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The economic importance and mobility of horses in the Roman Netherlands

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Abstract: Previous research has suggested that horse breeding, with the army as the intended buyer, was an important part of the local agrarian economy in the Roman Dutch eastern river area. Since it is very difficult to trace the origins of horses by traditional archaeozoological methods, strontium isotope analysis was used to investigate the origins of horses in both military and rural sites. These new data are integrated with data on horse frequencies and size to assess the economic importance of horses in rural communities in the eastern river area and further investigate possible supply networks. Both horse frequencies and horse size increase from the Early Roman period onwards, reflecting the significant economic importance of horses in this region. The laser ablation $^{87}Sr/^{86}Sr$ ratios show evidence for mobility in military horses but not in rural horses.

Keywords: Netherlands, horses, mobility, size, economic importance, civitas Batavorum

Introduction

The Roman conquest of the southern half of the Netherlands had a major impact on the agricultural economy of the area. Not only did the soldiers stationed in the army camps along the river Rhine and in Nijmegen need to be supplied with food and other essentials, but the start of urbanization had a further effect on the local economy. Administrators, craftsmen, and traders did not produce their own food, or did so only to a limited extent. Requisitioning by the army, production for the free market, and taxation were all stimulants encouraging the local farmers to produce more than they needed. The presence of imported goods in rural sites indicates that this was not just one-way traffic.

The central part of the Netherlands is one of the best-known areas archaeologically in the Roman provinces. Decades of developer-funded and research-driven excavations have yielded a large quantity of data, including archaeozoological data. Changes observed in animal husbandry can be connected to a shift from a subsistence to a surplus-producing system.[1] One striking characteristic of the eastern river area (in the central Netherlands) is the prominence of horses at many rural settlements in the Middle Roman period.[2] While some consumption of horsemeat took place in rural settlements,[3] different fragmentation and butchery patterns in comparison to cattle suggest that horses were not kept

[1] E.g., Lauwerier 1988; Laarman 1996a; Laarman 1996b; Groot 2008a; Groot 2008b; Groot 2016; Groot 2017; Groot 2020; Groot et al. 2009.

[2] E.g., Lauwerier and Robeerst 2001; Laarman 1996a; Laarman 1996b; Groot 2008a; Groot 2008b; Groot 2016, 128; Vossen and Groot 2009.

[3] Groot 2016, 118–20.

primarily for their meat.[4] Furthermore, horse bones show a decrease in the proportion of butchery marks during the Roman period – with the biggest decrease occurring in the Early Roman period – suggesting that consumption of horsemeat declined in importance.[5] High proportions of horse can thus not be explained by an increase in horsemeat consumption. The prominence of horse has instead led to the hypothesis that horses were bred in this region as an agricultural surplus, presumably with the army as the target market.[6] While this hypothesis makes sense in many ways – for example, it explains the high proportion of horse fragments and suits the local landscape – it is difficult to prove that horses bred in the Dutch eastern river area actually ended up with the Roman army.

A second hypothesis is derived from the increase in the withers height of horses that can be observed for the Dutch eastern river area during the Roman period.[7] It is assumed that this increase is a result of deliberate breeding of local horses with larger, imported horses.[8] Some horses received special treatment by being buried in rural settlements or cemeteries;[9] one explanation for this is that the horses were regarded as special because they were imported animals used in breeding programs to increase the size of the local horses.

Both hypotheses (horse breeding for the Roman army and import of large horses with subsequent interbreeding with local stock) are difficult to prove by traditional archaeozoological methods. Strontium isotope analysis can provide insight into the movement of horses, whether they were imported into rural settlements or sold to the army. This article will present new strontium isotope data from horse teeth and review data on horse frequencies and horse size to achieve an integrated perspective on horses in the *limes* region of the Roman Netherlands.

Research questions and background

This article will address the following questions: What developments in horse frequencies occurred during the Roman period? Do horses in the Roman Netherlands show any developments in size? Is there any evidence for mobility of military and rural horses? The article will focus on the area directly south of the river Rhine, from the Late Iron Age to the Late Roman period (Fig. 1). The so-called eastern river area, or the eastern part of the central Netherlands, coincides with the administrative unit of the civitas Batavorum.

Strontium isotope analysis

Stable and radiogenic isotope analyses of tooth enamel can provide valuable insights into the origins and movements of animals.[10] The ratio of $^{87}Sr/^{86}Sr$ varies between different

4 Lauwerier and Robeerst 2001; Groot 2016, 120.

5 Groot 2016, 119, fig. 5.45.

6 Hessing 2001, 162; Laarman 1996b, 377; Roymans 1996, 82; Lauwerier and Robeerst 2001; Vossen and Groot 2009.

7 Lauwerier and Robeerst 2001; Groot 2016, 122.

8 Lauwerier and Robeerst 2001; Robeerst 2005.

9 E.g., Groot 2008a, 126, 178; Groot 2009, 397; Esser et al. 2010.

10 E.g., Berger et al. 2010; Bendrey et al. 2009; Viner et al. 2010; Minniti et al. 2014; Gerling et al. 2017; Evans et al. 2019; Madgwick et al. 2019; Groot et al. 2020.

Fig. 1. *Map of the Netherlands showing the research area and the sites from which the horse teeth sampled for strontium isotope analysis came. (Map by Maaike Groot.)*

rocks and sediments.[11] This variation is directly reflected in the vegetation that is consumed by animals. Dietary Sr dominates skeletal-tissue $^{87}Sr/^{86}Sr$, rather than drinking water or atmospheric contributions as suggested by recent studies,[12] thus the body tissues of animals will have a similar ratio to the food consumed. After burial, however, bone and dentine will slowly take on the ratio of the local soil, while tooth enamel is not affected by

11 Bentley 2006.

12 E.g., Glorennec et al. 2016; Lewis et al. 2017.

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diagenesis and will retain the signal of the source region of the food consumed during the formation of the tooth enamel, which will usually be the region where the animal lived.[13] 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.[14] For the Netherlands, a map showing the different isoscapes with their bioavailable strontium values provides an essential tool for establishing whether animals can be regarded as compatible with the local bioavailable strontium isotope range.[15] Research into animal mobility in the Netherlands is not yet well established, but a few studies are available.[16]

Horses in the Roman army and the role of the Batavians

The training of horses in the Roman army is likely to have started when the animals were three years old.[17] According to Varro, horses should first be mounted when they are three years old; Virgil also states that horses can be ridden and taught the basics at that age.[18] At the military camp in Hod Hill, Dorset, shed milk teeth of horses have been found, indicating that horses younger than five years old were used by the army.[19]

While large size was admired in horses in Roman times, short stocky horses are likely to have been preferred due to their smooth ride.[20] A size increase could be accomplished by improved nutrition for young horses, since the amount and quality of food influences adult size.[21] It could also be achieved by interbreeding local stock with larger, imported horses. Hyland mentions the importation of 20 horses from Italy to Gaul in 170 BCE.[22]

The army used various ways to acquire horses, including requisitioning, taxation and tribute, purchasing, breeding in imperial or army stud farms, and the capture of enemy horses.[23] Auxiliary cavalry units recruited in the provinces would come with their own indigenous horses, but, over time, these would need to be replaced by horses from the region where the unit was stationed.[24] Trade in horses crossed provincial borders; in northern regions, indigenous ponies were used as pack animals.[25] There was no standard military horse, but every horse had to pass a trial period and a veterinary exam.[26]

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13 Bentley 2006.

14 E.g., Bentley and Knipper 2005; Viner et al. 2010; Minniti et al. 2014; Sykes et al. 2006; Towers et al. 2010.

15 Kootker et al. 2016, fig. 5.

16 Van der Jagt et al. 2012; Kootker et al. 2018; Groot et al. 2020; Roymans and Habermehl 2023.

17 Junkelmann 1990, 50; Hyland 1990, 46, 82.

18 Hyland 1990, 46–47; Varro, *Rust*. 2.7.13; *Verg. G*. 3.190.

19 Hyland 1990, 82.

20 Hyland 1990, 67, 69.

21 Hyland 1990, 43.

22 Hyland 1990, 21.

23 Davies 1969, 431, 453; Hyland 1990, 77.

24 Hyland 1990, 76.

25 Hyland 1990, 70.

26 Hyland 1990, 73.

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The army in the civitas Batavorum would have needed around 400 horses per year.[27] Acquisition of local horses through requisitioning, purchase, taxation, or recruiting together with their riders is likely to have accounted for many of these. The suitability of the river landscape for livestock raising, the high proportion of horse bones in rural settlements, and the close ties between the Batavians and the Roman army are arguments in favor of local horse breeding supplying the army.[28] The Batavians were known for their horsemanship; they supplied qualified horsemen for the imperial bodyguard and for the *ala Batavorum*.[29] Veterans from the Roman army, having returned to their home villages, may have played a pivotal role in horse breeding.[30]

Little attention has been paid to the presence of horse-donkey hybrids in the Netherlands. There are no finds of donkey from the Roman Netherlands. The damp climate is not very suitable for donkeys, and the breeding of mules or hinnies seems unlikely for this region.[31] Johnstone's biometric method of identifying horses, mules, and donkeys did not result in any definite identifications of mules or donkeys for the three sites in the Netherlands that were included in her study but did find some probable identifications of mules.[32] However, a recent archaeogenetic study has cast doubt on morphometric identifications of mules. This study analyzed DNA from 31 equids from Roman Switzerland, including 17 that had previously been identified as mules.[33] The results showed that the presence of mules has been overestimated and that morphological and biometrical identification of mules is unreliable. An earlier study had already cast doubt on the criteria, based on differences in dental morphology, used to identify equids, due to the large intraspecific variability.[34] Using the same methods as the Swiss study but a much larger dataset, mules were found to be relatively common in northern France (20% in the 1st c. CE, 25–34% in the 2nd c. CE, and 13% in the first half of the 3rd c. CE).[35] While donkeys were almost absent, mule breeding was not excluded by the authors because few male donkeys are needed. Another study focused on the *limes* region of Raetia, Noricum, Upper Pannonia – southern Germany, eastern Switzerland and Austria – examined 295 equids: 83% were identified as horse, 1% as donkey, and 16% as mules.[36]

Besides aDNA analyses, which can be expensive and are not always successful, another way to reliably identify equid species is ZooMS – collagen peptide mass fingerprinting. A recent study was able to identify horse and donkey, and the authors believe that mules should also be identifiable by ZooMS.[37] New methods for morphological identification have been developed in recent years,[38] but neither these nor ZooMS or genetic analysis

27 Vossen and Groot 2009, 96.

28 Vossen and Groot 2009; Groot 2008b.

29 Tac. *Hist*. 4.12; Alföldy 1968; Bellen 1981.

30 Groot 2011; Groot 2012.

31 E.g., Johnstone 2008, 129.

32 Johnstone 2004, 226.

33 Granado et al. 2020.

34 Chuang and Bonhomme 2019.

35 Lepetz et al. 2021.

36 Sharif et al. 2022.

37 Paladugu et al. 2023.

38 Hanot et al. 2017; Hanot and Bochaton 2018; Clavel et al. 2021.

have been applied to equid remains from the Netherlands. The equid remains included in the study by Granado and colleagues derive from urban and military contexts in a region much closer to the heart of the Roman Empire than the region that is the focus of the current study, while the samples in the study by Sharif et al. are nearly all from military contexts. If mules are already much less common than has previously been assumed in Germania Superior, Raetia, Noricum, and Upper Pannonia, then for the rural sites of the central Netherlands they can be expected to be even rarer. It cannot be excluded that some of the equids found in military and urban sites in the Netherlands are hybrids, but it seems far more likely that they are horses. Mules may have been used as pack animals and to draw light wagons, while cattle were used for heavier loads and ploughing. It is assumed that horses, on the other hand, were mainly or exclusively used for riding.

Material and methods

Five individual horses from both rural and military contexts were selected for strontium isotope analysis (Table 1; Fig. 1). The two rural sites included in this study (Tiel-Passewaaijse Hogeweg and Geldermalsen-Hondsgemet) are typical indigenous settlements. Both have high proportions of horse fragments in the Middle Roman period and are assumed to have bred horses as a surplus.[39] The original plan was to select only horse burials, but for some of the selected animals, the remains could not be found in the provincial archaeological depot. Therefore, in one case, an isolated third molar from Tiel-Passewaaijse Hogeweg was used. For Geldermalsen-Hondsgemet, the only horse burial was of a very young animal which did not yet have third molars; therefore, a tooth from a special deposit of a horse skull was used instead. The selection of horses from military sites was largely determined by availability. Horse remains are much less abundant in military sites than in rural sites. Furthermore, the number of military sites in the Dutch eastern river area for which well-dated animal bone assemblages have been analyzed is small. Kesteren-Prinsenhof is a horse cemetery dating to the later part of the Early Roman and the early part of the Middle Roman period.[40] Two horses from this site are included in the study. The five horses are all roughly contemporary and date to the later part of the Early Roman period and the early part of the Middle Roman period (40–140 CE).

Samples were taken from four third lower molars and one third upper molar and prepared for laser ablation by Claudia Gerling at IPNA, University of Basel. The samples were run at the University of Southampton by Alistair Pike. Enamel slices approximately 1–2 mm thick were removed from animal tooth specimens parallel to the growth axis of the tooth using a diamond-tipped cutting disc and a Dremel tool, then ultrasonicated in Milli-Q water, and subsequently dried in a vacuum oven. The slices were mounted in epoxy resin and manually polished using 220, 800, and 1200 grit papers. Strontium isotopic analysis was performed on a Thermo Scientific Neptune multi collector ICP-MS with a solid state homogenized-beam 213 nm laser (NewWave NWR213), using the oxide reduction technique of De Jong.[41] $^{87}Sr/^{86}Sr$ data were collected with an integration time of 1.14 seconds per measurement cycle. Krypton introduced as an impurity present in the helium carrier gas source was corrected for by carrying out an on-peak gas blank, and the $^{87}Sr/^{86}Sr$

39 Groot 2008a; Groot 2009.

40 Lauwerier and Hessing 1992.

41 De Jong et al. 2010; De Jong 2013; Lewis et al. 2014.

Table 1.
Information on the horse teeth selected for strontium isotope analysis and the mean, minimum, and maximum $^{87}Sr/^{86}Sr$ values, as well as the range.

Individual	*NL1*	*NL2*	*NL3*	*NL4*	*NL5*
Site	Kesteren-Prinsenhof	Kesteren-Prinsenhof	Tiel-Passewaaijse Hogeweg	Tiel-Passewaaijse Hogeweg	Geldermalsen-Hondsgemet
Find nr	XII.2.1	11–34	176.122	137.169	104.113
Date	50–125 CE (probably before 70 CE)	50–125 CE (probably before 70 CE)	40–100 CE	100–140 CE	50–120 CE
Site type	horse cemetery/dump related to *castellum* or *vicus*	horse cemetery/dump related to *castellum* or *vicus*	rural settlement	rural settlement	rural settlement
Age	ca. 6–7.5 years	ca. 6–7.5 years	ca. 7.5 years	ca. 6.25–7.75 years	ca. 5.5–6.5 years
Sex	female	male	male	unknown	female
Withers height	139–140 cm	145 cm	145 cm	unknown	unknown
Reference	Lauwerier and Hessing 1992	Lauwerier and Hessing 1992	Groot 2008a	Groot 2008a	Groot 2009
Tooth	lower M3	lower M3	lower M3	lower M3	upper M3
Enamel (mm)	77.3	79.5	76.8	66.9	70.1
$^{87}Sr/^{86}Sr$ mean	0.70910	0.71007	0.70895	0.70906	0.70921
$^{87}Sr/^{86}Sr$ min.	0.70797	0.70826	0.70779	0.70743	0.70832
$^{87}Sr/^{86}Sr$ max.	0.71036	0.71425	0.71029	0.70986	0.71013
$^{87}Sr/^{86}Sr$ range	0.00239	0.00599	0.00250	0.00243	0.00181

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value was corrected for the ^{87}Rb interference using the natural ^{87}Rb /^{85}Rb ratio of 0.385617. Instrumental mass fractionation was corrected for using an exponential fractionation law and the natural $^{86}Sr/^{88}Sr$ ratio of 0.1194.[42]

Laser tracks were positioned close to the center of the enamel section to avoid contamination or the effects of diagenesis at the surface of the tooth. A pre-ablation pass of the laser was performed to remove any remaining contamination from the sample cutting. Time series of strontium isotopes are obtained as continuous data by moving the tooth along the growth axis of the enamel (at $15 \mu m s^{-1}$) as the laser pulses with a repetition rate of 20 Hz and spot size 110 µm. Repeat analysis of an in-house pig tooth standard, bracketing the analyses of the horse teeth, showed a mean offset of +110 ± 74 ppm (1 SE) for the laser ablation analyses over TIMS values, which is similar to values reported by other laboratories using a similar methodology.[43] This is within the precision of individual measurements of 100–600 ppm and is therefore considered insignificant to our interpretation of the isotopes.

Third lower molar enamel in horses is mineralized between 21 (±3) and 55 (±2) months; maxillary teeth are believed to have similar mineralization timing.[44] The isotopic composition of tooth enamel is fixed after mineralization ends. Thus, strontium isotope analysis by either laser ablation or sequential sampling can capture a period of nearly three years in a horse's life, but only if the tooth is unworn or only lightly worn. Two complications should be borne in mind when interpreting the results. First, enamel is not mineralized in horizontal layers but subvertically, which means that samples taken as horizontal slices of tooth enamel reflect isotope values recorded in enamel over a period of several months.[45] This effect is somewhat mitigated by using a small laser spot size (110 µm) that produces a crater a few microns deep, so that while some averaging effect will remain, it will be substantially reduced. Second, the growth of horse teeth is not constant, but takes place at an exponentially decreasing rate.[46] This means that the total tooth length cannot simply be divided into sections representing equal time periods. Bendrey and colleagues developed a model to account for this exponentially decreasing growth rate.[47] In this paper, since we are not concerned with seasonal changes, we will not use their model but will instead take into account the exponentially decreasing growth rate when relating any changes in strontium values to a specific age.

Horse frequencies were calculated for each archaeological site based on the total number of identified specimens for cattle, sheep/goat, pig, and horse, the main livestock species. Site type was taken into account, distinguishing between rural and consumer sites: the latter include towns, vici, and military sites but exclude temples. Nearly all rural sites are small indigenous settlements, consisting of one to five farmhouses; the few exceptions are settlements with a larger, villa-like building (Druten-Klepperhei and Ewijk-Keizershoeve).

42 Russell et al. 1978; Nier 1938.
43 Willmes et al. 2016.
44 Hoppe et al. 2004.
45 Hoppe et al. 2004.
46 Bendrey et al. 2015.
47 Bendrey et al. 2015.

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Table 2.
Measurements included in the LSI analysis. Bd: distal breadth; BT: breadth of the trochlea; GL: greatest length; BFp: breadth of the proximal articular surface; BFd: breadth of the distal articular surface; Dp: proximal depth; LA: length of the acetabulum; LAR: length of the acetabulum on the rim; Dd: distal depth; GB: greatest breadth; LmT: length of the medial part of the trochlea tali.

	width	*length*	*depth*
humerus	Bd, BT	GL	
radius	Bp, Bd, BFp, BFd	GL	
metacarpal	Bp, Bd	GL	Dp
femur	Bp, Bd	GL	
pelvis		LA, LAR	
tibia	Bp, Bd	GL	Dd
calcaneum		GL	
astragalus	GB	LmT	
metatarsal	Bp, Bd	GL	Dp
phalanx 1	Bp, Bd	GL	Dp
phalanx 2	Bp	GL	

Standard periods were used to investigate chronological trends: Late Iron Age (250–12 BCE); Early Roman period (12 BCE–70 CE); Middle Roman period (70–270 CE); and Late Roman period (270–450 CE).[48] Overlapping periods were included when they added information. Many rural sites in the eastern river area have a transitional date, covering the Early Roman period and the early part of the Middle Roman period.

To investigate changes in horse size, the log size index (LSI) method was used.[49] This method calculates the decimal log of the ratio between a measurement and a standard value. The main advantage is that it allows plotting different measurements on the same scale, thus increasing sample size. The standard is composed of the means of measurements for a series of 10th-c. horse burials from Iceland.[50] Previously, horse size was investigated based on reconstructed withers height,[51] which limits the sample size and does not take into account changes in the robusticity of horses.

Only measurements taken on fused bones were used, although for published data, this is not always explicitly mentioned. All measurements on the scapula and the smallest breadth of the diaphysis of long bones were excluded, as they are strongly affected by post-fusion growth. Some postcranial measurements that may continue growing post-fusion in sheep and pig were included,[52] since excluding them would have limited the data set too much. The measurements that were used are listed in Table 2. Only one measurement per bone per dimension (anatomical plane) was included.

Length measurements provide information on the height of an animal, while width and depth measurements provide information on robustness. Tooth size is generally more conservative than the size of post-cranial bones, so that rapid changes in tooth size are likely to

48 E.g., Nationale Onderzoeksagenda Archeologie 2.0. https://noaa.cultureelerfgoed.nl.

49 Meadow 1984; Meadow 1999; Uerpmann 1990.

50 Measurements kindly provided by Helene Benkert.

51 Lauwerier and Robeerst 2001; Robeerst 2005; Groot 2016, 122.

52 Humerus Bd, radius Bp, metacarpus Bp, metatarsus Bp have been included (Davis 1996; Payne and Bull 1988; Popkin et al. 2012, 1780).

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indicate a change in genetic material and not just a change in husbandry. Width, length and depth measurements were analyzed separately, as recommended by Davis,[53] since measurements on the same anatomical plane are correlated more strongly than those between anatomical planes. Unfortunately, tooth measurements were not available.

The Mann-Whitney pairwise test was used (software: PAST 3) to determine statistical significance between different groups of logs; a p-value of less than 0.05 is seen as statistically significant.

Results

Strontium isotope analysis

Figure 2 shows the results of the strontium isotope analysis by laser ablation. Each tooth roughly reflects the period between 2 and 4.5 years of age. The three rural horses show no evidence of mobility; their values fall within the $^{87}Sr/^{86}Sr$ range for the river area.[54]

The minor fluctuations in $^{87}Sr/^{86}Sr$ values may be methodological or may reflect the use of different pastures. The female military horse is mostly consistent with the local strontium signature but shows higher values about halfway down the tooth. Perhaps this horse spent a brief time (a few months) in another location, outside the river area. Values between 0.7095 and 0.710 can be found in sandy regions directly adjacent to the eastern river area, both to the north and to the south.[55] The male military horse shows values consistent with the local strontium signature during the later part of tooth formation. During the early part, however, it has values that far exceed the local signature and actually point to different locations. In the early-formed part of the tooth, three distinct levels can be recognized (above 0.713, just above 0.712, and 0.711), before the values drop down to values found in the river area. In this region of the tooth, there is no correlation between Sr concentration and $^{87}Sr/^{86}Sr$ isotopic value (R^2=0.108), suggesting diagenesis is not an issue. The two highest values are not known for the Netherlands, although the isoscape map by Kootker and colleagues has some gaps where high values may be expected, such as in the boulder clay area in the northeast of the Netherlands.[56]

Horse frequencies

Figure 3 shows horse proportions for rural and consumer sites in the eastern river area. Clearly visible is the rise in the proportion of horse fragments in rural sites from a mean of 8% in the Late Iron Age to 22% in the Middle Roman period (Table 3); all differences are significant except for that between the overlapping Early/Middle Roman period and the Middle Roman period (Table 4). Furthermore, a strong decrease is seen in the Late Roman period, when the mean horse proportion drops to 8%. Consumer sites show much lower horse proportions in the Early and Middle Roman period. While the mean horse proportion in consumer sites increases somewhat from 3% in the Early Roman period to 5% in the Middle Roman period, this increase is not statistically significant. The only consumer site for the Late Roman period has a high proportion of 24%.

53 Davis 1996. See also Albarella et al. 2008; Rizzetto et al. 2017.

54 0.7088–0.7092; Kootker et al. 2016.

55 Kootker et al. 2016.

56 Kootker et al. 2016; McManus et al. 2013.

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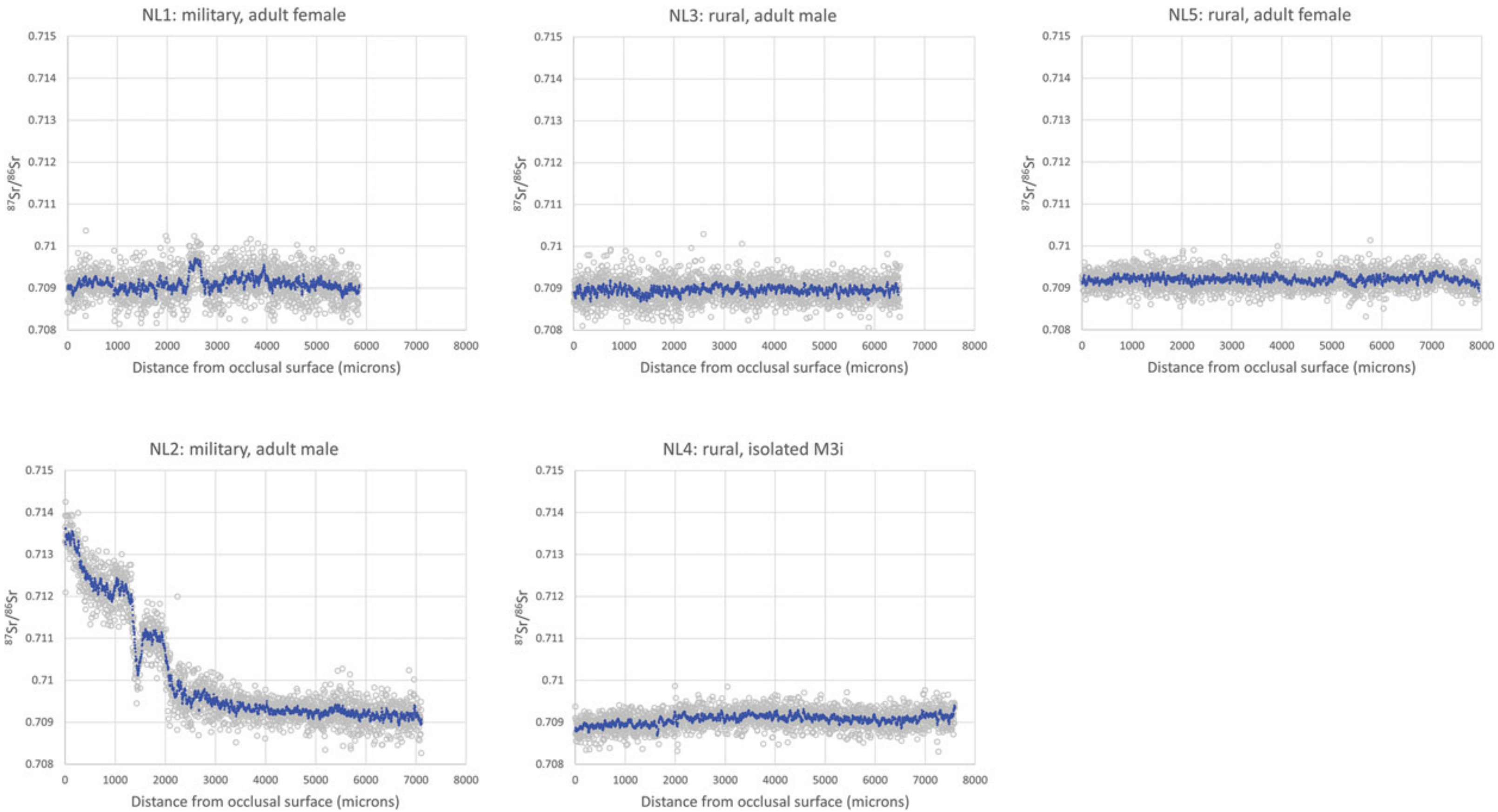

Fig. 2. *$^{87}Sr/^{86}Sr$ laser ablation MC-ICP-MS data for third lower molars from five horses from rural and military sites in the Dutch eastern river area. Individual measurements are shown in grey, with the darker line representing a 10-point moving average. (Figure by the authors.)*

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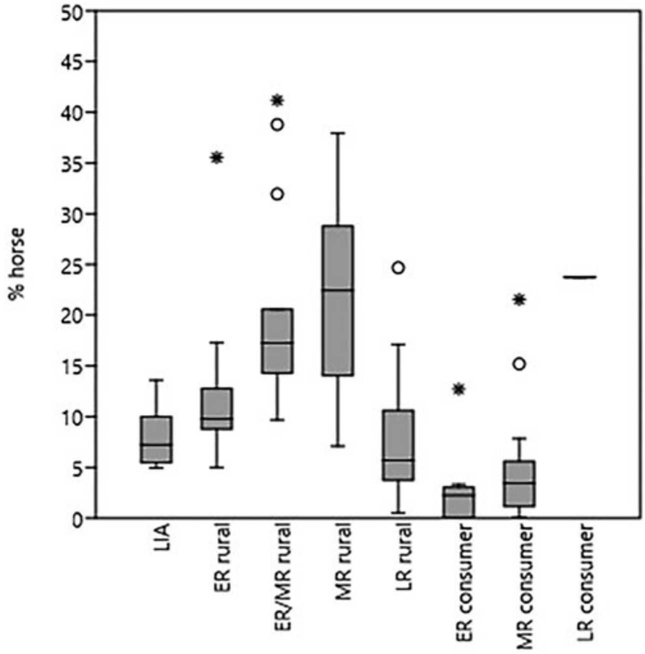

Fig. 3. *Box plot for horse proportions (out of total NISP for cattle, sheep/goat, horse, and pig). (Figure by Maaike Groot.)*

Table 3.
Number of sites and mean proportion of horse bones per period and site type.

	n rural sites	*mean % horse*	*n consumer sites*	*mean % horse*
Late Iron Age (LIA)	13	8.1	-	-
Early Roman (ER)	15	12.1	9	2.8
Early/Middle Roman (ER/MR)	15	20.3	-	-
Middle Roman (MR)	22	21.9	16	4.9
Late Roman (LR)	10	8.1	1	23.7

Table 4.
Summary of statistics for horse frequencies. * = p < 0.05; ** = p < 0.01; *** = p < 0.005; N = no significant difference (Mann-Whitney pairwise test). Because there is only one Late Roman consumer site, this site/period has not been included in the statistical analysis.

	ER – rural	*ER/MR rural*	*MR – rural*	*LR – rural*	*ER – consumer*	*MR – consumer*
LIA	*	***	***	N	***	***
ER – rural		***	***	*	***	***
ER/MR – rural			N	***	***	***
MR – rural				***	***	***
LR – rural					*	N
ER – consumer						N

Horse size: LSI

Log size values for width measurements show a large and significant increase from the Late Iron Age to the Early Roman period (Fig. 4; Tables 5–6). The slight size increase in rural sites from the Middle Roman period is not significant, but the larger increase in Middle Roman consumer sites is significant compared to both rural and consumer sites

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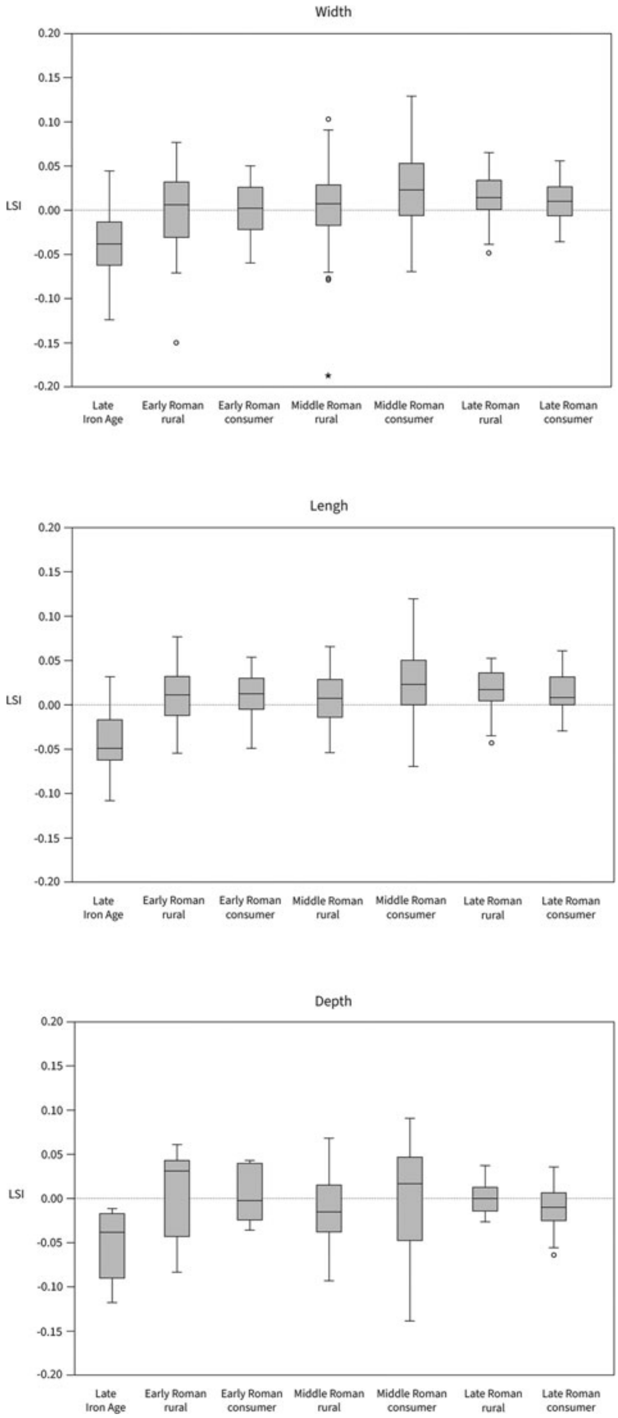

Fig. 4. *Box plots for log size index values for horses from the eastern river area. See Table 5 for the means and the number of measurements per period and Tables 6–8 for the results of statistical testing. (Figure by Maaike Groot.)*

from the Early Roman period. Rural sites show another slight size increase in the Late Roman period, but again this is not significant. The decrease in size of Late Roman consumer horses compared to Middle Roman consumer horses is significant. For the Early Roman period, horses from rural and consumer sites have similar width measurements. For the Middle Roman period, however, both the range and means of horses from consumer sites are larger than those from rural sites, a difference that is significant.

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Table 5.
Numbers of measurements and means for LSI values per period.

Period	*n width*	*means*	*n length*	*means*	*n depth*	*means*
Late Iron Age	20	-0.04345	14	-0.04420	5	-0.05441
Early Roman – rural	67	0.00275	38	0.01398	13	0.00770
Early Roman – consumer	26	0.00311	15	0.01395	7	-0.00114
Middle Roman – rural	285	0.00863	199	0.01015	51	-0.01232
Middle Roman – consumer	40	0.02436	25	0.02477	17	-0.01236
Late Roman – rural	51	0.01339	43	0.01972	7	-0.00309
Late Roman – consumer	78	0.00915	36	0.01555	33	-0.01186

Table 6.
Summary of statistics for LSI values for width measurements. * = p < 0.05; ** = p < 0.01; *** = p < 0.005; N = no significant difference (Mann-Whitney pairwise test).

	ER – rural	*ER – consumer*	*MR – rural*	*MR – consumer*	*LR – rural*	*LR – consumer*
LIA	***	***	***	***	***	***
ER – rural		N	N	*	N	N
ER – consumer			N	*	N	N
MR – rural				*	N	N
MR – consumer					N	*
LR – rural						N
LR – consumer						

Log size values for length measurements show very similar trends to the width measurements, with the largest size increase occurring in the Early Roman period (Fig. 4; Tables 5, 7). One difference is that the slight increase in rural horses in the Late Roman period is significant. Again, Early Roman rural and consumer horses are similar, while in the Middle Roman period, consumer horses show a larger mean and range than rural horses.

Sample sizes for depth measurements are much smaller; nevertheless, we see the same large size increase in the Early Roman period as was visible in width and length measurements (Fig. 4; Tables 5, 8). Depth measurements show no difference between Middle Roman rural and consumer means, although the consumer range is larger.

Table 7.
Summary of statistics for LSI values for length measurements. * = p < 0.05; ** = p < 0.01; *** = p < 0.005; N = no significant difference (Mann-Whitney pairwise test).

	ER – rural	*ER – consumer*	*MR – rural*	*MR – consumer*	*LR – rural*	*LR – consumer*
LIA	***	***	***	***	***	***
ER – rural		N	N	N	N	N
ER – consumer			N	N	N	N
MR – rural				*	*	N
MR – consumer					N	N
LR – rural						N
LR – consumer						

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Table 8.
Summary of statistics for LSI values for depth measurements. * = p < 0.05; ** = p < 0.01; *** = p < 0.005; N = no significant difference (Mann-Whitney pairwise test).

	ER – rural	*ER – consumer*	*MR – rural*	*MR – consumer*	*LR – rural*	*LR – consumer*
LIA	*	*	*	N	*	*
ER – rural		N	N	N	N	N
ER – consumer			N	N	N	N
MR – rural				N	N	N
MR – consumer					N	N
LR – rural						N
LR – consumer						

Discussion

The strontium isotope analysis shows some evidence for mobility in horses. While we cannot exclude a non-local origin in a similar geological region, the three rural horses are likely to have been born and raised in the river area. The female military horse may also be a local horse, but it seems to have spent a brief time outside the river area, possibly in an adjacent area. The male military horse shows high mobility during the early part of formation of the third molar (after the age of 21 months). Assuming that horses would not have been sold before the age of two years, the earliest, highest values would then reflect the place where this horse was born. The second level may reflect the location where the horse received its early training, somewhere between the ages of two and three years. The third level may reflect either another training facility or the horse's first posting. Finally, still as a young horse, it ended up in the eastern river area. Of course, we cannot exclude that the later part of the tooth was formed somewhere entirely different but with similar strontium values to the river area. It is also possible that the horse experienced further mobility between the end of third molar tooth formation and its death ca. 1.5–3 years later. However, the most straightforward explanation is that the horse came to the eastern river area during the later part of tooth formation and stayed there until its death.

Horse frequencies in rural sites in the eastern river area steadily increase from the Late Iron Age to the Middle Roman period, from a mean proportion of 8% to a mean proportion of 22%; the Late Roman period shows a drop to a mean proportion of 8%. Consumer sites show low horse frequencies in the Early and Middle Roman period; this can partly be explained by differences in disposal of dead horses in rural and consumer sites, as well as a difference in horsemeat consumption. The only Late Roman consumer site shows a very high proportion of horses (24%), which may reflect a change in disposal of horse cadavers. If higher proportions reflect increased economic importance, horses became important for rural communities in the Early Roman period but then even more so in the Middle Roman period. Breeding horses for the Roman army or other Roman markets remains the most likely explanation for the high horse frequencies.

Analysis of horse width, length, and depth measurements using the log size index method reveals that horse size increased in the Early Roman period; in fact, this was when the largest increases in all three dimensions occurred. The taller, more robust horses that are present from the Early Roman period may have resulted from a combination of the import of larger animals and the selected breeding of local stock; improved nutrition may also have played a role. Horses from Early Roman rural sites appear to have been similar in size and shape to those from consumer sites, but for the Middle Roman period, horses from

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consumer sites are somewhat taller and more robust. The larger range for Middle Roman consumer sites (despite a much smaller sample size) can be explained by consumer sites drawing horses from a much wider region. However, the Middle Roman rural range falls within the consumer range, and the consumer horse population is likely to have contained locally bred horses as well as imported ones. Our female military horse may belong to the former category and the male military horse to the latter. Interestingly, the range for the Early Roman consumer horses is smaller than for the rural horses and also smaller than for the Middle Roman consumer horses, suggesting a more homogenous population, perhaps supplied from a smaller region.

Previous research focused on withers height, which only takes into account length measurements. The largest size increase in rural sites was seen for the Early Roman period, after which horses continued to increase in withers height into the Late Roman period.[57] We can now confirm that horses became not only taller but also more robust. The dataset for withers height for horses from consumer sites was small for most periods; however, Early Roman horses in consumer sites had higher mean withers heights than those in rural sites. This conclusion cannot be maintained after the current LSI analysis, which is based on a much larger dataset and shows similarity between Early Roman rural and consumer horses. Change in livestock size during the Roman period is well documented for both the eastern river area and other parts of the Roman Empire.[58] For the eastern river area, the main difference between size changes observed for horse and for cattle is that for cattle, the main size increase occurs in the Middle Roman period, when cattle became taller and more robust,[59] while, as we have seen above, the main change in horse had already occurred in the Early Roman period. Sheep/goat and pig are more difficult to investigate in the eastern river area because of the low proportions in some periods, resulting in insufficient measurements for chronological analysis; however, analysis of sheep/goat withers heights showed no changes in size.[60]

Conclusion

This paper has presented the first strontium isotope data for Roman horses from the central Netherlands, which showed evidence for mobility of horses from military sites but not for horses from rural settlements. Of the two military horses studied, one seems to have come from outside the local region, while the second horse is likely to have been bred locally but may have spent a brief time outside the river area. Analysis of horse frequencies showed that during the Early and Middle Roman periods, horses were of significant economic importance in rural settlements. Already by the Early Roman period, larger and more robust horses are found in both consumer and rural sites. This size increase is likely to have been achieved through the import of larger horses, interbreeding with local stock, and selective breeding of local animals. If stallions were imported, just a few animals could have had a large impact on the

57 Groot 2016, 122.

58 E.g., Teichert 1984; Lauwerier 1988; Dobney et al. 1996, 31–33; Lepetz 1996; Peters 1998; Breuer et al. 1999; Schlumbaum et al. 2003; Albarella et al. 2008; MacKinnon 2010; Valenzuela et al. 2013; Colominas et al. 2014; Groot 2016; Groot 2017.

59 Groot and Albarella 2024.

60 Groot 2016, 122.

local stock.[61] While further sampling of teeth from rural horses may identify imported horses, this will be like looking for a needle in a haystack. This is not to say that this work should not be done; only that expectations need to be realistic. Systematic sampling of horses from military and other consumer sites is more likely to identify mobility and has the potential to reveal supply patterns. Considering the small sample size of this study, further research on horse remains from rural and consumer sites in the Netherlands and other *limes* areas is needed to understand horse management and mobility.

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