-51104-49	51104	425-400	1	4.7	46	17	3.2	−20.1	7.1		No
LATFR051	Caprine	Radius	os-53057-10	53057	450-425	1	5.0	34	12	3.5	−21.4	6.8		No
LATFR052	Caprine	Tibia	os-53229-20	53229	450-425	1	3.9	43	15	3.3	−19.7	8.4		No
LATFR053	Caprine	Tibia	os-53230-24	53230	450-425	1	7.4	43	16	3.2	−21.3	8.1		No
LATFR054	Caprine	Radius	os-53242-24	53242	450-425	1	2.2	44	16	3.3	−21.1	9.2		No
LATFR055	Caprine	Mandible	os-53328-2	53328	450-425	1	9.8	49	18	3.2	−20.0	6.6		No

LATFR056	Boar	Humerus	os-51104-78	51104	425-400	1	9.6	43	15	3.2	-20.7	8.2		No
LATFR057	Pig	Phalange II	os-50038-1	50038	450-425	1	8.2	47	17	3.2	-19.3	9.6		No
LATFR058	Pig	Metapodial	os-50292-75	50292	425-400	1	2.8	40	14	3.3	-20.6	4.9		No
LATFR059	Pig	Mandible	os-50292-43	50292	425-400	1	4.1	42	15	3.3	-19.8	5.0		Yes
LATFR060	Pig	Tibia	os-50311-15	50311	425-400	1	1.0	27	9	3.5	-20.3	12.1		No
LATFR061	Pig	Metapodial	os-50315-12	50315	425-400	1	7.9	44	16	3.2	-20.9	5.6		Yes
LATFR062	Pig	Metatarsal 5	os-50315-11	50315	425-400	1	6.4	44	16	3.3	-20.1	7.1		No
LATFR063	Pig	Radius	os-50332-9	50332	425-400	1	3.7	44	15	3.3	-20.8	4.5		No
LATFR064	Pig	Mandible	os-51104-62	51104	425-400	1	2.8	44	15	3.4	-19.0	9.9		No
LATFR065	Pig	Metapodial	os-53030-29	53030	450-425	1	1.4	37	13	3.4	-21.4	7.8		No
LATFR066	Pig	Ulna	os-53057-7	53057	450-425	1	7.9	35	13	3.2	-20.7	8.7		No
LATFR067	Pig	Phalange III	os-53229-36	53229	450-425	1	0.6	35	11	3.5	-20.8	6.4		Yes
LATFR068	Pig	Metacarpal 4	os-53230-16	53230	450-425	1	6.0	36	13	3.2	-20.8	6.2		No
LATFR069	Pig	Metatarsal 3	os-53242-14	53242	450-425	1	3.4	38	13	3.3	-20.2	10.4		No
LATFR070	Cat	Tibia	os-27648-3	27648	425-400	27	5.0	37	13	3.3	-19.6	8.8		No
LATFR071	Rabbit	Calcaneus	os-27463-11	27463	450-425	27	2.8	39	14	3.3	-21.9	10.1		No

Table 2 - List of animal bone samples analysed in this study. C:N molar ratios calculated using (%C/12)/(%N/14). Collagen yields were calculated using the weight of the resultant collagen as a percentage of the original bone sample. Those samples randomly excluded to achieve independence of samples when comparing means are indicated in the last column. * indicates sample was rejected for not meeting criteria for good quality collagen.

Samples selected for weed ecological analysis contained a minimum of 10 potential weed seeds (i.e. charred like the crop remains, identified more or less to species level, and excluding woody fruit/nut taxa that may have been collected resources and would in any case be unlikely to set seed as arable weeds) and three weed taxa. Since crop processing does not appear to bias functional weed ecological inferences of management intensity (Bogaard et al., 2005), samples of crop products, by-products, and mixtures of the two are considered together here.

Other studies have demonstrated that useful insights into past agricultural practices can be obtained using comparable sample coverage by integrating the isotopic compositions of animal bone collagen and charred crop remains (e.g. Vaiglova et al., 2014a) and functional weed ecology (Styring et al., 2017a). These studies also tend to focus on the main faunal domesticates (i.e. cattle, sheep/goat, pig) and important cereal crops such as free-threshing wheat, hulled barley, and a selection of pulses.

3.2 Sample Pre-treatment

Plant pre-treatment followed the method recommended by Vaiglova et al. (2014b), which includes the screening of a representative sub-sample using FTIR to determine the degree of carbonate, nitrate and humic acid contamination, if any, and hence the pre-treatment required. The nine samples chosen were measured in triplicate, with a different aliquot selected for each measurement and average values taken. Five samples were determined to have a slight carbonate presence corresponding to roughly 5-10% contamination according to Vaiglova et al.'s (2014b) experimental data (supplementary figs. 1-3). Humic acid and nitrate contamination were not detected.

In order to remove carbonate contamination, an acid only pre-treatment was applied to all plant samples. The samples were crushed into a homogenised powder and immersed in 0.5 M HCl at 80°C for 30 minutes. The acid was decanted and the samples rinsed three times in de-ionised water and then freeze-dried to remove any remaining liquid. The various pre-treatment steps resulted in an average loss of 46.6% (20.9-75.7%) in mass of the grain/seed.

Bone collagen was extracted using a modified version of the Longin (1971) method, outlined in Richards and Hedges (1999). Between 0.5-1.0g of bone was crushed into fragments with dimensions less than 3mm and then demineralised in 7ml of chilled 0.5 M HCl for seven days at 8°C. Following this, samples were rinsed three times with de-ionised water with the rinse water discarded. Gelatinisation of the samples was conducted at 65-75°C for 48 hours in pH3 HCl solution after which they were filtered using an Eze filter and freeze-dried.

3.3 Isotopic and elemental analyses

Isotopic and elemental analyses were conducted at the Research Laboratory for Archaeology and the History of Art, University of Oxford using a Sercon 20-22 stable isotope ratio mass spectrometer coupled to a Sercon Europa EA-GSL sample preparation system with helium carrier gas. Two-point linear normalisation of the results was performed using IAEA-CH-6 and IAEA-CH-7 for plant $\delta^{13}\text{C}$; IAEA-N-2 and IAEA-600 for plant $\delta^{15}\text{N}$; and seal collagen ($\delta^{13}\text{C}$: $\mu = -13.3$, $\sigma = 0.11$; $\delta^{15}\text{N}$: $\mu = 17.3$, $\sigma = 0.29$) and IAEA-600 for animal bone collagen $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$. Four samples of each standard were measured in each run with the exception of the single plant nitrogen run where three were used due to the incomplete combustion of one sample of each standard. An internal alanine standard ($\delta^{13}\text{C}$: $\mu = -26.91$; $\delta^{15}\text{N}$: $\mu = -1.63$) was used for drift correction and obtaining the raw sample values for uncertainty calculations. Intra-run precision was determined by calculating the uncertainty using Kragten's spreadsheet method (Kragten, 1994). Resultant carbon and nitrogen stable isotope values are expressed relative to international standards VPDB and AIR, respectively.

Plant $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values were measured in separate runs. Only one plant $\delta^{15}\text{N}$ run was possible due to delays caused by excessive sulfur build up in the mass spectrometer, likely from the sulfur content of the plant samples. Plant C:N ratios are similar to those of modern experimentally charred cereals and pulses (cf. Bogaard et al., 2013: Fig. S1). Of the collagen samples, 26 were analysed in duplicate with the means used. The average standard deviation for these duplicate runs was 0.20 for $\delta^{13}\text{C}$ and 0.17 for $\delta^{15}\text{N}$. Generally accepted indicators of good quality collagen are a C:N ratio of 2.9-3.6, carbon content greater than 13% and nitrogen greater than 4.8% (Ambrose, 1990). Only one sample did not meet these criteria (cattle bone LATFR001) and was rejected.

The average measurement uncertainty for animal $\delta^{13}\text{C}$ was ± 0.13 ‰ and ± 0.27 ‰ for $\delta^{15}\text{N}$. For plants, the average uncertainty was ± 0.13 ‰ for $\delta^{13}\text{C}$ and ± 0.31 ‰ for $\delta^{15}\text{N}$. Plant values have been adjusted for the effects of charring as per Nitsch et al. (2015), with 0.11 ‰ being subtracted from crop $\delta^{13}\text{C}$ and 0.31 ‰ from $\delta^{15}\text{N}$.

The $\Delta^{13}\text{C}$ of the C_3 crops were derived from the plant $\delta^{13}\text{C}$ (table 1) following Farquhar et al. (1982): $\Delta^{13}\text{C} = \frac{\delta^{13}\text{C}_{\text{air}} - \delta^{13}\text{C}}{1 + \delta^{13}\text{C}}$ (where $\delta^{13}\text{C}_{\text{air}}$ is the $\delta^{13}\text{C}$ of contemporary air). Contemporary $\delta^{13}\text{C}_{\text{air}}$ values were obtained from Antarctic ice core data and giving $\delta^{13}\text{C}_{\text{air}}$ of -6.4‰ (Elsig et al., 2009). The $\Delta^{13}\text{C}$ values were used to estimate moisture conditions based on Wallace et al.'s (2013) experimental results for well, moderately, and poorly watered wheat, barley and lentil.

All statistical tests were performed using the R (v2.15.1) base stats package and reported as significant at $\alpha=.05$. In all cases where parametric assumptions were met a parametric test was conducted, otherwise its non-parametric equivalent.

4. Results and discussion

4.1 Crop $\delta^{13}\text{C}$ and water availability ($\Delta^{13}\text{C}$)

The wetland environment and presence of a river near Lattara presented the potential for crops to receive significant amounts of water in addition to rainfall. Plots of crop $\Delta^{13}\text{C}$ values are shown together with Wallace et al.'s (2013) water availability ranges in figure 2. Barley thresholds should be around 1 or 2 ‰ greater than those of wheat based on modern studies of two- and six-row barley, respectively (Wallace et al., 2013), but a recent isotopic study of Neolithic six-row barley and wheat grains growing in fields receiving only rainfall and harvested in the same year demonstrate that this may be closer to 1 ‰ for *ancient* six-row barley (Styring et al., 2017a). Therefore a 1 ‰ offset from the wheat values has been incorporated into the six-row barley thresholds used here.

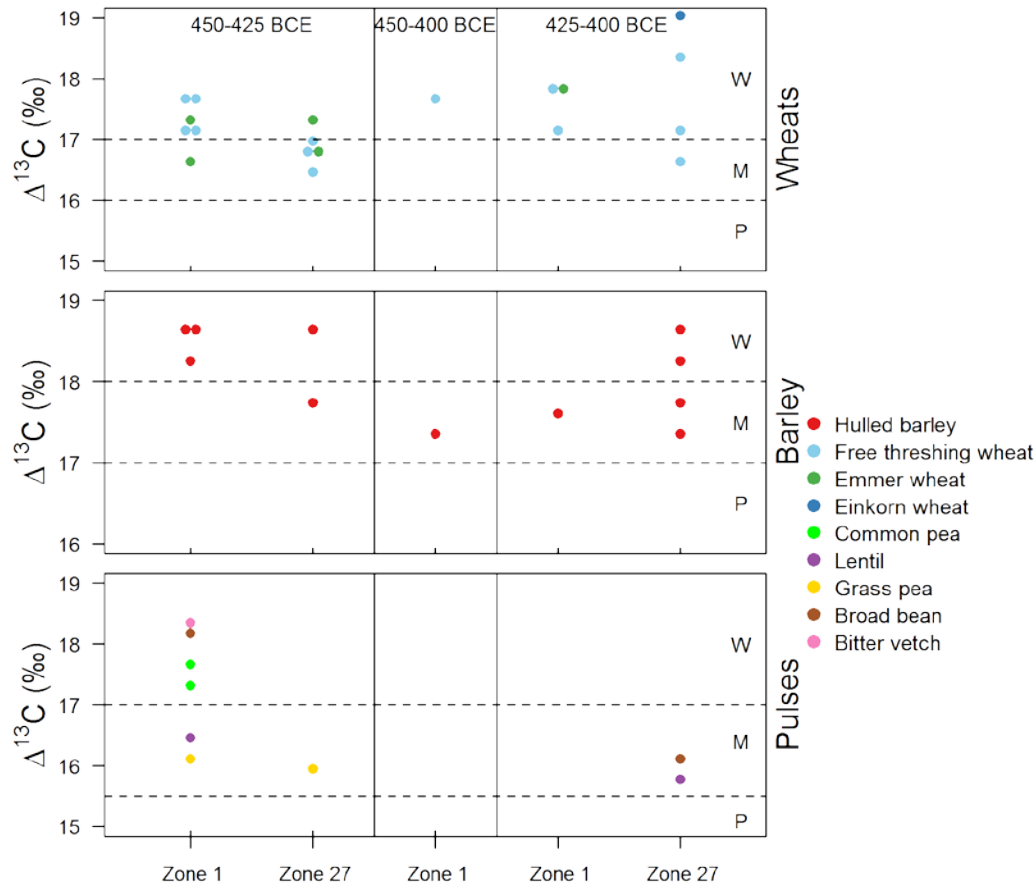


Figure 2 - Plot of crop $\Delta^{13}\text{C}$ and water availability ranges with dashed lines separating well (W), moderately (M) and poorly (P) watered zones, after Wallace et al. (2013). Barley reference lines incorporate a 1 ‰ offset from wheat values.

The average $\Delta^{13}\text{C}$ values of cereals indicate that on the whole they grew without water stress as might be expected for a settlement situated on a river delta with modern annual rainfall of 700-800mm (Ambert and Chabal, 1992). The pulses exhibit variable values with the means of bitter vetch, broad bean and common pea reflecting well watered conditions, while grass pea and lentil were moderately watered (Wallace et al., 2013). The range in values exhibited by both cereals and pulses can be accounted for by variability in soil moisture or by microenvironments, such as around wetlands, which can deplete ^{13}C through CO_2 respiration and calcium carbonate dissolution (Bouillon et al., 2011).

Differences in crop $\delta^{13}\text{C}$ between the two zones were examined across both periods (fig. 3). A statistically significant difference in mean $\delta^{13}\text{C}$ of free-threshing wheat between zones 1 ($\bar{x}=-23.3$ ‰, $s=0.26$) and 27 ($\bar{x}=-22.6$ ‰, $s=0.32$) during 450-425 BCE would suggest the grain was sourced from fields with different growing conditions at this time ($t(5)=2.97$, $p=.03$). $\Delta^{13}\text{C}$ values indicate that samples from zone 1 were grown in well watered conditions (mean $\Delta^{13}\text{C}=17.2$), while those from zone 27 were moderately watered (mean $\Delta^{13}\text{C}=16.5$). Between 425-400 BCE, free-threshing wheat from zones 1 and 27 shows no significant difference ($p=.86$) and was grown under well watered conditions (mean $\Delta^{13}\text{C}$ of 17.4 and

17.2, respectively). Neither hulled barley nor emmer exhibit any evidence for differentiation in their $\delta^{13}\text{C}$ values between the two zones.

The small quantity of pulses analysed prohibits a statistical comparison between zones. However, for those pulses analysed from both zones (i.e. broad bean, grass pea and lentil), those recovered from zone 1 grew under wetter conditions than those from zone 27 (fig. 2).

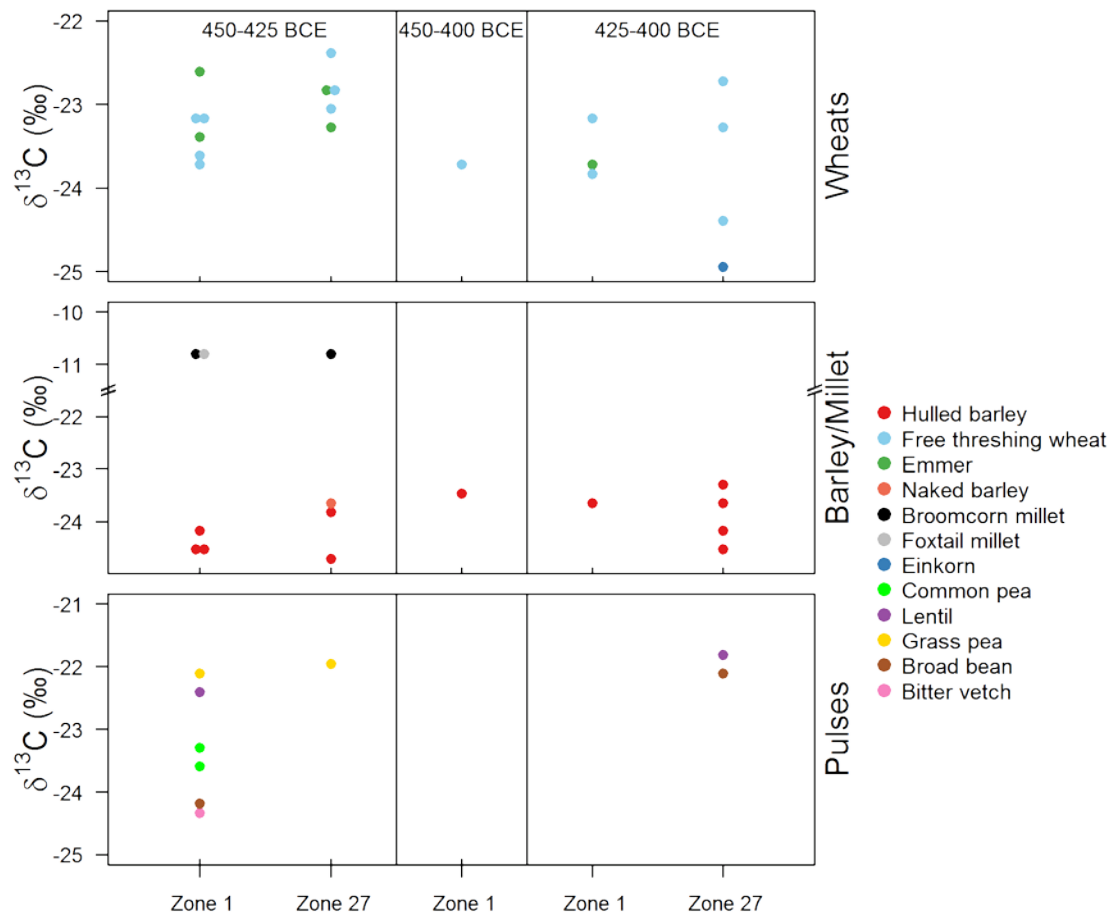


Figure 3 - Plot of crop $\delta^{13}\text{C}$ values. For C_3 crops the more negative the value, the more positive the $\Delta^{13}\text{C}$ and hence greater moisture available during the plant's development.

4.2 Crop $\delta^{15}\text{N}$

Since a number of conditions can affect crop nitrogen isotope values it is useful to evaluate the local growing environment when considering possible anthropogenic impacts. A local unmanaged vegetation 'baseline' was established using deer forage values. Both red and roe deer are mixed feeders and generally select open areas near the edges of forests when foraging (Myserud and Østbye, 1999), and so the deer $\delta^{15}\text{N}$ values may reflect a contribution of forest vegetation rather than solely arable land. This was not considered an issue, however, since the deer $\delta^{13}\text{C}$ values do not reflect significant "canopy effect", which is the depletion of ^{13}C due to CO_2 recycling from root respiration and decaying leaf litter as well as low-light photosynthesis in dense canopied forests (Ehleringer et al., 1987; Vogel, 1978). The local vegetation baseline range was calculated using the mean and standard deviation of the deer

bone collagen $\delta^{15}\text{N}$ and subtracting 4 ‰ for the trophic level shift (average of the 3-5 ‰ range). This results in a local baseline range of -0.9 - 1.1 ‰ (0.1 ± 1.0).

All of the cereal crops have values over 4.1 ‰ (fig. 4) suggesting that they were grown in different soil conditions to the unmanaged local vegetation as a result of anthropogenic factors (such as choice of arable soils and/or manuring). The possibility of crop manuring or middening at Lattara is hinted at by the presence amongst crop specimens of weeds that are found in nitrogen-rich soils, such as *Chenopodium album* and *Galium aparine*. Furthermore, weeds that grow in saline environments, such as *Salicornia* sp. and *Polypogon monspeliensis*, have been found in association with crops indicating some crops may have grown under saline conditions (Alonso and Rovira, 2010). Generally speaking, however, enriched ^{15}N due to soil salinity or the “sea spray effect” and arid conditions can be ruled out due to the elevated crop $\Delta^{13}\text{C}$ values, which would be lower in dry or saline environments (Isla et al., 1998). In such instances $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ would be positively correlated, which is not the case here ($r=-.33$, $p=.13$).

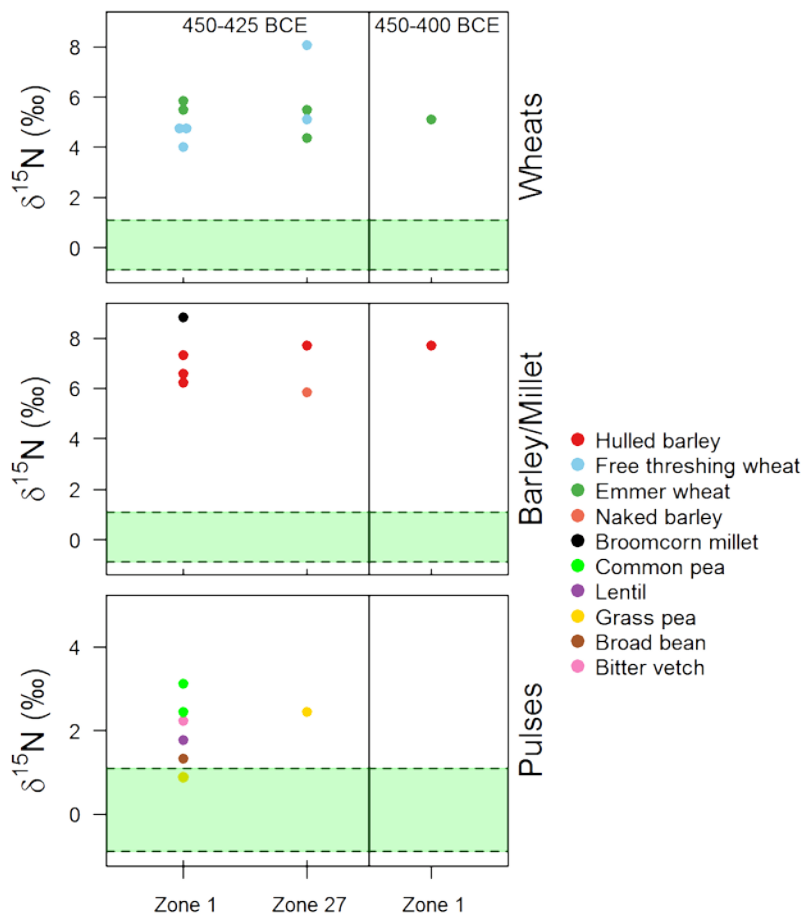


Figure 4 - Plot of crop $\delta^{15}\text{N}$ values. Shaded areas represent the local vegetation range calculated using the mean value of the deer collagen minus 4 ‰ for trophic level increase $\pm 1\text{sd}$ (i.e. -0.9 - 1.1 ‰).

The difference in mean $\delta^{15}\text{N}$ between hulled barley ($\bar{x}=7.2$ ‰) and emmer ($\bar{x}=5.3$ ‰) is statistically significant ($U=0$, $p<.01$). If the one free-threshing wheat outlier enriched in ^{15}N is excluded, then free-threshing wheat would also be significantly different to the hulled barley

(i.e. $\bar{x}=4.7\text{ ‰}$; $U=0$, $p=.02$). This observation indicates that barley likely grew on different plots to the wheats and the similarity in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of free-threshing wheat and emmer suggests they were grown in the same or similarly treated fields.

The observed pattern of isotopic differences between wheat and barley has roughly contemporary parallels at Early Iron Age sites in southwest Germany. Here it is believed that barley was treated favourably with greater amounts of manure due to its role in the production of beer, a beverage with symbolic social significance (Styring et al., 2017a). Such a role is not evidenced archaeobotanically at Lattara. However at Roquepertuse, some 130km to the east, germinated barley grains possibly used in beer production have been identified in 5th century BCE levels (Bouby et al., 2011). If preferential manuring of barley was indeed practiced by Iron Age ‘Celtic’ peoples in western Europe, then the pattern we are seeing at Lattara may reflect a widespread custom.

As expected for nitrogen-fixing taxa, the pulses exhibit the lowest $\delta^{15}\text{N}$, all under 4 ‰, and of these common pea has the highest values. Studies conducted by Fraser et al. (2011) revealed that only when treated with high levels of manure did pulse $\delta^{15}\text{N}$ show significant increases above atmospheric values (i.e. 0 ‰). More recently, Treasure et al. (2016) reported increases of ca. 1.5 ‰ in broad beans grown in plots treated with 70 tonnes of manure per hectare when compared to those grown in unmanured plots. The $\delta^{15}\text{N}$ of the Lattara broad bean sample is 1.4 ‰, which suggests it may have been grown in an intensively manured field. In fact, apart from one of the grass pea samples (0.8 ‰), the remaining pulses are all over 1.9 ‰, implying they too may have been subjected to intensive manuring.

The small sample size of plant $\delta^{15}\text{N}$ values does not permit a statistical comparison between zones; however, some patterns are apparent in the limited data. All of the free-threshing wheat, hulled barley and grass pea samples from zone 27 have higher values than those from zone 1 (fig. 4). In terms of agricultural intensity, lower crop $\delta^{15}\text{N}$ composition tends to reflect more extensive farming practices involving lower labour inputs per areal unit (Styring et al., 2017a).

4.3 Analysis on the basis of functional traits of arable weeds

Figure 5a shows the relationship of surveyed present-day fields managed with low-intensity cultivation in Provence, France and high-intensity cultivation in Asturias, Spain to the discriminant function extracted to distinguish between these regimes on the basis of semi-quantitative (presence/absence) weed attribute scores, using five functional attributes relating to soil fertility and disturbance as discriminating variables (cf. Bogaard et al., 2016). The discriminant function was used to classify archaeobotanical samples from Lattara (Fig. 5b). There is a tendency for samples from zone 27 to be distributed toward the ‘high-input’ (Asturias) end of the discriminant function, while samples from zone 1 occur towards the ‘low-input’ end of the function, though there is also overlap. The implication is that zone 27 crops tended to derive from growing conditions that were more intensively maintained (e.g. manured, weeded, thoroughly tilled) than those from zone 1.

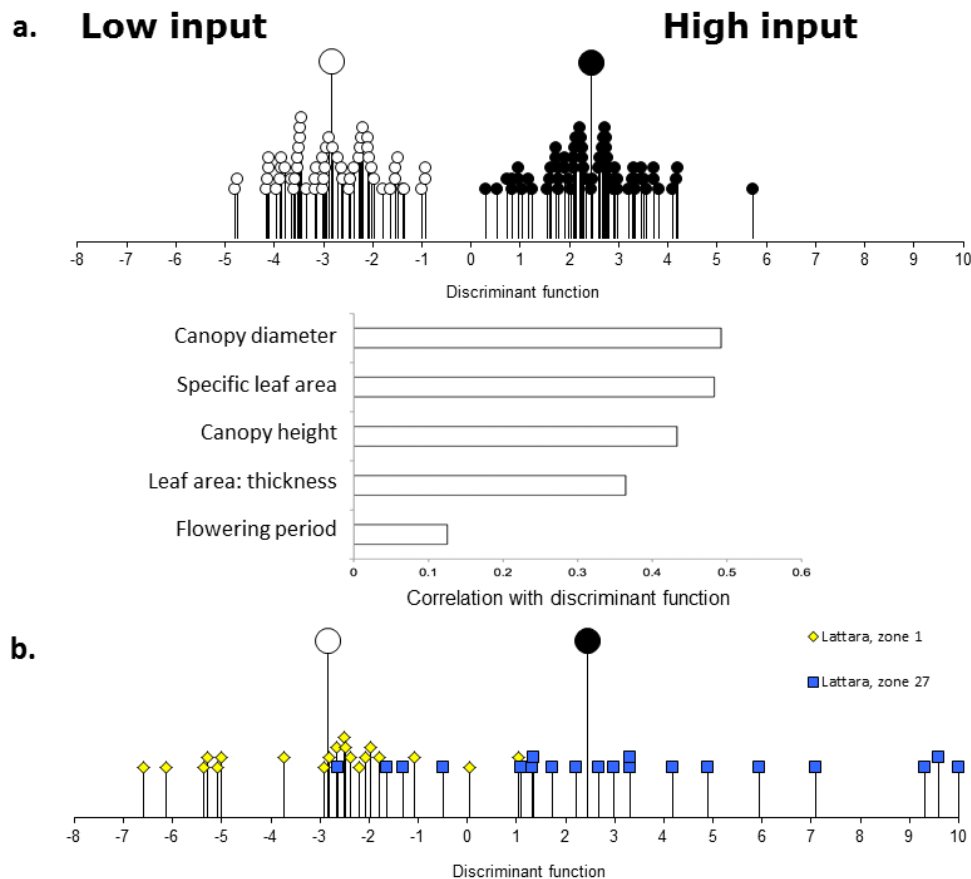


Figure 5 - (a) Relationship of modern weed samples from Provence (white circles) and Asturias (black circles) to the discriminant function extracted to distinguish between extensive and intensive regimes; large circles represent centroids. (b) Lattara samples extracted to the same discriminant function with yellow diamonds representing zone 1 and blue squares zone 27.

4.4 Animal management

Cattle, pig and caprine samples produced $\delta^{13}\text{C}$ values that were similarly constrained in range, between 2.4-3.1 ‰. Their $\delta^{15}\text{N}$, however, yielded greater variation within species with cattle having a range of 3 ‰, caprines 6 ‰ and pig 7.5 ‰ (table 2). The high range in values is a possible indication of different foddering strategies or, especially for herbivores, of herding through different vegetation types.

The numerous landscape zones around Lattara would have offered a range of options to farmers rearing livestock, with the variety of graze, browse and fodder potentially providing unique isotopic compositions. At times of the year when wild vegetation was less abundant or when animals needed fattening prior to slaughter, crop-related fodder would have been a useful dietary supplement.

The isotopic evidence points to a range of different animal management strategies (figs. 6 and 7). Elevated $\delta^{15}\text{N}$ of some herbivores relative to the wild deer indicates they were managed in such a way as to target specific forage or were foddered on crops and their by-products. No doubt farmers at Lattara would have herded animals on non-arable land such as that found along the wetlands proximate to the city, where forage values may have been elevated in $\delta^{15}\text{N}$ by soil denitrification and/or salinity. Moreover, fodder comprising chaff and straw from

crops enriched in ^{15}N would have been available in the fields where threshing likely took place (Alonso and Rovira, 2010); however, the lower nitrogen content of the non-seed components of crops, as well as their lower $\delta^{15}\text{N}$ relative to the seed, suggests a smaller overall impact on the nitrogen isotopic values than the grain/seed (Bogaard et al., 2007; Fraser et al., 2011; Styring et al., 2017a). The slightly enriched ^{13}C values of some cattle and caprines could indicate minor C_4 plant consumption if we consider a diet-to-collagen spacing of 5 ‰ above our C_3 grain/seed values, which are further elevated above other plant components such as chaff (Wallace et al., 2013). Modern cattle are known to graze on immature *Eragrostis minor* plants, a C_4 species that has been recovered from ancient levels at Lattara (Alonso and Rovira, 2010; Quattrocchi, 2006). However, due to the subtlety of the ^{13}C enrichment, any C_4 consumption would need to be confirmed using an alternate method such as high-resolution sampling of tooth enamel.

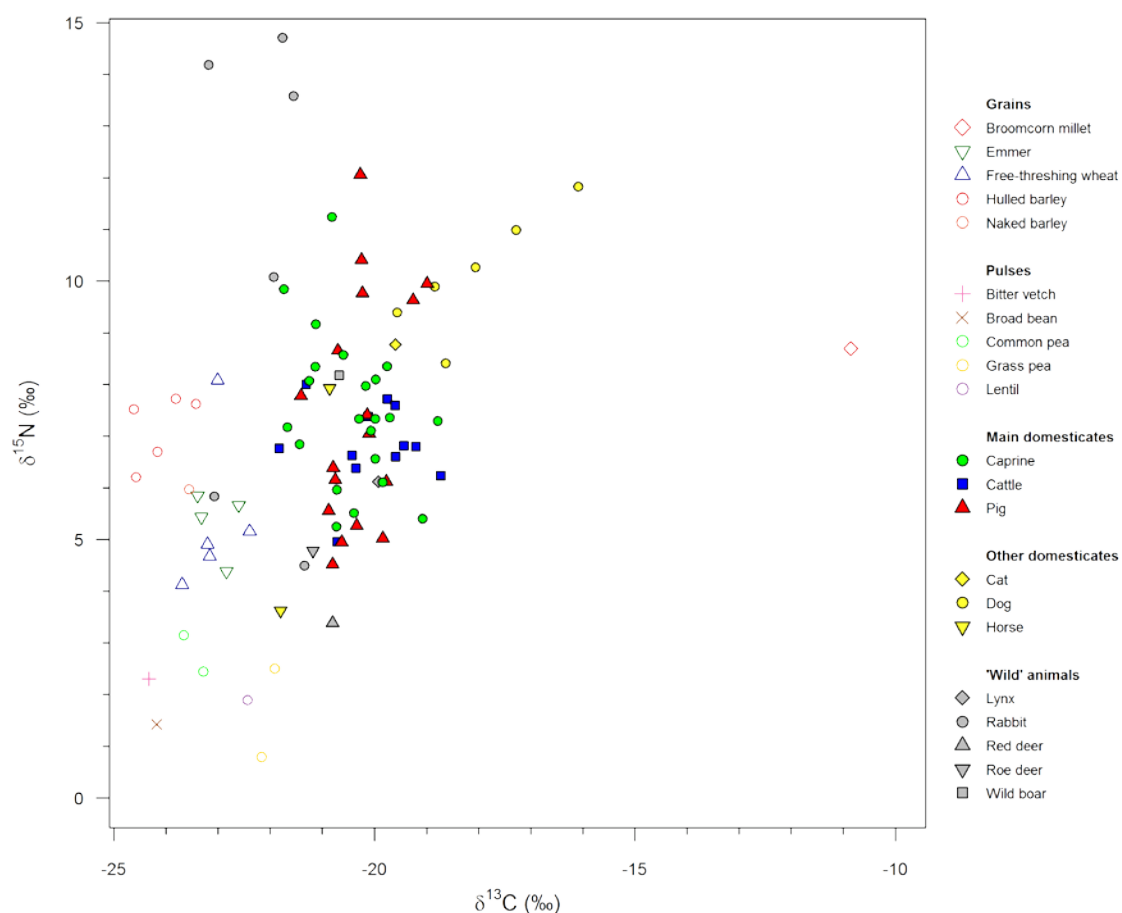


Figure 6 - Plot of animal and plant $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values.

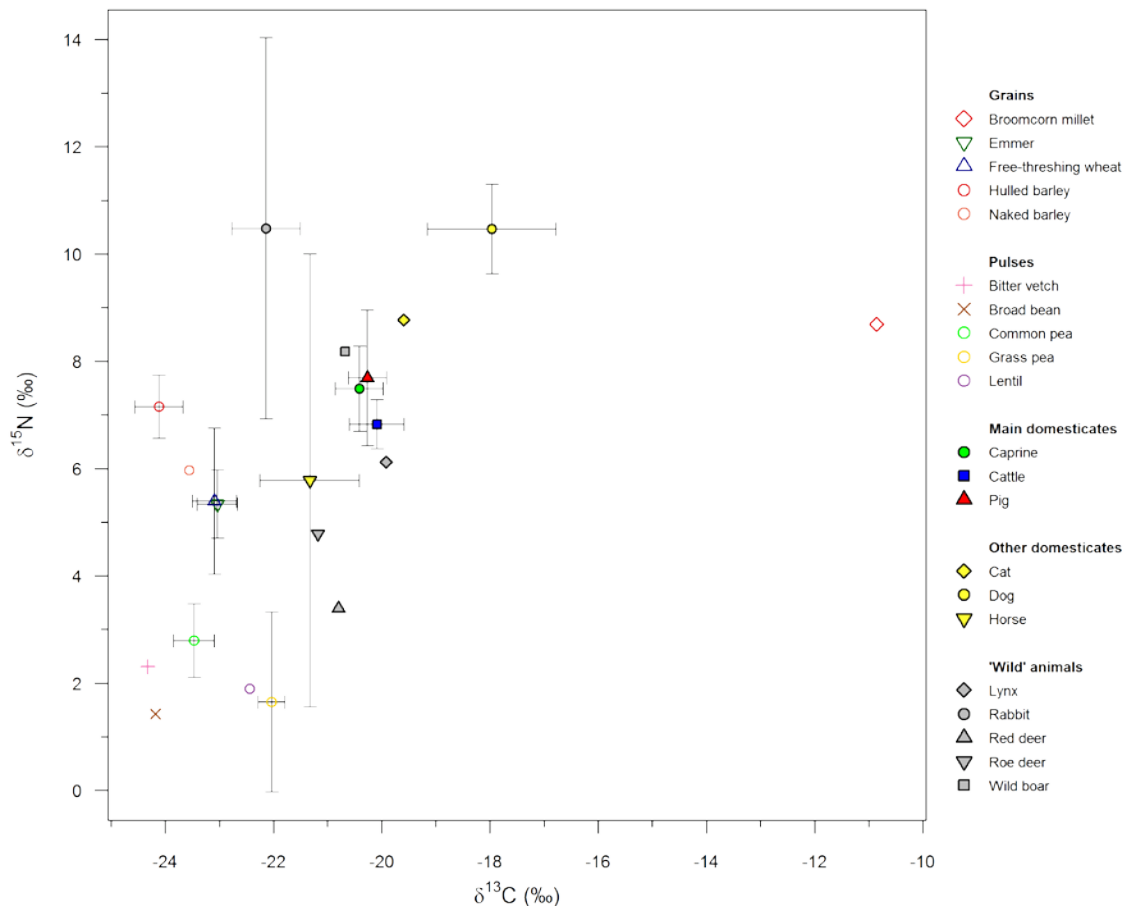


Figure 7 - Plot of animal and plant mean $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values with 95% confidence intervals.

Most cattle samples show small variance (fig. 8a), which could suggest they consumed a restricted diet as part of a focused foddering and/or herding strategy. Dental microwear analyses, which provide evidence from the last weeks of an animal's life rather than the average over their lifetime as is the case with bone collagen, reveal that cattle had extensive dietary input (Rieau, 2014). If most cattle were managed as part of a single large herd then we would expect the isotopic results to reflect a relatively narrow diet, as is the case here. Caprine values (fig. 8b), on the other hand, are more widely dispersed, indicating a broader range of diets that are also slightly elevated in $\delta^{15}\text{N}$ relative to cattle. The diversity in values may stem from the distribution of caprines in a number of scattered flocks.

As omnivores, pigs can eat just about anything including carrion, faeces, decaying vegetation and household waste. A number of the analysed samples exhibiting elevated nitrogen isotopic values (fig. 8c) might therefore result from the feeding of individuals close to or within the settlement on leftovers from human consumption. There is also a cluster of samples with $\delta^{15}\text{N}$ lower than the wild boar that could reflect significant legume consumption or indicate free-ranging individuals with a large proportion of wild plant-based protein in their diets. In fact, according to the 1st century BCE Roman author Strabo, the Gauls were noted for letting their pigs run wild (Strabo *Geography* IV.4.197).

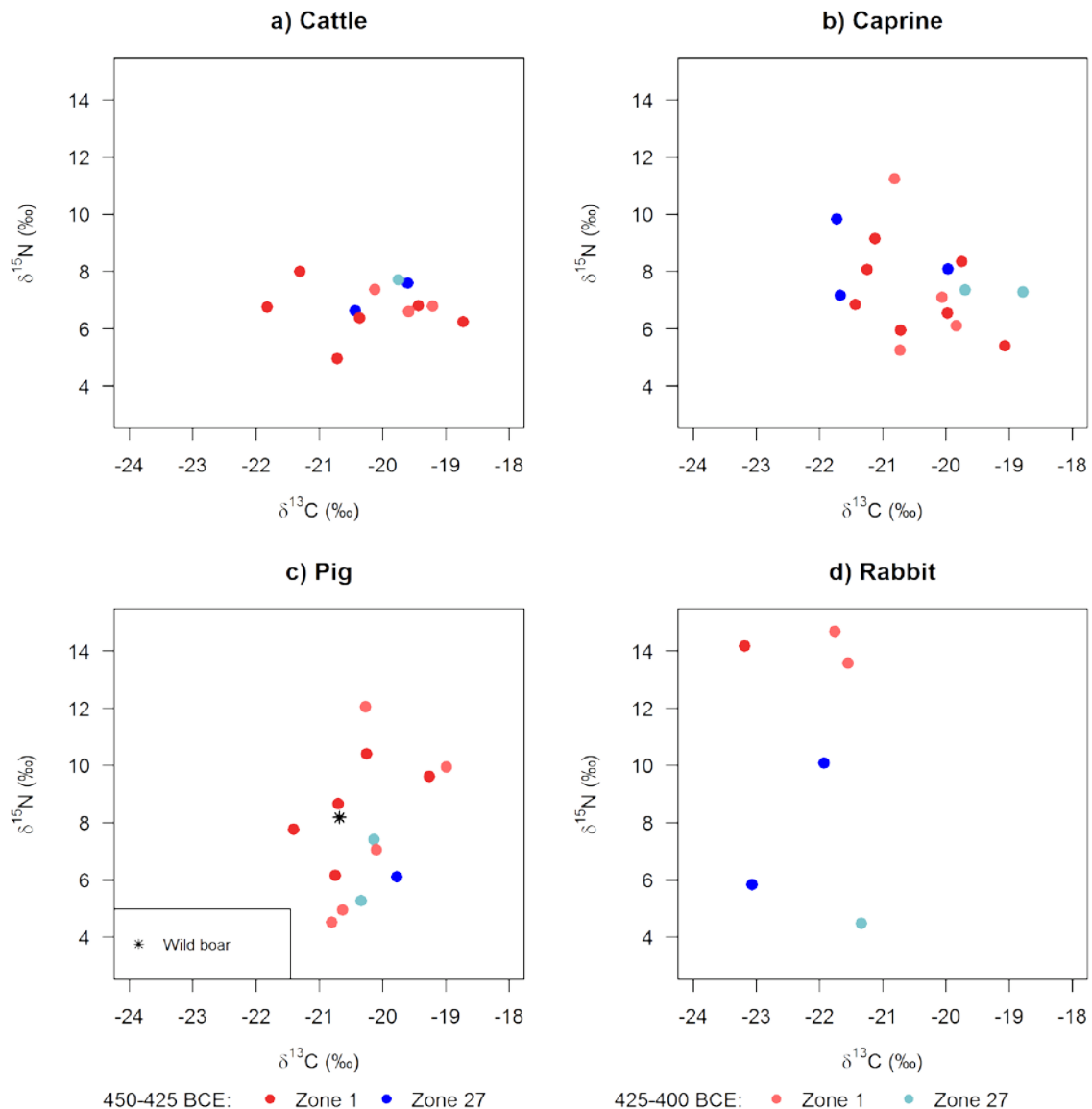


Figure 8 - Plot of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of (a) cattle, (b) caprine, (c) pig and (d) rabbit. Only those caprine and pig samples that were used to compare means (see table 2) are plotted here.

The mean dog $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values are higher than most other species (fig. 7). Dogs will consume human food waste and faeces and so develop similar isotopic signatures to humans, demonstrated to be within 2-3 ‰ of associated human values (Guiry, 2012). Dog isotopic compositions can thus provide useful data for a region where cremation was the predominant funerary practice during the Iron Age, since the excessive temperatures reached severely damage or destroy bone collagen. The positive correlation of $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values ($r=0.85$, $p=.03$) and enriched ^{13}C of most Lattara dogs (fig. 6) suggests they received most of their protein from animal sources, with marine foods a significant contributor. Based on artefacts and fish bone remains, the consumption of seafood would have played a considerable role in the human diet here (Piquès, 2010; Rivalan, 2010). Millet could also have featured in the canid (and human) diets at Lattara, resulting in elevated $\delta^{13}\text{C}$ as has been suggested for human populations living in northeastern France during the Iron Age (Goude et al., 2014).

4.5 Rabbits at Lattara

Rabbits are the only animals to produce evidence of isotopic differentiation between the two zones (fig. 8d). The difference in mean rabbit $\delta^{15}\text{N}$ between zone 1 ($\bar{x}=14.2\text{‰}$) and zone 27 ($\bar{x}=6.8\text{‰}$) is statistically significant ($t(4)=4.29$, $p=.01$), implying they were sourced differently. Duplicate measurements of two of the three highest samples (LATFR040 and LATFR042) revealed similar results (avg. s.d. $\delta^{15}\text{N}=0.03\text{‰}$). One of those over 14 ‰ comes from a weaned juvenile, so in this case the residual effects of nursing could be partly responsible since breast milk has been shown to enrich infant ^{15}N (Fogel et al., 1989; Steele and Daniel, 1978), but given the fast turnover of bone in rabbits the effect would only be subtle.

To attain such high $\delta^{15}\text{N}$ values the rabbits would have needed to feed primarily on a diet with highly elevated $\delta^{15}\text{N}$, such as vegetation growing in a saline or wetland environment. Rabbits have been observed living in sand dunes by salt marshes and consuming vegetation growing in these brackish conditions, such as *Aster tripolium* which has produced reasonably high $\delta^{15}\text{N}$ values in modern samples collected from Normandy (Riera, 2007; Rowan, 1913). Other factors that may have contributed somewhat to elevated $\delta^{15}\text{N}$ are nutritional stress and, in theory, rabbit coprophagy (Katzenberg and Lovell, 1999; Ugan and Coltran, 2011).

Rabbits were also the only species to exhibit evidence of diachronic change in isotopic values. There is a statistically significant rise in mean rabbit $\delta^{13}\text{C}$ between the two periods ($t(4)=2.83$, $p<.05$). The limited sample size combined with the small variance in means between the two periods implies this result should be tentative at best; however, the difference in mean $\delta^{15}\text{N}$ between the two zones is quite large implying a greater degree of confidence in the statistically significant result.

4.6 Variability of agricultural production in the context of early urbanisation

Studies comparing agricultural intensity during early urbanisation have demonstrated that increasingly extensive cultivation is often a necessary corollary to urban growth, with surplus production needed to support the growing population of craft specialists, merchants and other non-agriculturalist classes (Styring et al., 2017a; 2017b). These studies reveal that as settlements expand in size, their agricultural intensity (per unit area) decreases, since in principle extensive, low-input cultivation can achieve much greater surpluses than small-scale intensive cultivation.

Agriculture was the largest component of the ancient Mediterranean economy (Garnsey, 1999), and it is useful to view the results presented here in the context of the urbanisation phenomenon that commenced in the French Mediterranean about a century prior to our period of study (Py, 1993: 98-102). The foundation of the Greek colony of Massalia was the catalyst for indigenous urban development in mediterranean France, driven at least in part by Massalia's dependence on external grain supplies (Dietler, 2007; Garcia, 2005). Massalian reliance on grain imports would have encouraged indigenous settlements to extensify cereal production in exchange for commodities produced by the Massalians, especially wine, and

543 this would have stimulated further urbanisation and increased social stratification (Dietler,
544 1990; Garcia, 2005).

545 Trade at Lattara was firmly under the influence of Massalia during the late 5th century as
546 evidenced by ceramic imports that are overwhelmingly Massalian in origin (Gailledrat, 2015;
547 Janin and Py, 2012). With good access to navigable waterways and a hinterland sufficient to
548 cultivate cereals and pasture animals, Lattara was ideally situated to link into the commercial
549 network that had developed with the foundation of the Greek colony.

550 The cereal grains from Lattara analysed in this study received ample water and the range of
551 isotopic values imply some additional water availability such as from naturally wet soil,
552 possibly near the river; palynological data indicate that some cereals were likely grown in
553 plots near the river just to the north of the settlement, while the presence of saline species
554 (such as *Suaeda maritima*, *Ruppia maritima* or *Salicornia* sp.) in context with crops suggests
555 planting near liminal areas by the coast (Alonso and Rovira, 2010: fig. 17; Puertas, 1998).
556 Pulses were grown under varied watering regimes, suggesting planting in soils with differing
557 moisture levels and perhaps some manual irrigation. Nitrogen isotope values indicate that the
558 soils were generally nutrient-rich. Fields may have received manure from animals grazing on
559 crop stubble or during fallow periods. The herding of animals in the floodplains just outside
560 Lattara is evidenced by the identification of coprophagous insects associated with
561 herbivorous mammals less than a kilometre to the north (Bel and Daveau, 2008). Farmers
562 would no doubt have also taken advantage of non-arable land such as salt marshes for grazing
563 their cattle and caprines, contributing to elevated nitrogen isotopic values.

564 Evidence suggesting Lattara was involved in agricultural trade is provided by pollen core
565 samples taken near the ancient port. Concentrations of cereal pollen free from that of ruderal
566 weeds imply that clean grain was shipped since substantial threshing here is deemed unlikely
567 (Puertas, 1998). Possible trade in grain has also been suggested based on the evidence of
568 weeds from both wet and dry conditions found in association with crop remains (Rovira and
569 Alonso, 2010). It is uncertain, however, whether this trade in grain was inbound, outbound, or
570 both, considering Lattara may have been a transit point for market goods (Gailledrat, 2015;
571 Rovira and Alonso, 2017).

572 In fact, cereals arrived at Lattara already in a semi-clean state, ready for daily consumption.
573 Most of the cleaning operations carried out after the harvest (from threshing to coarse
574 sieving) would have been carried out near the fields, or in any case outside the city. Only fine
575 sieving and final hand cleaning, prior to grinding or other culinary preparation, would have
576 taken place inside the walls. Therefore, most of the samples correspond to grain products and
577 by-products from the last domestic crop-processing stages, generated by slow and repeated
578 deposition. As we have mentioned previously, in zone 1 the variety of plants consumed is
579 high, with naked wheat as the main cereal; the remains here are the product of regular
580 domestic consumption practices. However, in zone 27 the dominant plants are cereals, mainly
581 hulled barley, and they reveal a focus on activities associated with cereal processing in open
582 spaces. The abundant concentrations of charred hulled barley remains associated with ovens

are the result of rapid repeated and single depositions due to multiple roasting actions (Alonso and Rovira, 2010).

When growing primarily for the market, extensive cultivation is more likely to be the chosen farming regime in order to produce more tradeable surplus. The evidence from the two quarters implies that the residents of zone 1 were more inclined to consume crops grown in this fashion, while consumption patterns of people in zone 27 align more closely with small-scale subsistence agriculture. Moreover, the free-threshing wheat from zone 1 between 450-425 BCE was grown under wetter conditions than that from zone 27, also hinting at surplus cereal cultivation since water availability is positively correlated with grain yield (Condon et al., 1987). Although we premise that farmers did indeed live in Lattara during the 5th century BCE, our data support the proposal that zone 1 was home to people who were rather involved in mercantile or craft activities (Gailledrat, 2015:45-6), implying that they were not subsistence farmers and that much (if not all) of their food was sourced from those involved in surplus production.

The common presence of animals in the city is well attested during the Iron Age by the construction of enclosures near the houses, footprints in the streets, as well as the occurrence of coprolites and fodder waste in public spaces (Gardeisen 2003; Py 2012). Concerning husbandry practices, the lack of contrast in the isotopic composition of domestic animals between the two zones indicates they were likely managed or sourced similarly. The internal variability amongst the pigs and caprines suggests that these species may have been sourced from a number of suppliers, or that their management regimes varied annually based on the availability (or accessibility) of pasture and crop surpluses. The cattle, on the other hand, likely followed a similar diet and may well have been procured from the same supplier. The rabbits were the only animals that the two zones sourced from different places and would indicate distinct hunting grounds if the rabbits were not purchased from a vendor.

When both zones are considered together, our results exhibit some similarities to another study from the AGRICURB research group that analysed crop and faunal remains from Iron Age rural and fortified hilltop sites in south-west Germany (Styring et al., 2017a). As at Lattara, cattle reveal little variance and caprines a broader range of isotopic values. Barley from these sites shows evidence of greater manuring than other cereals, and crops in general were grown in nutrient rich soils. Weed functional data demonstrate a trend towards modest extensification during the Iron Age. Overall the results are believed to reflect a degree of variation between plots with no evidence of large scale control of agriculture (Styring et al., 2017a). The weed functional data from the two Lattara zones combined reveal a range of values and do not show any clear patterns, which is what we would expect to see in such a socio-economically diverse society as likely existed here.

5. Conclusions

The results of the stable isotope analyses of faunal and charred plant remains from Lattara, together with the functional ecological analysis of crop weed flora, have revealed new insights into agricultural production here between 450-400 BCE. Crops show evidence for taxon-specific approaches to soil treatment (or plot selection), while the range of domestic

animal isotope compositions suggests a variety of management strategies. The results thus obtained suggest that farmers in the city during the 5th century BCE exploited well watered nearby fields and probably other drier land, even if the importation of foodstuffs from the hinterland is not excluded. As regards to agriculture, cereals and pulses are the main crops for this period, but gradually Lattara developed a growing viticulture that would make it stand out from other contemporary Languedoc sites from the 3rd-2nd centuries BCE (McGovern et al., 2013; Rovira and Alonso, 2017). Livestock, at least in part, were also kept and managed in the city and consumed the products or by-products grown in the diverse fields attested. So, Iron Age urban centres, in particular coastal trading posts as Lattara, not only organised trade and craftwork but also agropastoral activities.

Our study has also highlighted the mixed nature of urban production and consumption patterns and, as hypothesised, the faunal and plant remains from the two archaeologically disparate zones at Lattara do exhibit ecological differences, supporting other evidence that they belonged to people from different social groups and/or economic means (Gailledrat, 2015; Py, 2009; 2012). The population included those who likely practiced a degree of intensive subsistence agriculture (zone 27) as well as those who may have been exclusively consumers of surplus crops produced under more extensive management (zone 1). As M. Dietler (2010: 184) points out, “people do not ingest calories or protein: they eat food, a form of material culture subject to almost unlimited possibilities for variation in terms of ingredients, techniques of preparation, patterns of association and exclusion, preferences and prohibitions, modes of serving and consumption, aesthetic and moral evaluations, and so forth”. Food practices are hence a key index for analysing identity, social status and cultural change around the world and through time. The results of our study demonstrate that the combination of crop and animal stable isotope compositions with weed functional ecology is a useful method to complement archaeological evidence in the identification of such socio-economic differences.

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