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Mobility of cattle in the Iron Age and Roman Netherlands

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ABSTRACT

$^{87}Sr/^{86}Sr$ isotope analysis was performed on 45 cattle teeth, 5 sheep/goat teeth and 2 pig teeth from two archaeological sites in the Netherlands, dating to the Iron Age and Roman period. This makes it one of the largest strontium isotope projects focusing on animals from the Netherlands - to date. An integrated approach was taken, combining the strontium results with those from archaeology and zooarchaeology. Mobility of cattle in the Iron Age is demonstrated for five of the 23 analysed samples from the rural settlement of Houten-Castellum by strontium isotope analysis. Three animals travelled over considerable distances (over 150 km) to Houten and oxygen and carbon stable isotope values support a non-local origin for one of these animals. There is little evidence for incoming animals at this site during the Roman period with only one animal recording a non-local strontium isotope signature. In contrast, strontium isotopes indicate at least four different geographic origins for livestock in the Roman town of Heerlen, with none of the cattle being local. The results highlight the differing behaviour in the two sites. Whereas for a rural settlement like Houten, the Iron Age influx of animals might be explained by gift exchange, trade or cattle raids, it is likely that the flow of traded livestock during the Roman Period would go from rural settlement to towns and army camps. Heerlen represented the destination of animals derived from the surrounding areas to supply an active Roman town.

1. Introduction

Iron Age society in the central part of the Netherlands was based on mixed farming with a strong pastoral component (Brinkkemper & Van Wijngaarden-Bakker, 2005). This ties in with the river landscape, which offered limited space for growing cereals and other crops but plentiful rich grazing land for livestock (Groot & Kooistra, 2009). Society was egalitarian and self-sufficient in terms of food. Zooarchaeological research has shown the dominance of cattle compared to other farm animals (Van Dijk, 2016; Brinkkemper & Van Wijngaarden-Bakker, 2005; Roymans, 1999, 292). Cattle always played a crucial role in this region, in supporting arable farming by traction and manure, in providing food in the form of meat and dairy products, and in providing raw materials for clothing and artefacts; they also had an important social and status significance (Van Dijk & Groot, 2013; Roymans, 1999).

Two hypotheses concerning Iron Age cattle are relevant to this paper. First, based on ethnographic parallels of other cattle-dominated societies, Roymans (1999) concludes that in the Iron Age Netherlands, cattle represented wealth and were used as a medium of gift exchange at social occasions, such as marriage. Second, cattle may have been the target of raiding (Hiddink, 1999, 174-177). The role of cattle as an exchange medium, cattle raiding and the movement of ethnic groups – almost certainly with their livestock (Roymans, 2004) – would all result in a strong mobility of cattle. The mobility of people and animals in this region in the Iron Age has recently been demonstrated (Kootker et al., 2017), but its extent remains unclear.

The incorporation of the southern half of the Netherlands into the Roman Empire had a major and widespread impact on farming; this included the introduction of new crops and animal species, a size increase in livestock, intensification of agriculture, a higher degree of specialisation and better organisation of storage and transport of surplus goods (e.g. Groot et al., 2009; Groot, 2016; Groot & Kooistra, 2009). The agrarian economy was transformed from mainly self-sufficient to surplus-producing. An early monetary economy facilitated transactions between the agricultural producers and the urban and military consumers, and a more distinct separation between town and countryside took place. There is evidence that some food was supplied from outside the region (Kooistra, 2009, 2018; Pals & Hakbijl, 1992), but most of the meat is assumed to have come from local supply, with cattle as the main meat provider in the Roman towns and army camps. Cattle were also important as transport animals.

Although species proportions, as well as age and biometric data,

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suggest both the local supply of cattle and the import of cattle from elsewhere (Groot, 2016; Kooistra & Groot, 2015), neither has been proven beyond doubt. The size increase occurring in cattle in the Roman period may have been at least partly due to interbreeding with imported cattle. Movement of ethnic groups also occurred in the Roman period: in the Early Roman period this has been suggested for sites in Utrecht-Leidsche Rijn (Langeveld, 2010), while in the Late Roman period, migrations are documented historically, and house types and pottery typical for the northern Netherlands have been identified in several sites in the central Netherlands (Heeren, 2006, 2009, 72–73; Van Renswoude, 2009). One way of tracing these movements would be through an analysis of livestock mobility. This paper will contribute to answering some of these questions by investigating radiogenic and stable isotope evidence from cattle from both an Iron Age-Roman rural settlement and a Roman town.

Strontium isotopes provide a mechanism for relating fauna to its geographic origin because of the link between soil strontium composition (transmitted via plants into the food chain) and the geographic distribution of the underlying, geological source of strontium. A clear relationship between food ingestion and tooth enamel composition in animals has been shown in modern experiments (Lewis et al., 2017) supporting the argument that animals provide a simple and direct link, via their food, to the areas which they grazed. Studies based on animal tooth enamel include using them to establish baseline data, on the assumption they are in situ and local (Zhao et al., 2012); using the animals' movements to trace/establish hunting routes (Haverkort et al., 2008; Britton et al., 2011); to provide a proxy for origin for their human "owners" at feast sites (Evans et al., 2019; Madgwick et al., 2019b; Vaiglova et al., 2018; Viner et al., 2010); tracing the introduction or spread of exotic species (Sykes et al., 2006); animal management strategy (Sharpe et al., 2018) and for assessing trade routes (Madgwick et al., 2019a; Minniti et al., 2014). The hypsodont structure of the herbivore tooth provides the opportunity for high resolution analysis of seasonal behaviour, commonly used in dietary and seasonality studies (Balasse, 2002; Towers et al., 2011). In this study we have chosen to maximize the number of animals we can study using strontium by taking a single sample from each animal (Minniti et al., 2014). Both strontium and stable isotope analyses in the Netherlands have so far mostly focused on humans (e.g. Kootker et al., 2019; Plomp et al., 2020; Schats et al., 2014; Smits & Van der Plicht, 2009; Smits et al., 2010; Waters-Rist & Palmer, 2016), with a few exceptions (e.g. Kootker et al., 2017; Kootker, 2019; McManus et al., 2013). Kootker et al. (2016) mapped the bioavailable strontium for different regions in the Netherlands, which provides a valuable tool for interpreting strontium values.

This paper will investigate mobility of cattle in the Iron Age and Roman Netherlands through radiogenic and stable isotope analysis (strontium, oxygen and carbon) of cattle teeth from two archaeological sites. This will provide insight into mobility of people, exchange and/or raiding of cattle in the Iron Age and short- and long-distance imports of cattle in the Roman period, whether as food, transport animals or to improve local stock.

Our main questions for this paper are:

- is there evidence for cattle mobility in a rural settlement, and are there changes over time in the extent of cattle mobility?

- is there evidence for cattle and other livestock mobility in a Roman town? If so, what was the geographic origin of the meat supply of a Roman vicus in the 1st century CE?

The two sites are located in different geological regions. The site of Houten in the Roman period is expected to have supplied livestock to towns and military camps within the same geological region, which means local movement of animals cannot be detected in those towns and military camps. Heerlen is located in a more geologically diverse region, so that we have a better chance of detecting movement of animals. Combining the two sites will provide a more comprehensive picture of animal movement in the Iron Age and Roman Netherlands.

2. Material and methods

Mobility of humans and animals can be investigated through isotope analysis. The ratio of $^{87}Sr/^{86}Sr$ varies between different rocks and sediments (Bentley, 2006). This variation is directly reflected in drinking water and vegetation consumed by livestock. The body tissues of livestock will have a similar ratio to the food and water consumed. After burial, however, bone and dentine will slowly take on the ratio of the local soil, while tooth enamel is not affected by diagenesis and will retain the signal of the region where the animal lived during the formation on the tooth enamel (Bentley, 2006). By comparing $^{87}Sr/^{86}Sr$ ratios of tooth enamel to known ratios of bioavailable strontium for the archaeological location where the animal was found, it is possible to identify non-local animals and establish a range of possible origins (e.g. Balasse et al., 2002; Bentley & Knipper, 2005; Viner et al., 2010; Minniti et al., 2014; Sykes et al., 2006; Towers et al., 2010). Recently, a map for the Netherlands was published that shows the different isoscapes with their bioavailable strontium values (Kootker et al., 2016, Fig. 5). The values from the samples in this study will be compared with this map to establish whether animals could be local or not.

The oxygen isotope ratio analysis of the carbonate fraction of tooth enamel can also provide insight into the origin of animals. δ^{18} oxygen values in tooth enamel are determined by the values in drinking water, which are related to values in precipitation (Longinelli, 1984), which in turn are linked to temperature (Dansgaard, 1964). Since precipitation and temperature vary geographically, $\delta^{18}O$ values also vary geographically. Although not exact enough to pinpoint a location (Lightfoot & O'Connell, 2016), analysis of oxygen isotopes can be useful in combination with strontium analysis.

2.1. Analytical Method- Sr isotopes

The enamel surface of the tooth was abraded from the surface to a depth of > 100 μm using a tungsten carbide dental bur and the removed material discarded. An enamel sample was cut from the tooth using a flexible diamond edged rotary dental saw. All surfaces were mechanically cleaned with a diamond bur to remove adhering dentine. The resulting sample was transferred to a clean (class 100, laminar flow) working area for further preparation. In a clean laboratory, the sample was first cleaned ultrasonically in high purity water to remove dust, rinsed twice, and then soaked for an hour at 60° C, rinsed twice, then dried and weighed into pre-cleaned Teflon beakers. The sample was mixed with ^{84}Sr tracer solution and dissolved in Teflon distilled 8 M HNO_3 and converted to chloride form using 6 M HCl. Strontium was collected using Eichrom AG50 X8 resin columns. Strontium was loaded onto a single Re Filament following the method of Birck (1986) and the isotope composition and strontium concentrations were determined by Thermal Ionisation Mass spectroscopy (TIMS) using a Thermo Triton multi-collector mass spectrometer. The international standard for $^{87}Sr/^{86}Sr$, NBS987, gave a value of 0.710273 ± 0.000016 ($n = 21$, 2σ) during the analysis of these samples and data are corrected to the accepted value for this standard of 0.710250. Data are presented in Tables 1 and 2.

2.2. The chemical preparation and isotope analysis of carbon and oxygen in structural carbonate

For the isotope analysis of phosphate carbonate oxygen, approximately 3 mg of prepared enamel was loaded into a glass vial and sealed with septa. The vials are transferred to a hot block at 90 °C on the GV Multiprep system. The vials are evacuated and 4 drops of anhydrous phosphoric acid are added. The resultant CO_2 was collected cryogenically for 14 min and transferred to a GV IsoPrime dual inlet mass spectrometer. The resultant isotope values are treated as a carbonate. $\delta^{18}O$ is reported as per mil (‰) ($^{18}O/^{16}O$) normalized to the PDB scale using a within-run calcite laboratory standard (KCM) calibrated against

Table 1
Results of strontium, oxygen and carbon isotope analysis for samples from Houten-Castellum. MIA: Middle Iron Age; LIA: Late Iron Age; ER: Early Roman; MR: Middle Roman.

Type	Species	Element	Period	Date	Sample	Sr ppm	$^{87}Sr/^{86}Sr$	average $\delta^{18}O$ (‰)$_{carb\ VSMOW}$	average $\delta^{13}C$ (‰)$_{carb\ VPDB}$
Enamel	Cattle	M3i	MIA – A	500–400/375 BCE	MG22	224	0.708795		
Enamel	Cattle	M3i	MIA – B	400/375–250 BCE	MG03	257	0.708779		
Enamel	Cattle	M3i	MIA – B	400/375–250 BCE	MG06	486	0.708711	24.67	−12.27
Enamel	Cattle	M3i	MIA – B	400/375–250 BCE	MG11	233	0.708899		
Enamel	Cattle	M3i	MIA – B	400/375–250 BCE	MG14	187	0.710996		
Enamel	Cattle	M3i	MIA – B	400/375–250 BCE	MG15	178	0.712271		
Enamel	Cattle	M3i	MIA – B	400/375–250 BCE	MG16	210	0.709195		
Enamel	Cattle	M3i	MIA – B	400/375–250 BCE	MG20	230	0.708739		
Enamel	Cattle	M3i	MIA – B	400/375–250 BCE	MG21	218	0.708818		
Enamel	Cattle	M3i	MIA – B	400/375–250 BCE	MG25	181	0.709706		
Enamel	Cattle	M3i	MIA – B	400/375–250 BCE	MG28	197	0.708944		
Enamel	Cattle	M3i	MIA – B	400/375–250 BCE	MG31	196	0.712208	25.3	−12.22
Enamel	Cattle	M3i	MIA – B	400/375–250 BCE	MG39	232	0.708764		
Enamel	Cattle	M3i	MIA – B	400/375–250 BCE	MG40	290	0.709145	24.68	−12.62
Enamel	Cattle	M3i	LIA – A	250–120 BCE	MG04	178	0.713571	26.54	−13.38
Enamel	Cattle	M3i	LIA – A	250–120 BCE	MG10	222	0.708843		
Enamel	Cattle	M3i	LIA – A	250–120 BCE	MG12	311	0.708954		
Enamel	Cattle	M3i	LIA – A	250–120 BCE	MG13	215	0.708829	24.54	−11.94
Enamel	Cattle	M3i	LIA – A	250–120 BCE	MG17	187	0.709146		
Enamel	Cattle	M3i	LIA – A	250–120 BCE	MG29	253	0.708706		
Enamel	Cattle	M3i	LIA – A	250–120 BCE	MG33	203	0.708851	23.69	−11.65
Enamel	Cattle	M3i	LIA – A	250–120 BCE	MG37	233	0.708666		
Enamel	Cattle	M3i	LIA	250–19 BCE	MG01	193	0.708814		
Enamel	Cattle	M3i	ER – B	CE 40–70	MG32	212	0.709012		
Enamel	Cattle	M3i	ER – B	CE 40–70	MG38	211	0.708731	24.43	−12.23
Enamel	Cattle	M3i	ER	19 BCE – CE 40	MG05	244	0.708760		
Enamel	Cattle	M3i	ER B/MR A	CE 40–120	MG19	218	0.709090		
Enamel	Cattle	M3i	ER/MR A	19 BCE-CE 120	MG27	332	0.709057		
Enamel	Cattle	M3i	MR – A	CE 70–120	MG02	208	0.708910		
Enamel	Cattle	M3i	MR – A	CE 70–120	MG07	159	0.709706		
Enamel	Cattle	M3i	MR – A	CE 70–120	MG08	258	0.708931	24.99	−11.9
Enamel	Cattle	M3i	MR – A	CE 70–120	MG09	284	0.708831		
Enamel	Cattle	M3i	MR – A	CE 70–120	MG18	270	0.709094		
Enamel	Cattle	M3i	MR – A	CE 70–120	MG23	237	0.708914		
Enamel	Cattle	M3i	MR – A	CE 70–120	MG24	232	0.708645	23.39	−12
Enamel	Cattle	M3i	MR – A	CE 70–120	MG26	261	0.709093	25.53	−11.99
Enamel	Cattle	M3i	MR – A	CE 70–120	MG30	289	0.708918		
Enamel	Cattle	M3i	MR – A	CE 70–120	MG34	230	0.708831		
Enamel	Cattle	M3i	MR – A	CE 70–120	MG35	438	0.708762		
Enamel	Cattle	M3i	MR – A	CE 70–120	MG36	427	0.709081		

Table 2
Results of strontium isotope analysis for samples from Heerlen-Thermenterrein.

Type	Species	Element	Date	Sample	Sr ppm	$^{87}Sr/^{86}Sr$
Enamel	Cattle	M3i	CE 25–50	MG41	120	0.709401
Enamel	Cattle	M3i	CE 25–50	MG42	161	0.712063
Enamel	Cattle	M3i	CE 25–50	MG43	107	0.712137
Enamel	Cattle	M3i	CE 50–100	MG44	141	0.71265
Enamel	Cattle	M3i	CE 25–75	MG45	152	0.714123
Enamel	Pig	M2i	CE 25–75	MG46	109	0.711491
Enamel	Pig	M2i	CE 25–75	MG47	138	0.710947
Enamel	Sheep/goat	M3i	CE 40–100	MG48	126	0.711251
Enamel	Sheep/goat	M3i	CE 40–100	MG49	150	0.712733
Enamel	Sheep/goat	M3i	CE 40–100	MG50	201	0.712988
Enamel	Sheep/goat	M3i	CE 25–75	MG51	151	0.711214
Enamel	Sheep/goat	M2i	CE 25–75	MG52	144	0.710791

SRM19, NIST reference material and were converted to the SMOW scale using the published conversion equation of (Coplen, 1988): SMOW = (1.03091 × $\delta\ ^{18}O_{VPDB}$) + 30.91. Analytical reproducibility for this run of laboratory standard calcite (KCM) is for $\delta\ ^{18}O_{SMOW}$ = ± 0.06‰ (1 σ, n = 40) and δ^{13}_{VPDB} is ± 0.03‰ (1 s, n = 40). The reproducibility of the enamel analysis, based on reproducibility of duplicate pairs of samples, for $\delta\ ^{18}O_{VSMOW}$ is ± 0.04‰ (1SD, n = 4). Data are presented in Table 1.

2.3. Samples and sample preparation

A total of 52 animal teeth are included in this study: 40 from Houten-Castellum and 12 from Heerlen-Thermenterrein (Fig. 1). The teeth from Houten are all from cattle, while for Heerlen, teeth from cattle, sheep or goat and pig were selected. For Houten, samples for strontium consisted of a small chip of enamel which was taken from the buccal side of the anterior lobe, near the apex of the tooth. For 10 teeth, sequential sampling for stable isotope analysis of oxygen and carbon was carried out by taking transversal slices along the length of the buccal surface of the anterior lobe, from apex to cervix. These chips of enamel were then ground into powder.

For Heerlen, after cleaning the surface of the teeth with a dental drill, samples were taken from the buccal surface of the teeth. Enamel powder was obtained by drilling along the entire anterior lobe, through the whole enamel layer. Sampling was slightly different for the two sites for the pragmatic reason that learning skills (including different ways of taking samples from teeth) is an essential part of the type of project in which this research was undertaken. The differences between sampling are not expected to affect the results.

Cattle lower third molars are formed between 9 and 23 months (Brown et al., 1960), with another 6 months before mineralisation is complete (Balasse, 2002). Sheep lower second molar formation starts at 2 months and is complete at 12 months, but Balasse et al. (2012) has shown that there is a 5–6-month delay in the completion of mineralisation. Sheep third molar crown formation takes place between 1 and

Fig. 1. Map of the Netherlands in the Roman period, which provides the best estimate of the geography of the country at around the time of this study. Sites mentioned in the text are marked. The dotted line represents the Roman border (Map: Marjolein Haars, BCL Archaeological Support). The map can be applied to the Middle and Late Iron Age as well, since not much changed in the outline of the country.

2 years (Hillson, 2005, 229-231). Pig lower second molar crown formation occurs between 1–2 and 6–8 months (Hillson, 2005, 234). This means that for the cattle from Houten, the strontium signal provides information about the location in the early second year of life, since samples were taken from the apex of the tooth, which is formed first. For the cattle from Heerlen, samples relate to the entire second year of life and early third year; for the sheep to about 7–18 months (second molar) and 17–30 months (third molar); and for pig to the first year of life.

2.4. *Strontium isotope and oxygen analysis: Selection of samples from Houten-Castellum*

Only lower third molars were selected and a preference for the right side was employed to avoid sampling the same individual twice. Where left molars were used, they were compared to the right ones from the same period to ensure they were from different individuals. The aim in selecting teeth was an equal spread over the four main time periods, but the uneven quantities of animal bones per period did not allow this. The 40 teeth are dated as follows: 14 from the Middle Iron Age, 9 from the Late Iron Age, 3 from the Early Roman period, 2 from the Early/early Middle Roman period and 12 from the Middle Roman period. The contexts from which the teeth derive were dated based on stratigraphy, typochronology for pottery and metal finds and ^{14}C dating on wood (Van Renswoude, 2017a). The 10 teeth for which samples were taken for oxygen were selected based on the length of the crown and a roughly equal distribution over the different time periods.

2.5. *Strontium isotope analysis: Selection of samples from Heerlen*

Twelve teeth were selected for strontium isotope analysis. All these teeth are from the period between CE 25 and 125. This period was chosen for several reasons. First, it is more tightly dated than any of the other phases for which teeth were available, which covered two or more centuries. Second, the number of available teeth is larger than for the later phases. Most of the mandibles or loose teeth were not assigned to a phase at all. Finally, this allows us to see how supply was organised in the early years of the vicus. The earliest teeth are CE 25–50, one dates CE 50–100, and the rest all date to wider phases starting CE 25, but the sample sizes are too small for a comparison between these subphases to be possible. The teeth are from the three main meat providers: cattle (5 lower third molars), sheep or goat (4 lower third molars and 1 lower second molar) and pig (2 lower second molars). The teeth are still in their mandibles, which means it was possible to age them (cattle: 1x 30–36 months old, 1x adult, 2x old, 1x very old (Grant, 1982; Halstead, 1985); sheep/goat: 1x 1–2 years, 1x 2–3 years, 2x 3–4 years, 1x 4–6 years (Grant, 1982; Payne, 1973); pig: 2x 7–14 months (Grant, 1982; Bull & Payne, 1982; Higham, 1968). Although a mixture of left and right mandibles was used for analysis, they clearly came from different individuals.

3. Archaeological background of the sites and earlier research

3.1. *Background Houten-Castellum*

The archaeological site of Houten-Castellum was a rural settlement inhabited in the Iron Age and Roman period (Van Renswoude & Habermehl, 2017). It is located in the central Dutch river area, within the border of the Roman Empire. The site consists of a residual channel containing settlement refuse and intentional deposits, as well as traces of habitation on the western bank of the channel. It seems to have been abandoned by the end of the 2nd century CE. The large quantity of finds includes ca. 86,000 animal bone fragments (excluding small fragments retrieved by sieving on the smaller mesh sizes) (Groot & Van Haasteren, 2017). Most of the finds come from layers within the residual channel, which can often be dated fairly accurately. Due to the waterlogged conditions, the preservation of the animal bones is excellent.

The site of Houten-Castellum is likely to have been a self-sufficient agrarian community, probably producing a surplus of food in the Roman period. Cattle is the main animal species in all periods, with the highest proportion occurring in the Middle Iron Age (Groot & Van Haasteren, 2017; Fig. 2). The presence of bones from foetal, neonatal and juvenile animals suggests that cattle were bred at this site in all periods. Slaughter ages of cattle show an increase in the proportion of adult (>3 years) animals over time, suggesting an increased focus on

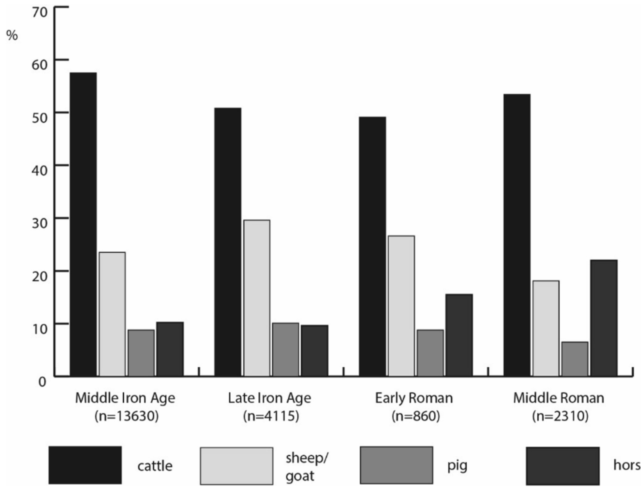

Fig. 2. Houten-Castellum. Proportions for the four main animal species over time, based on the total number of bone fragments (NISP).

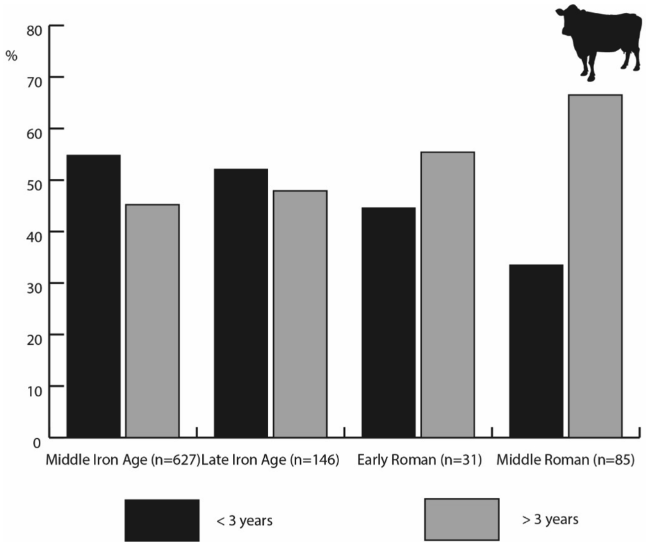

Fig. 3. Houten-Castellum. Slaughter ages of cattle, based on tooth eruption and wear (percentage out of the total number of aged mandibles and loose teeth).

secondary products (Fig. 3). Palynological data suggest that the landscape around Houten was open with scattered groves of trees in the early Middle Iron Age (Kooistra, 2017). A decline in tree pollen indicates that the landscape became more open over time and consisted mostly of grassland and arable fields.

The geology of the Netherlands is dominated by Holocene and Pleistocene deposits (Zagwijn et al., 1985). The site of Houten-Castellum, near Utrecht, was founded on Holocene deposits dominated by sand and clay. This results in biosphere values between 0.7088 and 0.7095 for the Houten area (Kootker et al. 2016).

3.2. Archaeological indicators for trade networks and/or human mobility at Houten

In the Middle Iron Age, metal finds indicate contacts with the Middle and Upper Rhine regions (Van Renswoude, 2017b; Van Renswoude & Habermehl, 2017, 889). In the Late Iron Age, the metal seems to be more regional. In the 1st century CE, seven types of brooch are found that originate from Germany, while a so-called dolphin fibula is from England (Van Renswoude, 2017b). Perhaps these finds are related to the movements of soldiers or slaves (Van Renswoude, 2017b).

The pottery in the Middle Iron Age shows influences from France in the so-called Marne style (450–375 BCE), although no definite imports have been found (Van den Broeke et al., 2017). From the 4th century, influences from the west and northwest are also found. In the Late Iron Age, there seems to be little influence from the northwest. The briquetage pottery comes from the western Netherlands, Zeeland and the Belgian coastal region. Already in the earliest phase of the Roman period, the inhabitants of Houten were able to tap into military trade networks, which mostly brought pottery from the Cologne region. Some northern influences are also found and some of the Chaucian/Frisian pottery may even have been imported in the pre-Flavian period. Military networks and trade along the Rhine remained important until the 2nd century. In the later 2nd century, pottery from the western part of the Netherlands is found at Houten.

Stone comes from the Eifel (e.g. tephrite from Mayen), the Belgian Ardennes, perhaps the area around Verdun and Norroy and, closer to home, the Utrechtse Heuvelrug (Boreel, 2017). Roman glass seems to have been imported from the Rhineland or further (Van Kampen, 2017).

3.3. Background Heerlen-Thermenterrein

The vicus of Heerlen was located on the crossroads of the *Via Belgica*, which ran from Boulogne-sur-Mer to Cologne, and the road from Xanten to Aachen, in the middle of the fertile loess zone. It was inhabited from the early 1st to the 4th century CE. It is best known for its bathhouse, which was excavated in the 1940s and opened as a museum in 1977. The area adjacent to the bathhouse was excavated in the 1950s. In 2015, a large-scale project started, which involved redevelopment of the museum and the area surrounding it, including a complete restoration of the bathhouse. Part of the project was to finally analyse the excavated features and material from the 1950s. The 1950s excavations took part on the northern, eastern and southern sides of the bathhouse (Vos, 2020). Several stone buildings, with an earlier wooden phase underneath, represent typical vicus striphouses. On the corner of two roads, a larger building with a porticus and possibly a courtyard was found. The earliest wooden phase of the buildings dates from ca CE 25 to ca CE 100, while the stone buildings date to the 2nd and 3rd centuries CE.

The animal bones from the 1950s excavation are of special interest because of the urban character of Heerlen (Groot, 2020). Only a few towns and vici from the Roman Netherlands have been the focus of zooarchaeological research. The main research aim was to gain insight into the activities carried out in the immediate surroundings of the bathhouse, but the zooarchaeological analysis also provided information about the consumption of meat in the vicus, the food supply to Heerlen and the function the vicus had for the surrounding countryside. The location of Heerlen on a crossroads was optimal for the supply and further transport of food and other products. While Heerlen is unlikely to have been one of the destinations of animals from Houten and other settlements in the River Area, it does allow us to investigate mobility of animals in Roman towns. Among the 544 identified animal bone fragments, those from cattle dominate, followed by pig, sheep or goat and horse (Fig. 4). The ratio between the main meat providers - cattle, pig and sheep or goat - fits with that for other urban centres in the region. Cattle and sheep or goats were mainly slaughtered as adults. There are no remains from foetal, neonatal or juvenile animals. It is assumed that the animals came from the surrounding countryside, but it is unknown from what distance. Various activities could be identified through the animal bones, including antler working, production of marrow, grease or glue, horn- and/or leatherworking and meat consumption. As expected for a Roman vicus, Heerlen was a centre of industrial activity.

The site of Heerlen, in the south of the country near Maastricht, was founded on Cretaceous-Palaeogene rocks of the eponymous Maastrichtian (Zagwijn et al., 1985). This results in biosphere values

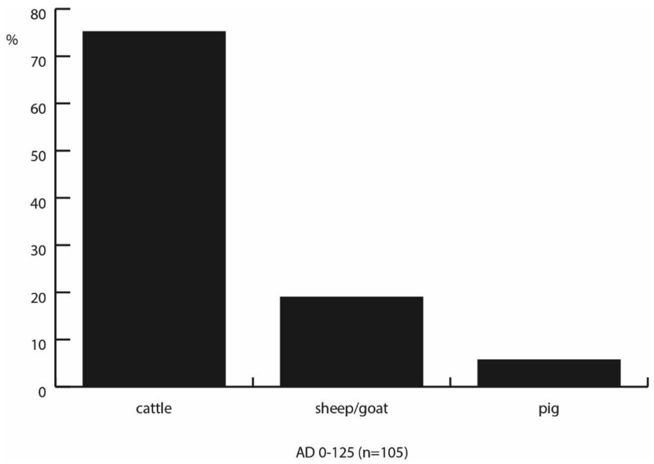

Fig. 4. Heerlen-Thermenterrein. Proportions for the three main animal species in the period CE 0–125, based on the total number of fragments (NISP).

between 0.7104 and 0.7113 for the Heerlen area (Kootker et al., 2016).

3.4. Archaeological indicators for trade networks and/or human mobility in Heerlen

Most of the stone that was used as construction material was local, but some of the decorative stone comes from other civitates (*civitas Tungrorum*, *civitas Treverorum*/Lorraine), some from the Eifel and one fragment of marble probably from the Mediterranean (Dreesen, 2020).

The pottery indicates various trade networks, which change over time (Van Kerckhove, 2020). In the pre-Claudian phase, the pottery was imported from different regions, such as Campania, Aosta, Lyon, the Belgian Meuse region, Cologne/Xanten and Mainz. In the period CE 40–70, pottery comes from the Mediterranean and the Cologne region. The local Heerlen production starts in this period. In the next period, CE 70–175, mainly Heerlen pottery was used, but some produced in Jülich and Düren is also found.

4. Results

4.1. Houten

Out of the 40 teeth that were sampled, 34 are consistent with the local signal (local signal suggested by Kootker et al., 2016) or only just outside the published range for the region (Fig. 5). Two teeth have higher values (0.70971) that are compatible with the published range of bioavailable strontium of Kootker *et al.*'s isoscapes D and E (0.7095–0.7110; Fig. 6). One tooth with an even higher value (0.71100) is compatible with isoscapes E and F (0.7095–0.7113). Three teeth, finally, have very high values which are not included on Kootker *et al.*'s map. However, similar values have been found for modern plants from the boulder clay area in the northeastern part of the Netherlands (Drenthe; McManus et al., 2013), which is a lacuna on the bioavailable strontium map due to the bad preservation of animal bones in this area's sandy soils. Other possible origins can be found outside the Netherlands. Of the six non-local teeth, four can be dated to the Middle Iron Age, one to the Late Iron Age and one to the Middle Roman period. It is important to realise that a 'local' signal for Houten does not necessarily mean that the animals were actually raised locally. Local in this case refers to a rather large area, covering most of the coastal and riverine areas of the Netherlands.

Fig. 7 shows the strontium concentration plotted against the $^{87}Sr/^{86}Sr$. It has been observed before that radiogenic Sr ratios are often linked to low strontium concentrations and this is also the case for the samples from Houten. In fact, all six non-local animals have low strontium concentrations (<200 ppm). Fig. 7 is similar in shape to graphs plotting strontium concentrations and ratios for British humans (Evans et al., 2012; Montgomery et al., 2019). In the study by Evans et al. (2012), many of the highest strontium concentrations derive from coastal Scotland, where seaweed was used as fertilizer, thus increasing strontium concentrations in people consuming locally grown crops. The samples with the highest strontium concentrations from Houten are consistent with the local signal, but this signal is typical for a large part of the Netherlands, including coastal regions.

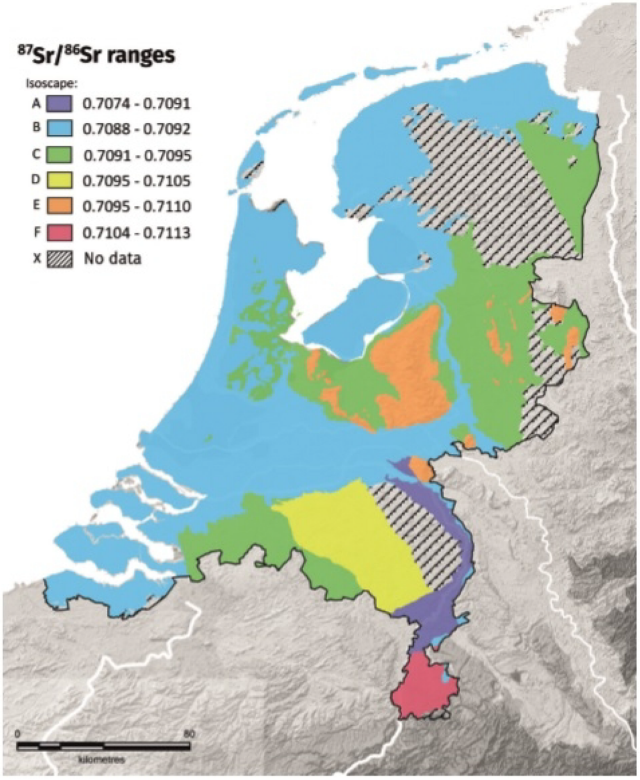

Fig. 6. Bioavailable strontium isoscape map of the Netherlands (Kootker et al. 2016, Fig. 5). Reprinted from Journal of Archaeological Science: Reports 6, *L.M. Kootker, R.J. van Lanen, H. Kars & G.R. Davies: Strontium isoscapes in the Netherlands. Spatial variations in $^{87}Sr/^{86}Sr$ as a proxy for palaeomobility, 1–13, 2016. Permission under STM permissions guidelines.*

The average oxygen and carbon values for 10 cattle teeth are displayed in Fig. 8 and listed in table 1. Of the two teeth that have non-local strontium ratios, MG31 fits in with the values for the teeth with local strontium signals. MG04, on the other hand, stands out in both oxygen and carbon.

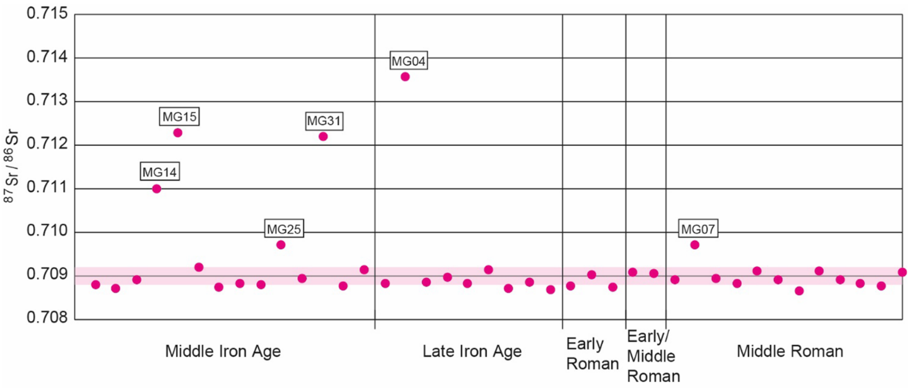

Fig. 5. $^{87}Sr/^{86}Sr$ for cattle teeth from Houten-Castellum. The local range is marked by the pale pink band. The local range is based on Kootker *et al.*'s range for isoscape B, in which Houten is located (2016; see Fig. 6).

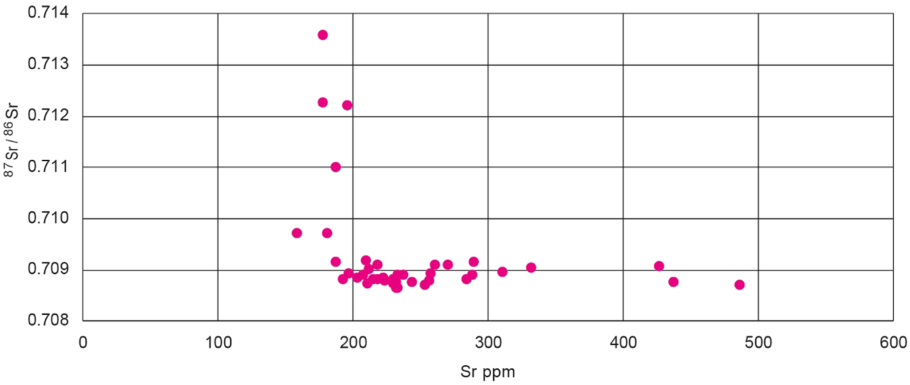

Fig. 7. Strontium concentrations for the cattle teeth from Houten-Castellum.

4.2. *Heerlen*

Out of the 12 samples, four fall within the range published by Kootker et al. (2016) for this region (isoscape F) (Fig. 9). The local range for isoscape F is on the higher end of the range for European loess (Nehlich et al., 2009). Samples for isoscape F derive from Borgharen, which is located in the Meuse river valley. Because the strontium ratios were higher than expected for Meuse river sediments and the local soil consists of gravel in alluvial loess, the values were concluded to reflect that of the loess region (Kootker et al., 2016, 7). One sample from Heerlen is just outside the range for isoscape F and can perhaps also be regarded as consistent with the local signal, especially since the difference between the values for this pig tooth and the other pig tooth with a local signal is very small. One value is much lower than the local range but falls within the range for European loess (Nehlich et al., 2009). The difference with the local range could reflect the natural variability of the landscape around Heerlen, with loess and river valleys. Six values are higher than the local range. Of the six higher values, one is especially high and probably from a different region than the other five. That would mean that cattle originate from at least three different sources (all non-local), sheep or goats from at least two (including Heerlen or surroundings) and the two pigs may both be local. ‘Local’ in this case is not necessarily the vicus itself but could also be the loess zone surrounding Heerlen (isoscape F).

5. Discussion

Based on the current data set, mobility at Houten seems strongest in the Middle Iron Age and weakest in the Roman period. However, it is possible that there was mobility within the isoscape of which Houten is part. Furthermore, our data only show evidence for mobility towards Houten and not from Houten to other places. Since Houten was a rural settlement, it is likely to have produced a surplus of animals in the Roman period, which ended up on the Roman markets. A problem in finding out where these animals went is that the assumed potential markets lie in the same isoscape as Houten.

For Iron Age Houten-Castellum, five out of 23 cattle have a non-local strontium ratio. That means they lived elsewhere during the early second year of life. The current data set shows more mobility in the Middle than the Late Iron Age (MIA: 4 out of 14 cattle non-local; LIA: 1 out of 9 cattle non-local), but this is something that should be tested in the future by adding more samples. There are several explanations for mobility of cattle in the Iron Age. First, farmers depended on their livestock and if they moved to a new location, they would have taken their animals with them. Second, the movement of individual people, for instance in the case of marriage, may also have included livestock (as dowry). Next, livestock may have been exchanged or traded for other goods, perhaps to introduce new bloodlines into herds to keep them healthy. Finally, cattle may have been stolen in cattle raids or brought back as spoils after a conflict. Strontium isotope analysis of human burials in the Early and Middle Iron Age in the River Area has

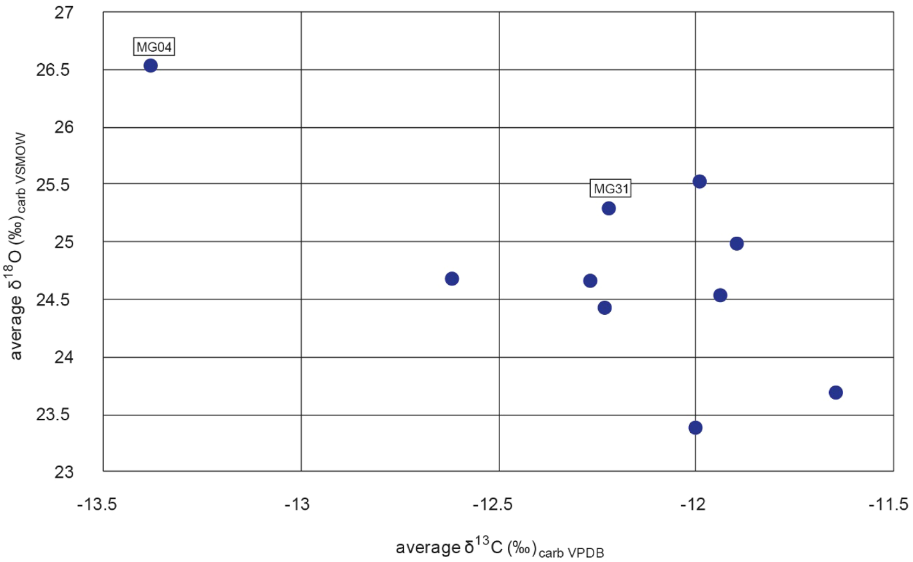

Fig. 8. Average oxygen and carbon values for cattle teeth from Houten-Castellum. MG04 and MG31 have non-local strontium ratios.

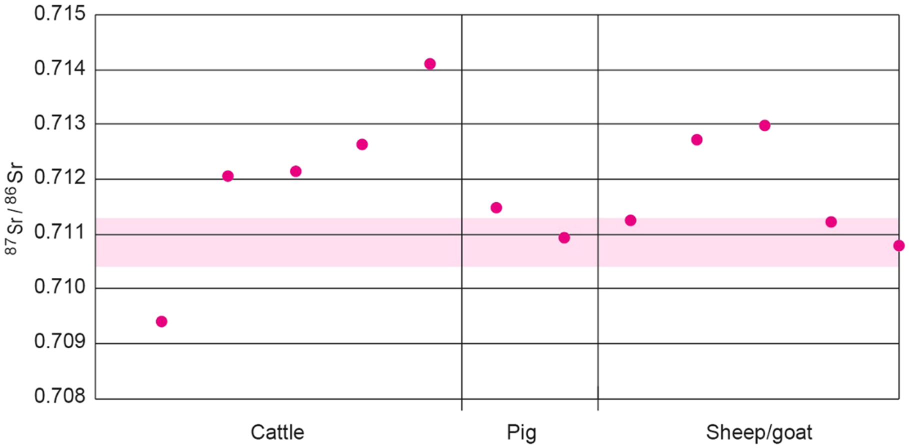

Fig. 9. $^{87}Sr/^{86}Sr$ for Heerlen. The local range is marked by the pale pink band.

shown a high degree of mobility among people, with 11 out of 23 people samples being of non-local origin (Kootker et al., 2017). Six out of 11 samples from animals (2 cattle, 3 pigs, 1 dog) were also non-local, with one cow and one pig showing very high values, consistent with the boulder clay area in the northeast of the Netherlands.

Oxygen and carbon results show one animal (MG04) deviating from the others for both isotopes. The higher oxygen value suggests that this animal came from a region which was wetter and/or warmer, while the carbon suggests its diet during the second year of life was different from the other cattle from Houten-Castellum, perhaps including grazing in a more wooded area. MG31 was identified by its $^{87}Sr/^{86}Sr$ ratio as non-local, but the oxygen and carbon values are similar to cattle with local $^{87}Sr/^{86}Sr$ ratios. Perhaps it came from a region with similar climate and rainfall as Houten and had a similar diet as the cattle in Houten.

It is impossible to say with certainty where the non-local cattle in Iron Age Houten came from, but the evidence for trade or exchange networks from metal, pottery and stone can provide some possibilities. Iron Age pottery shows influences from the west and northwest; unfortunately, it is unclear whether this includes the boulder clay area of Drenthe, which could account for the most radiogenic strontium values. Stone artefacts came from the Eifel, Ardennes and northern France, areas which could also account for high strontium values (Willmes et al., 2018).

In the Roman period, most of the samples from cattle in Houten are consistent with the local signal; there is little evidence for mobility. The single non-local animal could have come from an area that is not very far away (ca 15–20 km). Recent research looked into mobility of people and livestock in the Roman site of Tiel-Medel (Kootker, 2019), which is about 20 km from Houten-Castellum. Analysis of the pottery from this site showed strong indications for a non-local origin of the people living here in the earliest part of the Roman period. Since there are no human burials dating to this period, animals were sampled instead. Two cattle (out of 10 animals that were sampled – cattle, sheep/goat and a horse) showed values that differed from the other eight animals, which had values consistent with the local signature. Because the other animals' values were very close to each other, it was argued that the two cattle with deviating values are either non-local, grazed on different pasture or were fed other food. If they are non-local, then they could have come with the immigrants.

While the lack of mobility in Houten in the Roman period may seem puzzling at first, considering the amount of trade in this period, it is logical when we consider the type of site. Houten is a rural settlement, which would have raised livestock both for subsistence and to supply towns and military sites. Although some imported cattle may have reached the site to introduce new bloodlines and improve the local type, these were probably few and there is therefore a small chance of sampling them isotopically. The flow of animals was mainly from producer to consumer site, so although it is likely that there was mobility at Houten, it is archaeologically invisible, as the animals that moved did not die on site.

This is confirmed by the results for Heerlen. The strontium isotope ratios for Heerlen indicate at least four different origins of the animals, including Heerlen (or surroundings) itself. Considering the age of the cattle, it is likely that they were not prime-meat animals (with one exception of an animal aged 30–36 months) but had been used as traction animals first. They may have been used on a farm to draw a plough for a number of years and then sent to town or they may have pulled loads of imported goods to Heerlen and been left behind. The cattle show more variety in their origins than pigs and sheep or goats. The pigs were probably both raised in the town or its surroundings, the sheep and goats have two different origins (one of which local) and the cattle come from three different regions, none of which are local but one could be the same as the place of origin for two of the sheep or goats. This last region – if it is indeed a single region and not different regions with a similar geology – is the source of five of the 12 sampled individuals and therefore of considerable economic importance to Heerlen. Most sheep at Heerlen were slaughtered as adults and may have been exploited for wool before being sent to the town for meat. Perhaps we should look to a wool-producing region for the origin of some of the livestock at Heerlen. Stone artefacts and building stone found in Heerlen indicates trade networks with the Eifel, Lorraine and Belgium, while pottery indicates contacts with the Belgian Meuse, Cologne and Mainz regions. Strontium values of 0.712 and higher can be found in at least some of those regions (Willmes et al., 2018).

More research into mobility of livestock has been carried out in Britain. Isotope analysis of 95 cattle teeth from Iron Age and Roman Owslebury shows an increase in mobility of cattle over time (Minniti et al., 2014). For the Middle Iron Age, no non-local animals were identified, while for the Late Iron Age and even more so for the Roman period, cattle originated from different geographic regions, some at considerable distance from Owslebury. This fits in with a lack of trade or exchange of material culture in the Middle Iron Age and increasing trade in the Late Iron Age. Owslebury seems to have been connected with the market network and shows similarities to urban centres. That would make it a different kind of rural settlement from Houten. The difference in mobility in the Middle Iron Age between the two sites seems to reflect differences in exchange networks.

In Roman Worcester, teeth from six cattle were sampled, which were all non-local (Gan et al., 2018). The animals do not derive from a single herd and seem to have come from at least two different locations, perhaps Herefordshire and Wales. In Roman Ferry Fryston, West Yorkshire, at least two out of six cattle were non-local; the other four could derive from Yorkshire (Jay et al., 2007). In the Roman fortress of Caerleon, at least seven out of 37 animals originate from outside the local region (Madgwick et al., 2019a). Due to the wide range of the 'local' signal (due to a complex geology), the number of non-local animals is probably underestimated. Four of the seven non-local animals (including two cattle) come from a chalk geology, the nearest of which is a considerable distance from Caerleon. The common presence of non-local livestock, some from considerable distances away, fits into Stallibrass's model for long-distance cattle droving (in a parallel to post-medieval cattle droving from Scotland to London) as a means to produce and supply livestock to the frontier region of Northern England (Stallibrass, 2008). The post-medieval cattle that were part of the droving system were mostly adult animals, supplied in small numbers by individual farmers but collected in large groups for droving. Worcester, Ferry Fryston and Caerleon are similar to Heerlen in that they were supplied with food and raw materials from outside the immediate surroundings of the sites.

The results of the isotope analysis for Houten and Heerlen provide some new insights into mobility of livestock in the Iron Age and Roman Netherlands. This research largely breaks new ground for the region, but future analyses will increase the sample size and lead us to a better understanding of the extent and nature of livestock and human mobility. For the Roman period, a comparison of rural data with data from urban and military sites within the central Netherlands can test the hypothesis of local supply of meat. These sites mostly lie within the same isoscape, so any non-local animals in the urban and military sites would have been supplied from a different region. The same applies to the southeast of the Netherlands. What is needed is a comparison of the results from Heerlen with rural sites in the vicinity to confirm or exclude the possibility of local supply. This research thus provides the framework we needed to elaborate more nuanced questions about Iron Age and Roman life based on isotope evidence. To be effective, this will, of course, need to be integrated with other lines of archaeological evidence, as done in this paper.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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