Phenotypic diversity in Bronze Age pigs from the Alpine and Central Plateau regions of Switzerland
Miki Bopp-Ito, Thomas Cucchi, Allowen Evin, Barbara Stopp, Jörg Schibler

To cite this version:
Miki Bopp-Ito, Thomas Cucchi, Allowen Evin, Barbara Stopp, Jörg Schibler. Phenotypic diversity in Bronze Age pigs from the Alpine and Central Plateau regions of Switzerland. Journal of Archaeological Science: Reports, Elsevier, 2018, 21, pp.38-46. 10.1016/j.jasrep.2018.07.002 : hal-02351497

HAL Id: hal-02351497
https://hal.archives-ouvertes.fr/hal-02351497
Submitted on 1 Feb 2021

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L’archive ouverte pluridisciplinaire HAL, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d’enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Distributed under a Creative Commons Attribution 4.0 International License
Phenotypic diversity in Bronze Age pigs from the Alpine and Central Plateau regions of Switzerland

Miki Bopp-Ito, Thomas Cucchi, Allowen Evin, Barbara Stopp, Jörg Schibler

1. Introduction

Pigs played an important role in the economy of the Swiss Bronze Age (Bopp-Ito, 2012; Plüss, 2011; Schibler, 2017; Schibler and Studer, 1998; Stopp, 2015). Based on the number of identified specimens, we know that pigs were the main domestic animals along with cattle, sheep, and goats. While the latter were exploited for meat, milk, and wool, or were used as working animals, most pigs were being slaughtered for meat at a young age (Hüster Plogmann and Schibler, 1997; Schibler, 2017); however, little is known about their husbandry practices. Furthermore, the phenotypic diversity of Swiss Bronze Age pigs over time and space, especially across the east and west parts of the Swiss Central Plateau (hereafter called Plateau) and Alpine regions, has not previously been explored because osteometric data are limited due to heavy fragmentation and few adult individuals being available (Duval et al., 2015). Since the three regions previously mentioned are geographically, topographically, environmentally, and culturally divergent (Della Casa, 2013; Menotti, 2015a; Schibler, 2017; Reitmaier, 2012), they may also have required different husbandry practices (Schibler, 2017).

The earliest human presence in the Swiss Alpine region, up to over 2000 m above sea level (a.s.l.), was recorded during the Mesolithic (Cornelissen and Reitmaier, 2016; Hess et al., 2010). Human activity increased from the middle of the 4th millennium BC, the so called Copper Age (Late Neolithic), onwards (Della Casa, 2003). The number of settlements relevant to bronze production, copper mining activity,
farming, and pasturing were expanded during the Early Bronze Age (EBA) due to the influx of immigrants from the north and south (Della Casa et al., 2016; Dietre et al., 2016; Jecker, 2015; Murbach-Wende, 2016; Rageth, 1986; Reitmaier, 2010, 2012; Schaer, 2003), immigrants who might have brought livestock with them (Bopp-Ito et al., 2018). This, so called, Inner Alpine Bronze Age culture continued until the Middle Bronze Age (MBA) (Rychner et al., 1998). The increase in human activity above the tree line induced the expansion of grasslands (Nicolussi, 2012) and the culture changed to the Rhine-Swiss-East France Urnfield (Rhin-Suisse-France orientale) (RSFO), Main-Schwaben, and Laugen-Melaun cultures during the Late Bronze Age (LBA) (Jennings, 2016; Rychner et al., 1998). The Alpine economy was developed by the intensification of supra-regional trading and traffic, bronze production, and dairy based pastoralism using vertical transhumance (Della Casa, 2007; Jecker, 2015; Jennings, 2015a; Rageth, 1986; Reitmaier, 2010, 2012; Reitmaier et al., 2013, 2017). Vertical transhumance played an especially important role in the economic system of the Alpine region (Della Casa, 2013; Reitmaier et al., 2017) and deforestation for pastoralism was intensified (Dietre et al., 2016). Due to this, cattle became an even more important source of meat and the demand for cattle as working animals and for milk production increased (Bopp-Ito, 2012; Bopp-Ito et al., 2018; Plüss, 2011; Stopp, 2015); however, dairy activity has not been confirmed by lipid analysis (Carrer et al., 2016) at the Alpine sites discussed in this paper. Recent studies have provided new insights into cattle husbandry practices in the Alpine region (Bopp-Ito et al., 2018; Harmath et al., 2017; Reitmaier et al., 2017), although knowledge remains limited about pig husbandry practices.

In comparison, the lake shore settlements in the east and west Plateau regions were inhabited from approximately 4300 BC onwards, and the exploitation of cattle for dairy production, or for use as working power, began from the Middle Neolithic onwards (Ebersbach et al., 2012; Schibler, 2017). Some sites continued to be inhabited until the Bronze Age, even though major climatic crises arose (Arbogast et al.,

![Map of studied sites](image-url)
Table 2
Grouping of settlements and cultural background.

| No. | Settlement | BC References | Dating | Group | Altitude | Culture |
|-----|------------|---------------|--------|-------|----------|---------|
| 1   | Padnal H-B | 1350/1300–900/800 | Cl4 | Age, 1986 & pers. com. | Alpine LBA | 1223 | RSFO, Main-Schwaben, Laugen-Melaun |
| 2   | Cazis P14  | 1350–1100/800 | Cl4 | Wyss, 2002 | Alpine LBA | 766 | RSFO, Main-Schwaben, Laugen-Melaun |
| 3   | Cazis P14  | 1300–400 | Typo. | Murbach-Wende, 2016 | Alpine LBA | 1223 | RSFO, Main-Schwaben, Laugen-Melaun |
| 1   | Padnal H-C | 1450–1350/1300 | Cl4 | Age, 1986 & pers. com. | Alpine LBA | 1223 | RSFO, Main-Schwaben, Laugen-Melaun |
| 1   | Padnal H-D | 1550–1450 | Cl4 | Age, 1986 & pers. com. | Alpine LBA | 1223 | RSFO, Main-Schwaben, Laugen-Melaun |
| 2   | Cazis P10–12 | 1800–1550 | Cl4 | Wyss, 2002 | Alpine LBA | 766 | RSFO, Main-Schwaben, Laugen-Melaun |
| 4   | Scuol | 1750–1300 | Cl4 | Murbach-Wende, 2016 | Alpine LBA | 1223 | RSFO, Main-Schwaben, Laugen-Melaun |
| 1   | Padnal H-E | 1400 | Cl4 | Seifert, M., pers. com. | Alpine LBA | 1223 | RSFO, Main-Schwaben, Laugen-Melaun |
| 2   | Cazis P1–5, 8 | 2400–1800 | Cl4 | Wyss, 2002 | Alpine LBA | 1223 | RSFO, Main-Schwaben, Laugen-Melaun |
| 2   | Cazis P8 | 1850–1700 | Cl4 | Murbach-Wende, 2016 | Alpine LBA | 1223 | RSFO, Main-Schwaben, Laugen-Melaun |
| 2   | Cazis P1–5 | 2000–1850 | Cl4 | Murbach-Wende, 2016 | Alpine LBA | 1223 | RSFO, Main-Schwaben, Laugen-Melaun |
| 6   | Cortaillod | 1010–955 | Den. | Hochuli et al., 1998 | Alpine LBA | 765 | RSFO, Main-Schwaben, Laugen-Melaun |
| 7   | Champ. | 1054–1037 | Den. | Hochuli et al., 1998 | Alpine LBA | 765 | RSFO, Main-Schwaben, Laugen-Melaun |
| 5   | Alpenquai | LBA | Typo. | Hochuli et al., 1998 | Alpine LBA | 765 | RSFO, Main-Schwaben, Laugen-Melaun |
| 3   | Mozart. | EBA | Typo. | Bleicher, 2011 | Alpine LBA | 765 | RSFO, Main-Schwaben, Laugen-Melaun |

EBA = Early Bronze Age, MBA = Middle Bronze Age, LBA = Late Bronze Age, Typo. = Typology, Den. = Dendrochronology, pers. com. = personal communication, RSFO = Rhine-Swiss-East France Urnfield culture (Rhin-Suisse-France orientale), E. P. = East Plateau, W. P. = West Plateau, Cazis P = Planum, Padnal H = Horizont, Mozart = Zürich-Mozartstrasse, Alpenquai = Zürich Alpenquai, Champ. = Hauterive-Champréveyres, Cortaillod = Cortaillod-Est, Cazis = Cresta-Cazis, Padnal = Savognin-Padnal, Scuol = Scuol-Avant Muglins.

Fig. 2. Visualisation of the second (left image; M2) and third (right image; M3) lower molar coordinates of all specimens after superimposition.
Table 1. The Alpine sites are located in the Alpine valleys approximately 750–1200 m a.s.l. (Table 2). Cazis and Padnal were inhabited throughout the Bronze Age and Scuol was inhabited during the MBA (Murbach-Wende, 2016; Rageth, 1986; Wyss, 2002; Seifert, Personal communication). The climatic influence on the Alpine samples used in this study is not known due to the lack of dendrochronology (Schibler, 2017).

The Plateau sites in this study were lake dwellings located at approximately 400 m a.s.l. (Table 2). Zürich-Mozartstrasse (hereafter called Mozartstrasse) at Lake Zurich in the east Plateau region was inhabited from the Early Neolithic to the EBA (Bleicher, 2011; Hüster Plogmann and Schibler, 1997). However, there is no dendrochronological dating for the EBA samples from Mozartstrasse used in this study (Hüster Plogmann and Schibler, 1997). Zürich-Alpenquai (hereafter called Alpenquai) (Wettstein, 1924) was one of the central trading sites in the east Plateau region during the LBA (Jennings, 2015a). Alpenquai was occupied throughout the Hallstatt B period (from ca. 1050 to 800 BC) and several layers were dated based on dendrochronology (Jennings, 2015b; Künzler Wagner, 2005; Mäder, 2001a, 2001b; Wiemann et al., 2012). However, since our samples came from a very early excavation by dredger (Jennings, 2015b) only typological dating was available. Cortaillod-Est (Chaix, 1986), and especially Hauterive-Champréveyres (hereafter called Champréveyres) (Studer, 1991) at Lake Neuchâtel, were one of the largest trading sites in the west Plateau region (Jennings, 2015a). From both the east and west Plateau sites, only EBA and LBA data were available because the lake shores were abandoned due to climatic deterioration during the MBA (Della Casa, 2013; Menotti, 2015a, 2015b).

The permanent second (M2) and third (M3) lower molar teeth were used as phenotypic markers. Archaeological specimens were identified as domestic pigs using traditional biometry data (Albarella et al., 2009; Boessneck et al., 1963; Rowley-Conwy and Dobney, 2007; Rowley-Conwy et al., 2012) and the reference collection of the Institute of Integrative Prehistory and Archaeological Science (IPAS), University of Basel, Switzerland. However, a few specimens were difficult to identify as either domestic pigs or wild boars (or hybrids) because of an overlap in size (Evin et al., 2013, 2014); therefore, we could not completely exclude the possibility that our samples include a few wild boar (or hybrid) specimens. Only specimens from animals older than one year, based on teeth eruption and wear patterns (Habermehl, 1975; Horard-Herbin, 1997), were analysed in the present study. Detailed information about the samples is provided in Supplementary Table 1.

This study used GMM methods and statistical analyses following a standardized protocol described by Cucchi et al. (2011, 2016), Evin et al. (2013, 2015b), and references therein. Images were obtained with a 2D digital camera (Nikon D90 and D300S with a 60 mm Micro lens; Nikon Corporation, Tokyo, Japan). We acquired seven and eight landmarks on the occlusal surfaces of 109 M2 and 139 M3 respectively, and 70 semi-landmarks (both M2 and M3) according to Cucchi et al. (2011) and Evin et al. (2013) using tpsDig2 version 2.16 (Rohlf, 2010a) and tpsUtil version 1.53 (Rohlf, 2012). Generalized Procrustes analysis (GPA) was performed using the Procrustes distances approach to slide the semi-landmarks (Fig. 2) using tpsRelw version 1.49 (Rohlf, 2010b). The centroid size (CS) and shape variables (Procrustes coordinates) were obtained after the GPA.

We tested the heterogeneity of log-transformed CS between pig populations with a Kruskal-Wallis rank sum test and visualized the variation in size using boxplots. Pairwise comparisons of the populations were performed using multiple Wilcoxon rank tests by pooling the specimens by region and chronological phase.

Differences in shape were tested using multivariate analyses of variance (MANOVA), quantified by leave-one-out cross validation of discriminant analyses (canonical variate analysis), and were visualized by neighbour-joining networks based on Mahalanobis distances. Before multivariate analyses, the dimensionality of the shape data was reduced following Baylac and Frisse (2005) by selecting the N first components.
of a principal component analysis that maximizes variability between the groups. Cross-validation percentages corresponded to the maximum value of the 95% confidence interval obtained for a balanced sample size between groups (100 iterations), as per Evin et al. (2013).

Differences were considered significant if \( p < 0.05 \) (significance level \( \alpha = 0.05 \)), where the significance of the \( p \) values was examined after adjustment for multi-test comparisons following the methods described by Benjamini and Hochberg (1995).

Statistical analyses were performed using R v 2.13.1 (R Development Core Team, 2011), with the packages 'ape' (Paradis et al., 2004), ‘geomorph’ (Adams and Otarrowa-Castillo, 2013), and ‘Rmorph’ (Baylac, 2012).

3. Results

3.1. Diversity in the molar size of pig populations

When the specimens were analysed by site and period (Fig. 3), only the M2 size differed between populations (for M2: \( \chi^2 = 24.2, p = 0.007 \), for M3: \( \chi^2 = 15.9, p = 0.1 \)). However, when specimens were divided into six populations by region and period, both the M2 (\( \chi^2 = 16.5, p = 0.006 \)) and M3 (\( \chi^2 = 11.2, p = 0.048 \)) showed significant differences. Pairwise comparisons (Table 3) revealed that the M2 size of the east Plateau LBA population was significantly smaller than that of all other populations (Fig. 3). These findings also show that the molar size of the Alpine populations did not change throughout the Bronze Age, but that molar size in the east Plateau populations declined from the EBA to the LBA.

3.2. Diversity in the molar shape of pig populations

Regional and chronological populations (specimens divided by region and period) differed with respect to both their M2 (F [60, 480] = 2.62, \( p = 7e-9 \)) and M3 (F [70, 620] = 2.1, \( p = 9e-07 \)) shapes. Discriminant analyses a posteriori classified only 45.8% of the M2 and 41.75% of the M3 to the correct group. These low percentages are the result of a notable overlap of all Alpine and east Plateau LBA populations.

Unrooted neighbour-joining networks based on Mahalanobis distances showed a structuration of the variation in molar shape for both M2 and M3 (Fig. 4). The east Plateau and Alpine populations exhibited an important phenotypic distance for M2 during the EBA. However, the distance between these populations decreased during the LBA. Compared to the significant distance between the east Plateau EBA and the east Plateau LBA populations, no significant difference was observed between the Alpine populations. M3, on the other hand, displays a strong geographic signal, which clearly separates the three regional pig populations.

4. Discussion

Our analyses revealed an overall size homogeneity of the teeth of Bronze Age pigs from Switzerland. However, we did observe one pig population with smaller molars in the east Plateau region during the LBA at the site of Alpenquai, for which there are several possible explanations.

Natural factors influence the size of wild boars (Albarella et al., 2009; Rowley-Conwy et al., 2012), including climate (Davis, 1981; Payne and Bull, 1989). Therefore, domestic Alpenquai pigs would also have been influenced by these environmental factors if they were kept in the forest. Major climate deterioration around lake settlements in both the east and west Plateau regions occurred during the final stage of the LBA (Menotti, 2015a, 2015b). Since the west Plateau settlements were occupied before the final stage of the LBA (cf. Table 2), the molar size of the pig populations at those sites was probably not yet influenced by the climate deterioration. However, it is not known if the Alpenquai samples used in this study (Wettstein, 1924) belong to the older or younger Hallstatt B period due to the LBA (e.g. Mäder, 2001a, 2001b), due to the lack of dendrochronological dating when they were excavated in the early 20th century. Consequently, we cannot completely exclude the possibility of climatic effects on the Alpenquai samples. However, the climate during the LBA in the east and west Plateau regions might have been favourable for the duration of the lake side settlements (Menotti, 2015h). Therefore, the smaller molar size of the Alpenquai pigs may be due to other factors.

Changes in husbandry practices, such as the reduction of nutrient supply (Tonge and McCance, 1965) or confinement during an animal's growth, could act as environmental perturbations that affect the developmental process, causing a decline in the size of animals (Cucchi et al., 2016). Such changes in husbandry practices could have been induced by the decline of the forest cover close to the Lake Zurich settlements. The intensification of wood management during the LBA (Bleicher et al., 2013) might have forced pig herders from Alpenquai to...
change from forest to farmyard husbandry. In fact, small ruminants at Alpenquai are postulated to have been kept indoors at times (Kühn and Heitz-Weniger, 2015). The lack of size reduction in LBA Alpenquai cattle (Bopp-Ito et al., 2018) showed that Alpenquai people did not change their husbandry practices or the environment for cattle, but they might have changed pig husbandry practices, and perhaps sheep and goat husbandry practices, in order to keep them on the settlement as farmyard animals. However, further studies exploring pig diet are necessary. In addition, the use of biochemical indicators, such as isotopic analyses (Doppler et al., 2017; Balasse et al., 2016; Cucchi et al., 2016; Frémondeau et al., 2012; Reitmaier et al., 2017) would be helpful to refine our hypothesis.

The M₂ results revealed no significant changes in shape over time among the Alpine populations. However, the M₂ results indicated a divergence in shape between the EBA and LBA for the east Plateau pig populations. The history of the west Plateau population is not known, due to the lack of zooarchaeological material from the EBA. Considering that variation in M₂ shape reflects changes in the history of pig populations (Cucchi et al., 2011, 2016), several plausible explanations for the change in shape of M₂ between the east Plateau EBA and LBA populations are available. Different choices, such as free-ranging forest or farmyard husbandry could have influenced molar size and shape (Cacchi et al., 2016). Alternatively, pigs from the east Plateau EBA might have been genetically different from all other populations. However, our hypotheses are again based on limited information from the east Plateau region, and further evidence from genetic (Evin et al., 2015a; Meiri et al., 2013; Ottoni et al., 2013) approaches are necessary to support this hypothesis.

Contrary to the results observed for M₂, M₃ shows a clear geographic signal clustering the pig populations into three regions. In particular, the lack of change in molar size and shape of Alpine pigs indicates that the Alpine community relied on stable populations of pigs, suggesting the retention of the same breeding strategy through time. Two plausible explanations exist for the unchanged phenotype of Alpine pig teeth. One explanation is that continuous immigrants into the Alpine region (Jecker, 2015; Reitmaier et al., 2017) brought the same phenotypic pig populations with them. Alternatively, the MBA and LBA immigrants continued to use EBA pigs as the original prototype for breeding, both, as, unlike the EBA immigrants, they brought little or no animals with them. This autonomy in pig husbandry at the Alpine sites was also documented for cattle husbandry, which showed no size reduction of the animals (Bopp-Ito et al., 2018). Furthermore, the decline of mitochondrial DNA haplotypes of cattle at the Alpine site of Padnal (Harmath et al., 2017) suggests that breeding occurred within the limited cattle population of the Alpine region. The same might have happened to the pig population. However, further studies are required to confirm this hypothesis.

The phenotype in the west Plateau LBA pig population is noticeably different to that of the east Plateau and the Alpine populations. A lack of genetic interaction among these three regional pig populations might have occurred due to the topographical, geographical, and environmental divergence, and different cultural traditions between the Alpine and Plateau regions, as well as between east and west Plateau regions (e.g. Della Casa, 2013; Jennings, 2015a; Menotti, 2015a, 2015b; Reitmaier, 2012). These regional differences influenced to animal husbandry practices (e.g. Bopp-Ito et al., 2018; Cucchi et al., 2016; Duval et al., 2015; Plüss, 2011; Schibler, 2017; Schibler and Studer, 1998; Stopp, 2015). We hypothesise that geographical, topographical, environmental, and cultural factors probably influenced local pig husbandry practices and the phenotypic diversity of pig molars between regions (Cucchi et al., 2016; Duval et al., 2015).

5. Conclusions

Analysis of the phenotypic diversification of molar size and shape proxies revealed changes in pig husbandry in Bronze Age Switzerland, demonstrating that husbandry choices were influenced by different geographical, topographical, environmental, and cultural situations between three regions. Chronological continuity within the Alpine region suggests the stability of pig husbandry practices and the close interrelationship of human communities in this region. Conversely, the Plateau region showed the greater phenotypic diversity over time and space, possibly due to the more open topographical situation than the Alpine region and different cultural traditions between east and west Plateau human communities. The small molars of LBA east Plateau pig population might be due to the strong impact of deforestation on pig husbandry practices. However, a broader study using comparative materials, primarily from eastern and western Switzerland is required, alongside genetic and isotopic information, in order to explore these trends further.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2018.07.002.

Acknowledgments

We thank Jürg Rageth, Thomas Reitmaier, and Mathias Seifert for their assistance with the pig taxonomic analyses.
Carrer, F., Colonese, A.C., Lucquin, A., Guedes, E.P., Thompson, A., Walsh, K., Reitmaier, T., Craig, O.E., 2016. Chemical analysis of pottery demonstrates prehistoric origin for high-altitude Alpine dairying. PLoS One 11 (4), e0151442. http://dx.doi.org/10.1371/journal.pone.0151442.

Chia, L., 1986. La fauna. Unrera, M.A., Brochier, J.L., Chia, L., Hadorn, P. (Eds.), Nature et environnement. Cortaillod-Est, un village du Bronze final 4. Archéobiologie Neuchâteloise (Neuchâtel 1986) 4, St-Blaise, pp. 47–73.

Cornelissen, M., Reitmaier, T., 2016. Filling the gap: recent Mesolithic discoveries in the central and south-eastern Swiss Alps. Quat. Int. 423, 9–22. http://dx.doi.org/10.1016/j.quaint.2015.10.121.

Cuucci, T., Fujita, M., Dobney, K., 2009. New insights into pig taxonomy domestication and human dispersal in Island South East Asia: molar shape analysis of Sus from remains of Nile caves, Sarawak. Int. J. Osteoarchaeol. 19, 508–530. http://dx.doi.org/10.1002/oa.974.

Cuucci, T., Hulme-Beaman, A., Yuan, J., Dobney, K., 2011. Early Neolithic pig domestication at Jihua, Henan Province, China: clues from molar shape analyses using geometric morphometric approaches. J. Archaeol. Sci. 38, 11–22. http://dx.doi.org/10.1016/j.jas.2010.07.024.

Cuucci, T., Dai, L., Balase, M., Zhao, C., Gao, J., Hu, Y., Yuan, J., Vigne, J.D., 2016. Social complexity and pig (Sus scrofa) husbandry in early China: a combined geometric morphometric and isotopic approach. PLoS One 11 (7), e0158523. http://dx.doi.org/10.1371/journal.pone.0158523.

Cuucci, T., Mohaseb, A., Peigné, S., Debue, K., Orlando, L., Mashkour, M., 2017. Detecting taxonomic and phylogenetic signals in equal cheek teeth: towards new palaeontological and archaeological proxies. R. Soc. Open Sci. 4, 160997. http://dx.doi.org/10.1098/rsos.160997.

Davis, S.J.M., 1981. The effects of temperature change and domestication on the body size of domestic Pleistocene to Holocene mammals of Israel. Paleobiology 7, 101–114. http://dx.doi.org/10.1017/s009483730003821.

Della Casa, P., 2003. Concepts of Copper Age mobility in the Alps based on land use, raw materials and a framework of contact. Preistoria Alpina 39, 203–216.

Della Casa, P., 2007. Transalpine pass routes in the Swiss Central Alps and the strategic use of topographic resources. Preistoria Alpina 42, 109–118.

Della Casa, P., 2013, Switzerland and the Central Alps. In: Fokkens, H., Harding, A.F. (Eds.), The Oxford Handbook of the European Bronze Age. Oxford University Press, Oxford, pp. 706–722. http://dx.doi.org/10.1093/oxfordhb/9780199572861.0001.

Dobney, K., Lepeut, S., Horard-Herbin, M-P., Cuucci, T., 2015. Did Romanization impact Gallic pig morphology? New insights from molar geometric morphometrics. J. Archaeol. Sci. 57, 345–354. http://dx.doi.org/10.1016/j.jas.2015.03.004.

Duval C., Cuucci T., Horard-Herbin M-P and Lepeut S., (unpublished). The development of transalpine networks in the Late Neolithic (~4000 BC) in Central Europe: a stone tool diachronic approach; Béat Arnold and... 44
Frémond, D., Ducchi, T., Casabianca, F., Ugozzo-Monfrini, J., Horard-Herbinc, M.P., Balasse, M., 2012. Seasonality of birth and diet of pigs from stable isotope analyses of tooth enamel (18O, 13C): a modern reference data set from Corsica. France J. Archaeol. Sci. 99. http://dx.doi.org/10.1016/j.jas.2012.04.004.

Gunz, P., Mitteroecker, P., Bookstein, F.L., 2005. Semi-landmarks in three dimensions. In: Slice, D.E. (Ed.), Modern morphometrics in physical anthropology. Klwer Academic/Plenum Publishers, New York, pp. 73–98.

Huber-Morath, K.H., 1975. Uberlebensstromung bei Haus- und Laboratorium. 2. Auflage. Verlag Paul Parey, Berlin, Hamburg.

Harmath, M., Pichler, S., Schumbauer, A., 2017. Alte DNA – Fragestellungen, Probenentnahme und Anwendung. Neue archäogenetische Erkenntnisse zu bronzezeitlichen Rindern aus Savinog GR-Padul und deren kulturarchäologische Bedeutung. Jahrbuch Archäologie Schweiz. 100. pp. 135–141.

Hess, T., Reitmaier, T., Zimmermann, E.J., Ballmer, A., Dobler, I., Della Casa, P., 2010. Menotti, F., 2015a. The lake-dwelling phenomenon: myth, reality and archaeology. In: Künzler Wagner, N., 2005. Zürich-Alpenquai V: Tauchgrabungen 1999 – 2001. Seeufersiedlungen. Die spätbronzezeitliche Seeufersiedlung Zürich-Thesenfluss. Oxbow Books, Oxford, Philadelphia, pp. 211–250.

Mäder, A., 2001a. Seeufersiedlungen. Die spätbronzezeitliche Seeufersiedlung Zürich-Thesenfluss. Oxbow Books, Oxford, Philadelphia, pp. 125–224. http://dx.doi.org/10.1007/s10073-011-1015-7.

Paradis, E., Claude, J., Strimmer, K.A.P.E., 2004. Analyses of phylogenetics and evolution in R language. Bioinformatics, 20. 289–290. http://dx.doi.org/10.1093/bioinformatics/bth314.

Payne, S., Bull, G., 1989. Components of variation in measurements of pig bones and teeth, and the use of measurements to distinguish wild from domestic pig remains. Archaeozoologia II (1.2). 27–66.

Plüss, P., 2017. Archäozoologische Untersuchungen der Tierknochen aus Cresta-Cazis (GR) und ihre Bedeutung für die Umwelt-, Ernährungs- und Wirtschaftsgeschichte während der Alpiner Bronzezeit (Inaugural dissertation). Zur Erlangung der Würde eines Doktors der Philosophie vorgelegt der Philosophisch naturwissenschaftlichen Fakultät der Universität Basel, Brugg.

Plüss, P., 2011. Die Bronzezeitliche Siedlung Cresta bei Cazis (GR). Die Tiere. In: Collectio Archaeologica 9. Schweizerisches Nationalmuseum, Chronos Verlag, Basel.

R Development Core Team, 2011. R: a Language and Environment for Statistical Computing. In: R Foundation for Statistical Computing. Austria. URL, Vienna. http://www.R-project.org/.

Rohlf, F.J., 2012. Tps Util, version 1.53. Thin plate spline utility. In: Ecology and Evolution. State University of New York at Stony Brook, Stony Brook, New York.

Rohlf, F.J., 2010a. Tps Dig 2, version 2.16. Thin plate spline digitizer. In: Ecology and Evolution. State University of New York at Stony Brook, Stony Brook, New York.

Rohlf, F.J., 2000. Statistical power comparisons among alternative morphometric methods. Am. J. Phys. Anthropol. 111, 463–478. http://dx.doi.org/10.1002/ (SICI)1096-861X(200005)111:3<463::AID-AJPA1>3.0.CO;2-L.

Rohlf, F.J., 2007. Tps Dig, version 2.13. Thin plate spline digitizer. In: Ecology and Evolution. State University of New York at Stony Brook, Stony Brook, New York.

Rowley-Conwy, P., Dobney, K., 2012. Distinguishing wild boar from domesticated pigs: a method based on tooth enamel (18O, 13C): a modern reference data set from Corsica. France J. Archaeol. Sci. 99. http://dx.doi.org/10.1016/j.jas.2012.04.004.

Ricaut, F.X., Hoelzel, A.R., Mashkour, M., Fatemeh Mphaseb Karimlu, A., Sheikhi Senni, N., Ricaut, F.X., Hoelzel, A.R., Mashkour, M., Fatemeh Mphaseb Karimlu, A., Sheikhi Senni, N., Strudwick, J., Brothwell, D., Pinhasi, R., Jongho, H., Perez-Enciso, M., Rammohan, M., Lorenz, M., Legens, H.J., Crooijmans, R., Groenen, M., Arbuckle, B., Benecke, N., Strand Varsidottir, U., Burger, J., Ducchi, T., Larson, G., Dobbey, K., 2013. Pig domestication and human-mediated dispersal in western Eurasia revealed through ancient DNA and geometric morphometrics. Mol. Biol. Evol. 30, 824–832. http://dx.doi.org/10.1093/molbev/msm261.

Schilder, J., 2017. Zoorarchaologische resultaten uit Neolithisch en Bronze Age wetland en droogland sites in the Central Alpine Foreland. In: Albarella, U., Rizzetto, M., Russ, H., 2012. Die Mittelneolithischen Tierknochen aus Kneusel-Muttgau (GR): Ein Beitrag auf den server der institute des IPAS, University of Basel, Switzerland, publiziert in 2010.

Strand Vidarsdottir, U., Burger, J., Cucchi, T., Larson, G., Dobney, K., 2013. Pig domestication and human-mediated dispersal in western Eurasia revealed through ancient DNA and geometric morphometrics. Mol. Biol. Evol. 30, 824–832. http://dx.doi.org/10.1093/molbev/msm261.

Takada, S., Jennings, B., 2015a. Bronze Age trade and exchange through the Alps: in M. Bopp-Ito et al. Journal of Archaeological Science: Reports 21 (2018) 38–46.

Takada, S., Jennings, B., 2015a. Bronze Age trade and exchange through the Alps: in M. Bopp-Ito et al. Journal of Archaeological Science: Reports 21 (2018) 38–46.

Takada, S., Jennings, B., 2015a. Bronze Age trade and exchange through the Alps: in M. Bopp-Ito et al. Journal of Archaeological Science: Reports 21 (2018) 38–46.
Schibler, J., Jacomet, S., 2010. Short climatic fluctuations and their impact on human economies and societies: the potential of the Neolithic lake shore settlements in the Alpine foreland. Environ. Archaeol. 15 (2), 173–182. http://dx.doi.org/10.1179/146141010x12640787648856.

Schibler, J., Studer, J., 1998. Haustierhaltung und Jagd während der Bronzezeit der Schweiz. In: Hochuli, S., Niffeler, U., Rychner, V. (Eds.), SPM III Bronzezeit: Die Schweiz vom Palolithikum bis zum frühen Mittelalter. Vom Neandertaler bis zu Karl dem Großen. Verlag Schweizerische Gesellschaft für Ur- und Frühgeschichte, Basel, pp. 171–191.

Stopp, B., 2015. Animal husbandry and hunting activities in the Late Bronze Age Circum-Alpine region. In: Menotti, F. (Ed.), The End of the Lake-Dwellings in the Circum-Alpine Region. Oxbow Books, Oxford, Philadelphia, pp. 179–210.

Straus, R.E., Bookstein, F.L., 1982. The truss: body form reconstruction in morphometrics. Syst. Zool. 31, 113–135.

Studer, J., 1991. La faune de l’âge du bronze final du site d’Hauterive-Champréveyres (Neuchâtel, Suisse). In: Synthèse de la faune des sites littoraux contemporains. Thèse de l’Université de Genève, Genève.

Thesleff, I., 2006. The genetic basis of tooth development and dental defects. Am. J. Med. Genet. A 140A, 2530–2535. http://dx.doi.org/10.1002/ajmg.a.31360.

Tonge, C.H., McCance, R.A., 1965. Severe undernutrition in growing and adult animals. The mouth, jaws and teeth of pigs. Br. J. Nutr. 19, 361–372 (PMID: 5891038).

Wettstein, E., 1924. Die Tierreste aus dem Pfahlbau am Alpenquai in Zürich. Vierteljahrschrift der Naturforschenden Gesellschaft in Zürich 69, 78–127.

Wiemann, P., Kühn, M., Heitz-Weniger, A., Stopp, B., Jennings, B., Rentzel, P., Merotti, F., 2012. Zurich-Alpenquai: a multidisciplinary approach to the chronological development of a Late Bronze Age lakeside settlement in the northern Circum-Alpine region. J. Wetland Archaeol. 12 (1), 58–85. http://dx.doi.org/10.1179/jwa.2012.12.1.004.

Wynn, R., 2002. Archaeologische Forschungen. Die bronzezeitliche Hügelsiedlung Cresta bei Cazis, Ergebnisse der Grabungen von 1943 bis 1970. Band 1 Teil I, Die Siedlungen. Teil II, Die Kleinfunde (ohne Keramik). Schweizerisches Landesmuseum, Zürich.

Zelditch, M.L., Swiderski, D.L., Sheets, A.D., Fink, W.L., 2004. Geometric Morphometrics for Biologists: A Primer. Elsevier, Berlin.