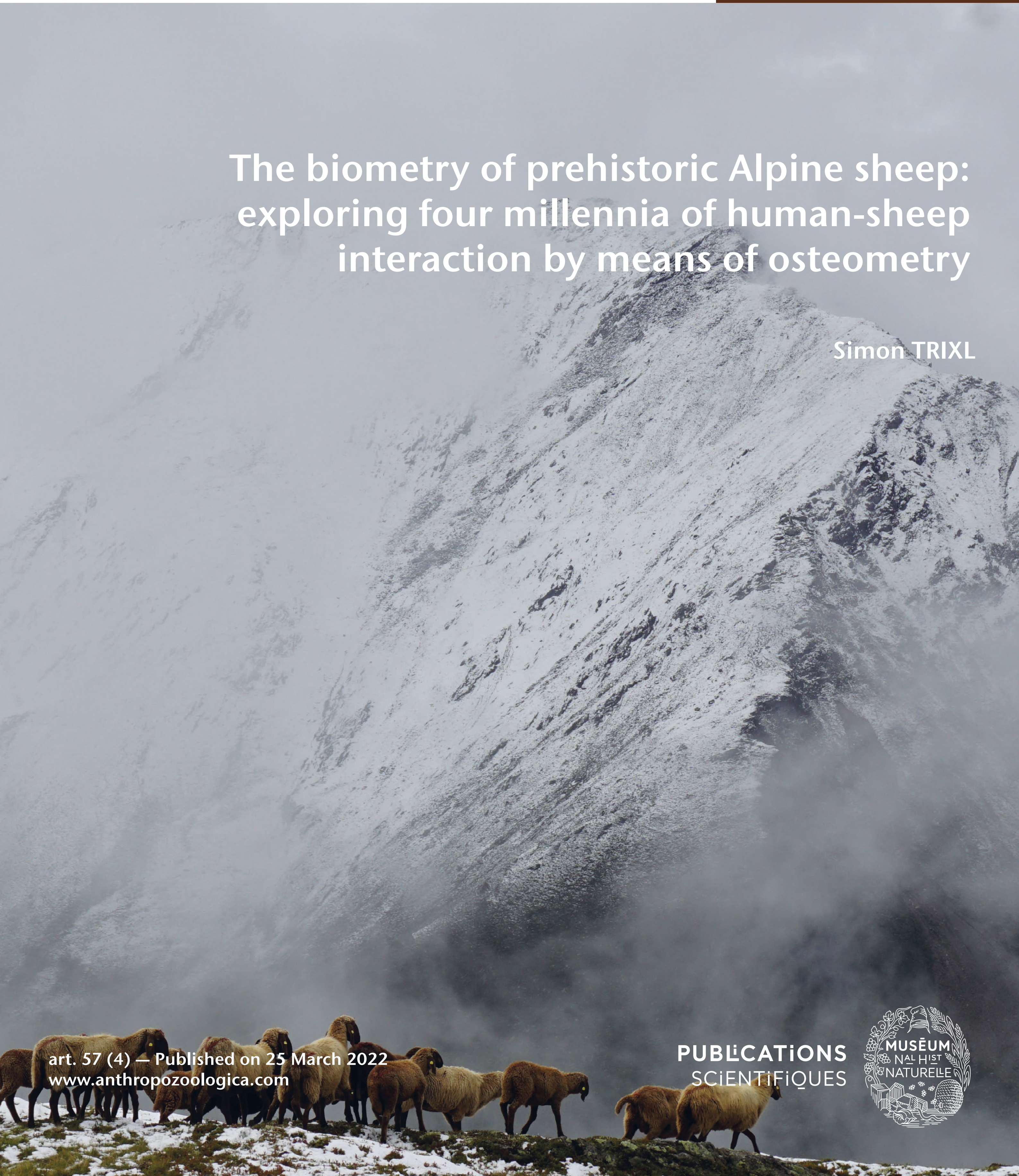
anthropozoologica

2022 • 57 • 4



The biometry of prehistoric Alpine sheep: exploring four millennia of human-sheep interaction by means of osteometry

Simon TRIXL

art. 57 (4) — Published on 25 March 2022
www.anthropozoologica.com

PUBLICATIONS SCIENTIFIQUES
MUSÉUM NAL HIST NATURELLE

Couverture / *Cover* :
Moutons alpins. Crédit photo : S. Trixl/*Alpine sheep. Photo credit: S. Trixl.*

Anthropozoologica est indexé dans / Anthropozoologica *is indexed in:*

– Social Sciences Citation Index
– Arts & Humanities Citation Index
– Current Contents - Social & Behavioral Sciences
– Current Contents - Arts & Humanities
– Zoological Record
– BIOSIS Previews
– Initial list de l'European Science Foundation (ESF)
– Norwegian Social Science Data Services (NSD)
– Research Bible

Anthropozoologica est distribué en version électronique par / Anthropozoologica *is distributed electronically by:*
– BioOne® (https://www.bioone.org)

Anthropozoologica est une revue en flux continu publiée par les Publications scientifiques du Muséum, Paris, avec le soutien du CNRS.
Anthropozoologica *is a fast track journal published by the Museum Science Press, Paris, with the support of the CNRS.*
Les Publications scientifiques du Muséum publient aussi / *The Museum Science Press also publish:* ***Adansonia***, ***Zoosystema***, ***Geodiversitas***, ***European Journal of Taxonomy***, ***Naturae***, ***Cryptogamie*** **sous-sections** ***Algologie***, ***Bryologie***, ***Mycologie, Comptes Rendus Palevol***.

Diffusion – Publications scientifiques Muséum national d'Histoire naturelle
CP 41 – 57 rue Cuvier F-75231 Paris cedex 05 (France)
Tél. : 33 (0)1 40 79 48 05 / Fax : 33 (0)1 40 79 38 40
diff.pub@mnhn.fr / https://sciencepress.mnhn.fr

ISSN (imprimé / *print*) : 0761-3032 / ISSN (électronique / *electronic*) : 2107-08817

The biometry of prehistoric Alpine sheep: exploring four millennia of human-sheep interaction by means of osteometry

Simon TRIXL
Institute of Palaeoanatomy, Domestication Research and the History of Veterinary Medicine, Ludwig Maximilian University of Munich, 37 Kaulbachstraße, Munich, D-80539 (Germany)
and State Office for Cultural Heritage Management Baden-Wuerttemberg, 3 Stromeyersdorfstraße, Constance, D-78467 (Germany)
simon.trixl@palaeo.vetmed.uni-muenchen.de

Submitted on 26 February 2021 | Accepted on 26 August 2021 | Published on 25 March 2022

Trixl S. 2022. — The biometry of prehistoric Alpine sheep: exploring four millennia of human-sheep interaction by means of osteometry. *Anthropozoologica* 57 (4): 117-139. https://doi.org/10.5252/anthropozoologica2022v57a4. http://anthropozoologica.com/57/4

ABSTRACT
Sheep were vital to Alpine subsistence strategies during the Neolithic as well as the Bronze and Iron Ages. The present study deals with the question of phenotypic alterations in Alpine sheep during these 4500 years of prehistoric Alpine livestock farming. It furthermore addresses the issue of to what extent morphological developments were triggered by processes of economic, cultural or ecological change. To answer these questions, bone measurements of sheep from 59 find complexes in an Alpine model region were examined. The region stretches between the Northern Pre-Alps and the Padanian Plain and comprises the valleys of Inn, Isarco and Adige along with adjacent regions. As shown by the application of logarithmic size index analyses and withers height calculations, the phenotypic development of sheep was characterised by micro-regional differences; for example, while the Inn Valley population underwent a size reduction from the Late Bronze Age onwards, the conspecifics of the southern Alpine fringe grew synchronously larger. For other regions, no diachronic changes were observed. Based on the osteometric analysis, the following factors are discussed as potential triggers for phenotypic alterations in Alpine livestock: climatic fluctuations, a physical adaptation to high altitude pasturing, the emergence of wool farming, the introduction of allochthonous livestock in the context of cultural transfer and shifts in the sex ratios caused by changing exploitation patterns. In order to evaluate the possible influence of these aspects on sheep morphology, the osteometric results are compared to different data on the cultural and climatic development of the Alpine region.

KEY WORDS
Alps,
archaeozoology,
Prehistory,
exploitation patterns,
Logarithmic Size Index,
Neolithic,
Bronze Age,
Iron Age.

RÉSUMÉ

La biométrie des moutons alpins préhistoriques: exploration de quatre millénaires d'interaction entre l'homme et le mouton au moyen de l'ostéométrie.

Les moutons étaient d'une importance vitale pour les stratégies de subsistance alpines au Néolithique ainsi qu'aux âges du bronze et du fer. La présente étude traite de la question des altérations phénotypiques des moutons alpins au cours de ces 4500 ans d'élevage préhistorique dans les Alpes. Elle aborde en outre la question de savoir dans quelle mesure les développements morphologiques ont été induits par des processus de changement économique, culturel ou écologique. Pour répondre à ces questions, les données ostéométriques de moutons provenant de 59 assemblages archéologiques dans une région alpine modèle ont été examinées. Cette région s'étend des Préalpes du Nord à la plaine Padane et comprend les vallées de l'Inn, de l'Isarco et de l'Adige et les régions adjacentes. Comme le montre l'application des analyses de *Logarithimic Size Index* (LSI) et des calculs de la hauteur au garrot, le développement phénotypique des moutons a été caractérisé par des différences micro-régionales: ainsi, tandis que la population de la vallée de l'Inn a subi une réduction de taille à partir de la fin de l'âge du bronze, celle de leurs congénères de la frange des Alpes du Sud a augmenté de manière synchrone. Pour quelques autres régions, aucun changement diachronique n'a été observé. Sur la base de l'analyse ostéométrique, les facteurs suivants sont examinés en tant que sources potentielles de modifications phénotypiques des moutons alpins: les fluctuations climatiques, l'adaptation physique aux pâturages de haute altitude, l'émergence de l'exploitation de la laine, l'introduction d'un type allochtone dans le cadre de transfert culturel et les changements dans la répartition des sexes causés par l'évolution des modes d'exploitation. Afin d'évaluer l'influence possible de ces aspects sur la morphologie des moutons, les résultats ostéométriques sont comparés à diverses données sur le développement culturel et climatique de la région alpine.

KEY WORDS
Alpes, archéozoologie, Préhistoire, modes d'exploitation, *Logarithmic Size Index*, Néolithique, âge du bronze, âge du fer.

INTRODUCTION

Thanks to physical characteristics such as sure-footedness in rugged mountain areas and frugality with regard to food intake, the sheep represents a farm animal of central importance in the Alpine region today. Numerous archaeozoological studies prove that this has been the case since the beginning of livestock farming in this mountainous region. In most Neolithic, Copper Age, Bronze Age and Iron Age faunal assemblages, both north and south of the main Alpine ridge, small domestic ruminants, and sheep in particular, are the most important or at least one of the best represented species (Fig. 1) (e.g., Guem 1956: 18-79; Würgler 1962; Riedel 1976a, 1986, 2002; Riedel & Tecchiati 1999: 295-297; Plüss 2007: table 3; Schmitzberger 2007: 625, 659, 666; Festi *et al.* 2011: 373; Tecchiati 2012: 34; Tecchiati & Zanetti 2013: 232; Deschler-Erb *et al.* 2015: 368; Trixl 2019: 58). During this long period of prehistoric livestock farming, the Alpine region underwent a series of fundamental socioeconomic changes that were not without impact on animal husbandry. This includes the controversial issue of different forms of mobile livestock farming from the Neolithic onwards (e.g., Patzelt *et al.* 1997; Spindler 2005; Oeggl *et al.* 2009), the emergence of copper and salt mining including specialised food supply structures during the Bronze Age (e.g., Saliari *et al.* 2020) and, last but not least, the appearance of wool farming during the Early Bronze Age (e.g., Grömer & Saliari 2018: 147, 148).

Closely linked to these economic innovations is the role of the Alps as a region of high cultural and socioeconomic dynamics; the mountain range was by no means a mere topographical barrier, but rather a contact zone linking Central Europe and the Mediterranean region, in which throughout Prehistory a wide variety of cultural influences are to be noted (e.g., Metzner-Nebelsick *et al.* 2017). An early example of this is the introduction of livestock farming in the Alpine region, which followed two different routes in distinct Neolithic communities (e.g., Schmölcke *et al.* 2018: 106). Also during the Metal Ages, the Alps were characterised by cultural dynamics as evidenced, for example, by the emergence of the North Tyrolean Urnfield Culture triggered by cultural transfer or migration from the Northern Alpine foreland (e.g., Grupe *et al.* 2017: 233-241). In recent decades, the question whether such shifts in socioeconomic structures and cultural networks are additionally dependent on well-evidenced climatic fluctuations has become an important research issue for bioarchaeology, especially with regard to developments during the Bronze and Iron Ages (e.g., Magny *et al.* 2009; Oeggl & Nicolussi 2009).

In view of the considerable importance of sheep for prehistoric Alpine subsistence strategies, the question arises if the cultural, ecological and socioeconomic changes between the arrival of the first herder communities (c. 4500 BCE) and the Roman occupation (c. 100-15 BCE) also affected the phenotypic development of sheep in the mountain area. This becomes even more likely given the fact that numerous archaeozoological investigations have shown alterations in husbandry practices and in exploitation patterns of pre-modern livestock as having often been accompanied by changes in the animal populations' body size, stature, hair coat and horn shape (e.g., Pucher 2010: 9; Halstead & Isaakidou 2011: 68; Trixl 2019: 253-267). Furthermore, in addition to chronological developments we must also consider the possible coexistence of different livestock phenotypes in neighbouring micro-regions. This may be true in particular of prehistoric Alpine sheep populations, as shown by

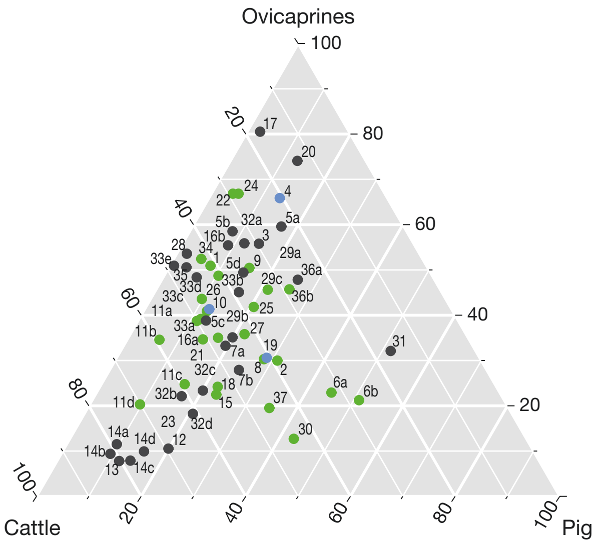


FIG. 1. — The percentage of the main livestock species animals in Prehistoric Alpine find complexes. ●, Neolithic/Copper Age; ●, Bronze Age; ●, Iron Age. Site numbering, see Table 1.

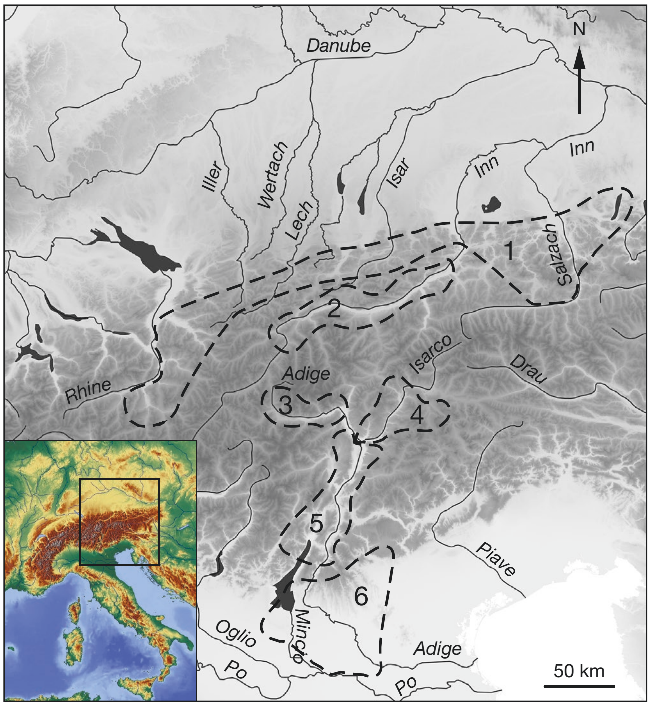


FIG. 2. — The working area with separately studied micro-regions. **1**, Northern Pre-Alps and Limestone Alps; **2**, Inn Valley; **3**, Val Venosta; **4**, Isarco Valley; **5**, Adige Valley; **6**, Southern Alpine fringe and northern Padanian Plain. Map basis: https://srtm.csi.cgiar.org; https://maps-for-free.com, last consultations on 26 February 2022.

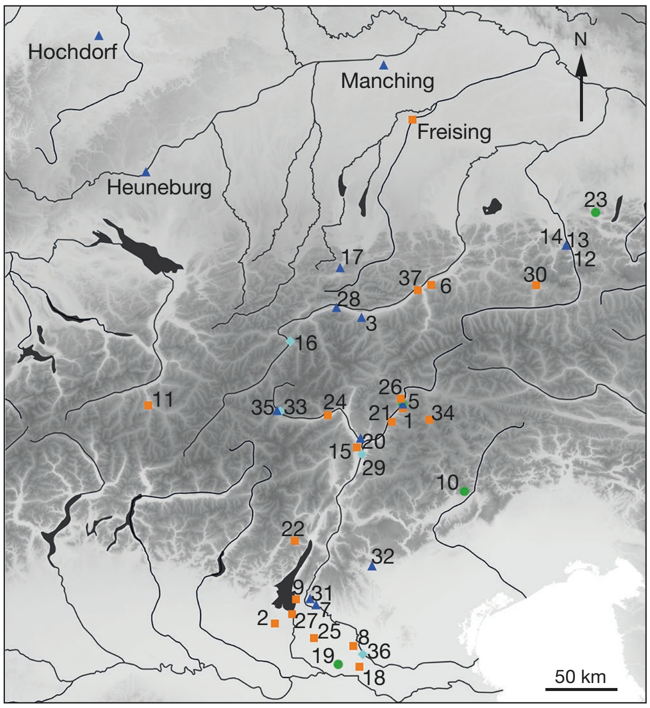


FIG. 3. — Location of the sites considered in this study. ●, Neolithic / Copper Age; ■, Bronze Age; ▲, Iron Age; ◆, several periods; site numbering, see Table 1. Map basis: https://srtm.csi.cgiar.org, last consultation on 26 February 2022.

several bioarchaeological studies stressing the fact that sheep of different Alpine regions vary in withers height and body shape (e.g., Rueger 1942; Riedel 2003; Plüss 2007; Grömer & Saliari 2018; Schmölcke *et al.* 2018).

The aim of the present study is to evaluate the phenotypic variability of prehistoric Alpine sheep in spatial and temporal terms. Subsequently, possible cultural, ecological and socioeconomic reasons for chronological and/or regional patterning are discussed.

MATERIAL AND METHODS

An osteometric approach was applied, in order to investigate these questions. The material basis comprises 2536 width measurements taken from sheep Humeri, Radii, Metacarpi, proximal phalanges, distal phalanges, Ossa femoris, Tibiae and Metatarsi according to von den Driesch (1976). As far as this was evident from the literature, only the measurements of skeleton elements with fused epiphyseal joints were considered. In addition to the distal (Bd) and proximal (Bp) breadth, 1096 length measurements (GL [greatest length] and GLl [greatest length lateral]) recorded at long bones as well as on Tali and Calcanei were also included in the study. Those data derive from 37 prehistoric sites located in an Alpine model region, which also comprises selected find complexes from the immediate Alpine foothills in order to enable osteometric comparison between mountain populations and their conspecifics in the Circum-Alpine plains (Figs 2, 3). A site overview including information on dating and references is given in Tables 1 and 2. Based on C14 dating, stratigraphy or archaeological find material, some of these faunal assemblages such as Bressanone-Stufles/Brixen-Stufels (Distr. Bolzano, Italy; Riedel 1986) and Cazis near Cresta (Distr. Grisons, Switzerland; Plüss 2007) were chronologically subdivided. Taking into account this intra-site periodisation, a total of 59 find complexes constitute the material basis of the present study.

Statistical analysis of width measurements was mainly carried out using the logarithmic size index technique (LSI; Meadow 1999). A modern female sheep skeleton housed in the

Table 1. — Overview of the archaeofaunas considered in the study. Abbreviations: **BA**, Bronze Age; **EBA**, Early Bronze Age; **EIA**, Early Iron Age; **IA**, Iron Age; **LBA**, Late Bronze Age; **LIA**, Late Iron Age; **MBA**, Middle Bronze Age; **NCA**, Neolithic/Copper Age; **NISP**, number of identified specimens.

Site no.	Site	Country/District	References	NISP	Period
1	Albanbühel near Bressanone/Brixen	Italy/Bolzano	Rizzi 1997	17818	MBA
2	Barche di Solferino	Italy/Mantova	Riedel 1976b	3402	EBA
3	Birgitz	Austria/Innsbruck	Guem 1956; Trixl 2019	3424	LIA
4	Bressanone-Stufles/Brixen-Stufels	Italy/Bolzano	Tecchiati & Zanetti 2013	443	NCA
5a	Bressanone-Stufles/Brixen-Stufels Gruppe I	Italy/Bolzano	Riedel 1986	49	EIA
5b	Bressanone-Stufles/Brixen-Stufels Gruppe II	Italy/Bolzano	Riedel 1986	760	EIA
5c	Bressanone-Stufles/Brixen-Stufels Gruppe III	Italy/Bolzano	Riedel 1986	771	LIA
5d	Bressanone-Stufles/Brixen-Stufels Gruppe IV	Italy/Bolzano	Riedel 1986	85	LIA
6a	Brixlegg, EBA	Austria/Schwaz	Riedel 2003	4355	EBA
6b	Brixlegg, LBA	Austria/Schwaz	Boschin & Riedel 2011	1346	LBA
7a	Castelrotto, 4th century BCE	Italy/Verona	Riedel 1985a	2469	LIA
7b	Castelrotto, 5th century BCE	Italy/Verona	Riedel 1985a		LIA
8	Cavalzara	Italy/Verona	Riedel 1979	164	LBA
9	Cisano	Italy/Verona	Riedel 1990	588	EBA/MBA
10	Col del Buson	Italy/Belluno	Fontana *et al.* 2015	766	NCA
11a	Cresta-Cazis, EBA 1	Switzerland/Grisons	Plüss 2007	12613	EBA
11b	Cresta-Cazis, EBA 2	Switzerland/Grisons	Plüss 2007		EBA
11c	Cresta-Cazis, MBA	Switzerland/Grisons	Plüss 2007		MBA
11d	Cresta-Cazis, LBA	Switzerland/Grisons	Plüss 2007		LBA
12	Dürrnberg-Putzenfeld	Austria/Hallein	Schmitzberger 2012	7260	LIA
13	Dürrnberg-Putzenkopf Nord	Austria/Hallein	Saliari *et al.* 2016	9820	LIA
14a	Dürrnberg-Ramsautal Horizont 1	Austria/Hallein	Pucher 1999a	2711	LIA
14b	Dürrnberg-Ramsautal Horizont 2	Austria/Hallein	Pucher 1999a	3776	LIA
14c	Dürrnberg-Ramsautal Horizont 3	Austria/Hallein	Pucher 1999a	4502	LIA
14d	Dürrnberg-Ramsautal Horizont 4	Austria/Hallein	Pucher 1999a	1172	LIA
15	Appiano/Eppan	Italy/Bolzano	Riedel 1985b	1426	LBA
16a	Faggen, Bronze Age	Austria/Imst	Tecchiati 2012	1973	MBA
16b	Faggen, Iron Age	Austria/Imst	Tecchiati 2012	171	LIA
17	Farchant	Germany/Garmisch-Partenkirchen	Trixl pers. comm.	2176	EIA/LIA
18	Fondo Paviani	Italy/Verona	Riedel 1979	284	LBA
19	Gazzo Veronese	Italy/Verona	Riedel & Rizzi-Zorzi 2006	1958	NCA
20	Castel del Porco/Greifenstein	Italy/Bolzano	Riedel *et al*. 2002	1334	IA
21	Laion/Lajen	Italy/Bolzano	Tecchiati *et al.* 2010	1208	MBA/LBA
22	Ledro	Italy/Trento	Riedel 1976a	8449	EBA/MBA
23	Mondsee	Austria/Vöcklabruck	Pucher & Engl 1997	5144	NCA
24	Naturno/Naturns	Italy/Bolzano	Riedel & Tecchiati 2000	374	EBA
25	Nogarole Rocca I Camponi	Italy/Verona	Riedel 1992	1118	MBA
26	Nössing near Varna/Vahrn	Italy/Bolzano	Riedel & Tecchiati 1999	1797	EBA/MBA
27	Peschiera	Italy/Verona	Riedel 1982	399	MBA/LBA
28	Pfaffenhofen-Hörtenberg	Austria/Innsbruck-Land	Trixl pers. comm.	1625	LIA
29a	Vadena/Pfatten Horizont I	Italy/Bolzano	Riedel 2002	1458	EIA/LIA
29b	Vadena/Pfatten Horizont II	Italy/Bolzano	Riedel 2002	1699	EIA
29c	Vadena/Pfatten Horizont III	Italy/Bolzano	Riedel 2002	585	LBA
30	Saalfelden-Katzentauern	Austria/Zell am See	Pucher 2019	4449	EBA/MBA
31	San Giorgio di Valpolicella	Italy/Verona	Tecchiati 2006	522	LIA
32a	Santorso, Phase 2	Italy/Vicenza	Cassoli & Tagliacozzo 1991	38	LIA
32b	Santorso, Phase 3	Italy/Vicenza	Cassoli & Tagliacozzo 1991	610	LIA
32c	Santorso, Phase 4	Italy/Vicenza	Cassoli & Tagliacozzo 1991	451	LIA
32d	Santorso, Phase 5	Italy/Vicenza	Cassoli & Tagliacozzo 1991	333	LIA
33a	Ganglegg near Sluderno/Schluderns, MBA	Italy/Bolzano	Schmitzberger 2007	4585	MBA
33b	Ganglegg near Sluderno/Schluderns, early LBA	Italy/Bolzano	Schmitzberger 2007	947	LBA
33c	Ganglegg near Sluderno/Schluderns, Laugen-Melaun A	Italy/Bolzano	Schmitzberger 2007	455	LBA
33d	Ganglegg near Sluderno/Schluderns, Middle La Tène	Italy/Bolzano	Schmitzberger 2007	3948	LIA
33e	Ganglegg near Sluderno/Schluderns, Late La Tène	Italy/Bolzano	Schmitzberger 2007	1574	LIA
34	Sotciastel near Badia/Abtei	Italy/Bolzano	Salvagno & Tecchiati 2011	9096	MBA/LBA
35	Tartscher Bichl near Tarces/Tartsch	Italy/Bolzano	Schmitzberger 2007	825	LIA
36a	Terranegra, Iron Age	Italy/Verona	Depellegrin *et al.* 2018	1011	EIA
36b	Terranegra, LBA	Italy/Verona	Depellegrin *et al.* 2018	1793	LBA
37	Wiesing	Austria/Schwaz	Pucher 1984	1863	EBA

Bavarian State Collection for Anthropology and Palaeoanatomy Munich (inventory number SAPM-MA-02718), served as the standard individual (Manhart 1998). The results were tested for statistical significance using the pairwise Wilcoxon rank-sum test with alpha error correction according to Bonferroni (Table 3). The difference between two populations is considered statistically significant if the P-value is <0.05. The statistical program R (R Core Team 2020) with the packages ggplot2 (Wickham 2016) and ggtern (Hamilton & Ferry 2018) was used for data analysis.

TABLE 2. — Comparative archaeofaunas from the Northern Alpine Foreland and find complexes which were combined for the data analysis. Abbreviations: **EBA**, Early Bronze Age; **EIA**, Early Iron Age; **LBA**, Late Bronze Age; **LIA**, Late Iron Age; **MBA**, Middle Bronze Age. The capital letters refer to the site labelling in Figures 5 to 10.

Site no.	Site	Country/District	References	Period
A	EBA total	Several	Several	EBA
B	EBA/MBA total	Several	Several	EBA/MBA
C	MBA total	Several	Several	MBA
D	MBA/LBA total	Several	Several	MBA/LBA
E	LBA total	Several	Several	LBA
F	EIA total	Several	Several	EIA
G	EIA/LIA total	Several	Several	EIA/LIA
H	LIA total	Several	Several	LIA
I	Northern Alps total	Several	Several	Several
J	Inn Valley total	Several	Several	Several
K	Vintschgau total	Several	Several	Several
L	Eisack Valley total	Several	Several	Several
M	Etsch Valley total	Several	Several	Several
N	Southern Alps total	Several	Several	Several
O	Heuneburg near Hundersingen	Germany/Sigmaringen	McEneaney-Schneider 1984	EIA/LIA
P	Hochdorf	Germany/Ludwigsburg	Schatz 2009	LIA
Q	Manching	Germany/Pfaffenhofen an der Ilm	Boessneck *et al*. 1971	LIA
R	Freising	Germany/Freising	Manhart 2004	EBA/LBA

TABLE 3. — Results of the Wilcoxon rank-sum test. The capital letters refer to the site numbering in Figures 5 to 10.

	Statistically significant deviation between:											
Figure no.	A	B	C	D	E	F	G	H	I	J	K	L
5	B, C	A, C	A, B	–	–	–	–	–	–	–	–	–
6a	B	C, D, E	–	–	–	–	–	–	–	–	–	–
6b	C, G	C, G	–	–	–	–	–	–	–	–	–	–
6c	–	–	–	–	F	–	–	–	–	–	–	–
6d	H, I	–	–	H, I	–	H	–	–	–	–	–	–
6e	B, C, D, E	–	–	–	–	–	–	–	–	–	–	–
6f	H, I, J	H, I, J	H, I, J	H, I, J	H, I, J	I	I	–	–	–	–	–
9	–	–	–	–	–	–	–	–	–	–	–	–
10	C, D	C, D	–	–	–	–	–	–	–	–	–	–

TABLE 4. — Calculation of LSI-values in statistically meaningful archaeofaunas separated according to different body regions. Abbreviations: **LSI**, logarithmic size index; **NM**, n measurements.

	Stylo-/Zeugopodium		Metapodium		Basipodium		
Site	LSI median	NM	LSI median	NM	LSI median	NM	Statistic significant deviation
Albanbühel	–0.147401005	126	–0.141521605	52	–0.144697077	127	–
Brixlegg (EBA)	–0.11270428	29	–0.111828685	46	–0.10909477	60	–
Castelrotto (5th-4th century BCE)	–0.115157517	30	–0.129525191	28	–0.128116732	18	–
Dürrnberg (complete)	–0.130185807	116	–0.136582718	25	–0.103904064	22	*Metapodium-Basipodium*: p = 0.039
Farchant	–0.087864119	44	–0.097734102	22	–0.102551215	88	–
Ledro	–0.175626286	146	–0.170173557	134	–	–	–
Mondsee	–0.162727297	13	–0.150514998	7	–0.178743214	11	–
Sotciastel	–0.146128036	50	–0.132237975	19	–0.124938737	43	*Stylo-/Zeugopodium-Metapodium*: p = 0.0163 *Stylo-/Zeugopodium-Basipodium*: p = 0.0052
Terranegra (Bronze Age)	–0.129910273	15	–0.117282404	16	Only 1 value available	–	–
Terranegra (Iron Age)	–0.1349815	14	–0.104878943	62	-0.111508494	12	*Stylo/Zeugopodium-Metapodium*: p = 0.0066
Wiesing	–0.096910013	11	–0.115983894	9	-0.10317903	33	–

In this context, however, it is important to consider that depending on the studied animal population, the results of osteometric indexing methods can vary between different skeleton elements (e.g., Davis 1996). Therefore, differing patterns in skeleton element representation can potentially bias osteometric results. To test this possibility for the present sheep bone assemblages, the LSI was calculated separately for the Stylopodium/Zeugopodium, Metapodium and Basipodium in some large Alpine find complexes covering a wide chronological and regional range (Table 4). The majority of those

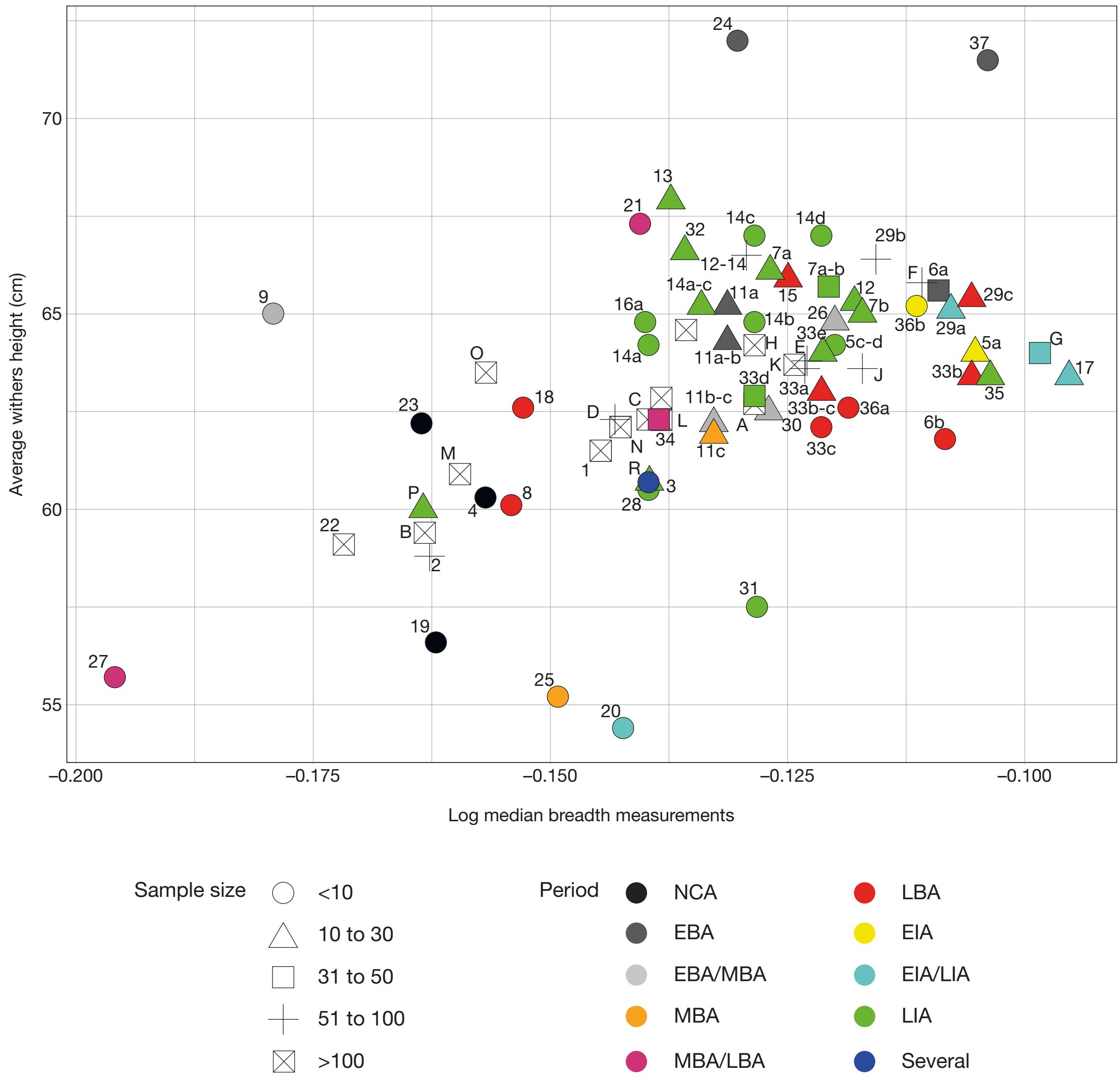


FIG. 4. — The LSI median values of width measurements compared with the shoulder height of sheep in individual find complexes. Furthermore, sample size in shoulder height values is considered. Abbreviations: **BA**, Bronze Age; **EBA**, Early Bronze Age; **EIA**, Early Iron Age; **IA**, Iron Age; **LBA**, Late Bronze Age; **LIA**, Late Iron Age; **MBA**, Middle Bronze Age; **NCA**, Neolithic/Copper Age. Site numbering, see Tables 1, 2.

archaeofaunas demonstrate good agreement in the results of the three body regions and no statistically significant deviation. Only at Dürrnberg (Distr. Hallein, Austria; Pucher 1999a; Schmitzberger 2012; Saliari *et al.* 2016), Sotciastel (Distr. Bolzano, Italy; Salvagno & Tecchiati 2011) and Terranegra (Distr. Verona, Italy; Depellegrin *et al.* 2018) do internal variances manifest. The case of the latter archaeofauna, however, is probably due to the low number of Basipodium elements (n = 14), contrasting with a huge assemblage of Stylopodium/Zeugopodium finds (n = 62). The small find numbers may also explain the internal variations observed within the Dürrnberg material. The case of Sotciastel, however, is different, since the material amount is quite large with respect to both, remains of the Stylopodium/Zeugopodium as well as the Basipodium. The logarithmic deviation of the first-mentioned body part attains higher values than that of the Phalanges. Thus, it cannot be excluded that specific patterns in the distribution of skeleton elements also bias the osteometric results in some of the archaeofaunas considered here. However, the statistical results presented in Table 4 suggest a low overall influence on the results.

As is evident in the Results chapter, the LSI technique helps to identify statistically significant differences between the width measurements of several sheep populations. However, this approach does not allow clear conclusions about the question whether these biometric variabilities are merely due to differences in withers height or if size-independent differences in body shape also occurred, with some populations being built sturdier than others. In order to distinguish between differences in body shape and withers height, an additional osteometric comparison of length and width measurements was made by comparing the LSI median values and the average shoulder height within several faunal assemblages (Fig. 4). Withers height estimation is based on the length measurements, and was carried out according to Teichert (1975). If shoulder height and width measurements do not behave proportionally to each other, it can be assumed that differences in body shape existed. Differences in body size alone are most likely for the assemblages that take a diagonal distribution in the scatterplot. In this regard, however, sample size may be an issue, as indicated by Figure 4: this graph clearly demonstrates that predominantly small assemblages, for which a maximum of ten shoulder height values are available, deviate from the diagonal distribution. As a rule, larger datasets with more than ten values are usually grouped in the area of a proportional gradient. However, there are deviations even among these valid datasets. In contrast to the small units, these may actually indicate differences in body shape, as discussed in detail below.

The study area (Figs 2, 3) comprises essentially the Northern Pre-Alps and Limestone Alps between the Salzach and Rhine Rivers, the Alpine Inn Valley with its side valleys as well as the Adige and Isarco Valleys including their surroundings. This area was chosen as a model region because it is not only a zone of great diversity with regard to its cultural development and eco-geographical settings, but also because a good state of archaeozoological research has been developed here since the first half of the 20th century (Table 1; Fig. 3). Nevertheless, some factors have a negative impact on the data basis: first, the difficulties in sorting the sheep from goat remains should be mentioned here. Although various methodological studies have dealt with the anatomical differentiation of these species (e.g., Boessneck *et al.* 1964), a large quantity of osseous remains are only identifiable up to small domestic ruminant level. For this reason, there is insufficient data available for osteometric analyses on sheep remains from a large number of sites whose osteological source material is quite adequate for other archaeozoological approaches such as consideration of species distribution patterns. This applies to the Iron Age complexes of Laion/Lajen (Distr. Bolzano, Italy; Pisoni & Tecchiati 2010) and Bressanone-Elvas/Brixen-Elvas (Distr. Bolzano, Italy; Boschin 2006), among others. However, Neolithic and Copper Age archaeofaunas such as those from Velturno/Feldthurns (Distr. Bolzano, Italy; Riedel & Rizzi 1996), Moletta near Arco (Distr. Trento, Italy; Riedel 1984a), Castel Badia/Sonnenburg (Distr. Bolzano, Italy; Riedel 1984b), Castelrotto/Kastelruth (Distr. Bolzano, Italy; Salvagno & Tecchiati 2017), Casalmoro (Distr. Mantova, Italy; Clark 1984) and Thaur (Distr. Innsbruck-Land, Italy; Deschler-Erb *et al.* 2015) are particularly affected by the problem. As a result, little data is available for the earliest phase of sheep breeding in the study area.

Another methodological problem is studies published before the establishment of standardised measurement methods in archaeozoology. So as to ensure comparability of the results, these assemblages were excluded from the statistical analysis. An example of this are the animal remains recovered at Kelchalpe (Distr. Kitzbühel, Austria; Amschler 1939).

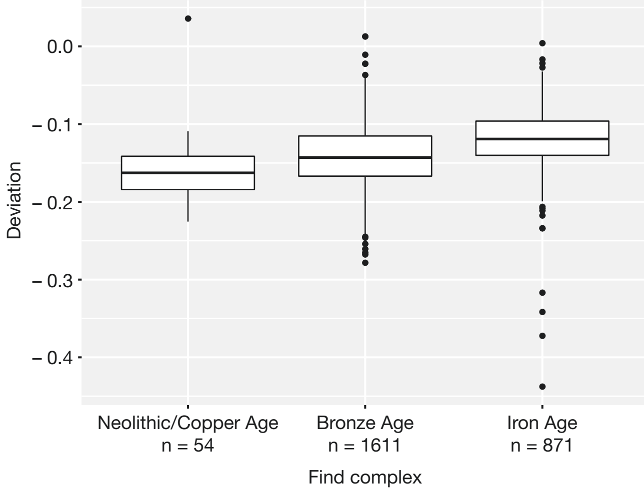


Fig. 5. — LSI of sheep bone width measurements in broad chronological subdivision. For the results of the significance test, see Table 3.

RESULTS

In order to identify possible trends in the phenotypic development of prehistoric Alpine sheep populations, the complete dataset was subdivided into three major chronological units: Neolithic/Copper Age (c. 4500-2200 BCE), Bronze Age (c. 2200-850 BCE) and Iron Age (c. 850-100/15 BCE). The LSI analysis seems to reveal a steady increase of sheep width measurements between the initial period of Alpine livestock breeding and the eve of the Roman occupation (Fig. 5). This is also consistent with the results obtained by applying pairwise Wilcoxon rank-sum test, which detects statistically significant deviations between the three chronological units (Table 3).

However, as already mentioned above, the results of previous archaeozoological investigations revealed phenotypic differences at a small-scale regional level for the Neolithic, Bronze Age and Iron Age sheep of the working area. For this reason, it is necessary to examine the data presented in Figure 5 separately, by individual micro-regions. The model region was divided into six sub-areas, based on environmental, geographical and archaeological criteria (Fig. 2): the Northern Pre-Alps and Limestone Alps, the Inn Valley, Val Venosta, the Isarco Valley and its surroundings, the southern section of the Adige Valley and finally the southern drop of the Alps including the Lessinian Mountains and the northernmost part of the Padanian Plain. It actually turns out, in applying this approach, that the phenotypic development of sheep differs significantly between single valleys.

The Northern Pre-Alps and Limestone Alps

In contrast to the overall material, LSI analysis reveals no diachronic tendency in the development of the sheep bone width measurements for the northernmost part of the working area (Fig. 6A). Although the joint breadth clearly increases from the Copper Age site Mondsee (Distr. Vöcklabruck, Austria; Pucher & Engl 1997) to the Bronze Age assemblages, the distribution of the width values from Middle Bronze Age Saalfelden (Distr. Zell am See, Austria; Pucher 2019) is quite similar to the data obtained at Late Iron Age Dürrnberg. At the same time, however, the comparison of width measurements and withers height implies that size-independent differences in body shape existed between the Saalfelden and Dürrnberg populations, with the latter being significantly more slenderly built than their Bronze Age conspecifics (Fig. 4.12-14, .30). Moreover, this is not the only locally specific phenotype among the sheep kept in the Northern Pre-Alps and Limestone Alps, as evidenced by the osteometric data from the Iron Age site of Farchant (Distr. Garmisch-Partenkirchen, Germany; Trixl pers. comm.); even if this assemblage from the Loisach Valley is only slightly older than the finds from Dürrnberg, the Loisach Valley population shows higher joint width values and at the same time reaches a lower average shoulder height. Thus, those sheep represent a very stocky type, which is not evidenced at any other site investigated in this study (Fig. 4.17) except of some assemblages of low statistical significance.

Finally, the animals kept in the Bronze Age settlement of Cazis near Cresta (Plüss 2007), located far west in the working area within the Hinterrhein Valley, are morphologically closely related to their conspecifics from Saalfelden in terms of both breadth measurements and shoulder height. The chronological breakdown of the osteometric data from Cazis also suggests that, at least in the Alpine Rhine Valley, there was no phenotypic change in sheep between c. 2200-1500 BCE.

It is essential in interpreting such osteometric patterns to consider the potential influence of sexual dimorphism on the distribution of bone measurements. Local peculiarities in sheep exploitation, e.g., with an emphasis on dairy farming on the one hand and on meat or wool production on the other, may cause differences in the ratio of gracile ewes to more robust rams or wethers (e.g., Trixl *et al.* 2020). In order to clarify the question, as to whether osteometric patterns result from differences in sex ratios or from real phenotypic variations, statistical results on bone measurements must be crosschecked with information on the sex ratios. In addition, depending on the sexual dimorphism within a population, the range of data dispersion also can provide information about the homogeneity or heterogeneity of the sexual composition of pre-modern animal herds. For the sheep populations of the Northern Pre-Alps and Limestone Alps, we can hardly note any correlation between the sex distribution and the osteometric results. In the majority of the find complexes, the ratio of males and females is almost balanced, or only very slightly tilted in favour of ewes or rams (Plüss 2007; Schmitzberger 2012: 97; Pucher 2019: 49). An exception are the sheep remains recovered at Farchant, where females clearly prevail (Trixl pers. comm.). However, it is precisely this population that is characterised by a striking robust stature. A dependence of the osteometric results on the sex distribution is therefore unlikely, and the results observed in Fig. 6A, which are at least partially confirmed by statistical testing (Table 3), are likely to be due to genuine differences in growth form.

The opposite situation prevails in the assemblage from Dürrnberg, with its strikingly tall but slender-built animals; based on horn core and pelvis finds, a balanced ratio between females and males was calculated for this find complex (e.g., Schmitzberger 2012: 97). However, among the males the proportion of neutered individuals is hard to estimate due to methodological difficulties in morphologically sorting the wethers from the rams (e.g., Bökönyi 1984: 46). In fact, the data distribution observed in Fig. 4 may indicate an unusually large proportion of castrated males for the Dürrnberg material; due to castration, the epiphyseal fusion in long bones is delayed, so that in some skeleton elements of neutered sheep greater bone lengths may be achieved than in uncastrated ones (Davis 2000). This issue and its implications for the local Iron Age subsistence economy are discussed in detail later.

The Inn Valley

South of the Northern Limestone Alps lies the Inn valley, one of the most important prehistoric settlement and transit areas north of the main Alpine ridge. However, despite long years of archaeological and zooarchaeological research, up to now not sufficient osteometric data has been recorded for the Neolithic and Copper Age sheep to enable a comparison with contemporaneous sites such as Mondsee. The earliest find complexes with an adequate amount of sheep bone measurements reach back to the Early Bronze Age, with the archaeofaunas of Wiesing (Distr. Schwaz, Austria; Pucher 1984) and Brixlegg (Distr. Schwaz, Austria; Riedel 2003; Boschin & Riedel 2011). Both sites are located in the lower Inn Valley. The LSI median values clearly show that Early Bronze Age values from Brixlegg (Fig. 4.6) and Wiesing (Fig. 4.37) rank well above the level calculated for contemporaneous sites in the Northern Pre-Alps and Limestone Alps, such as Cazis near Cresta (Fig. 4.11). This leads to the assumption that Bronze Age sheep in the Inn Valley were larger than their conspecifics in the Northern Limestone Alps. However, there is a striking exception, as shown by an internal LSI comparison of osteometric data from the Inn Valley sites (Fig. 6B): the sheep from Faggen (Distr. Imst, Austria; Tecchiati 2012), a Middle Bronze Age site in the Upper Inn Valley, were smaller than the individuals in the Lower Inn Valley and show a stronger correspondence with conspecifics from Cazis near Cresta (Fig. 6A, B). This is all the more relevant, as although these two archaeofaunas were assigned to two different micro-regions for the present study, they are geographically relatively close to each other. This supports the assumption that the unique sheep type, which was widespread in the Northern Limestone Alps during the Bronze Age, was also distributed in the Upper Inn Valley. Variations in sex distribution are probably not responsible for the osteometric differences of sheep in the Upper and Lower Inn Valley, as males took a similar proportion in the archaeofaunas from Faggen and Brixlegg (Riedel 2003: 221; Tecchiati 2012: 51).

For the Iron Age, we can note a striking decrease in both bone breadth and length in the Lower Inn Valley sheep population (Figs 4; 6B). This becomes clear also from the results of the Wilcoxon rank-sum test, providing a statistically

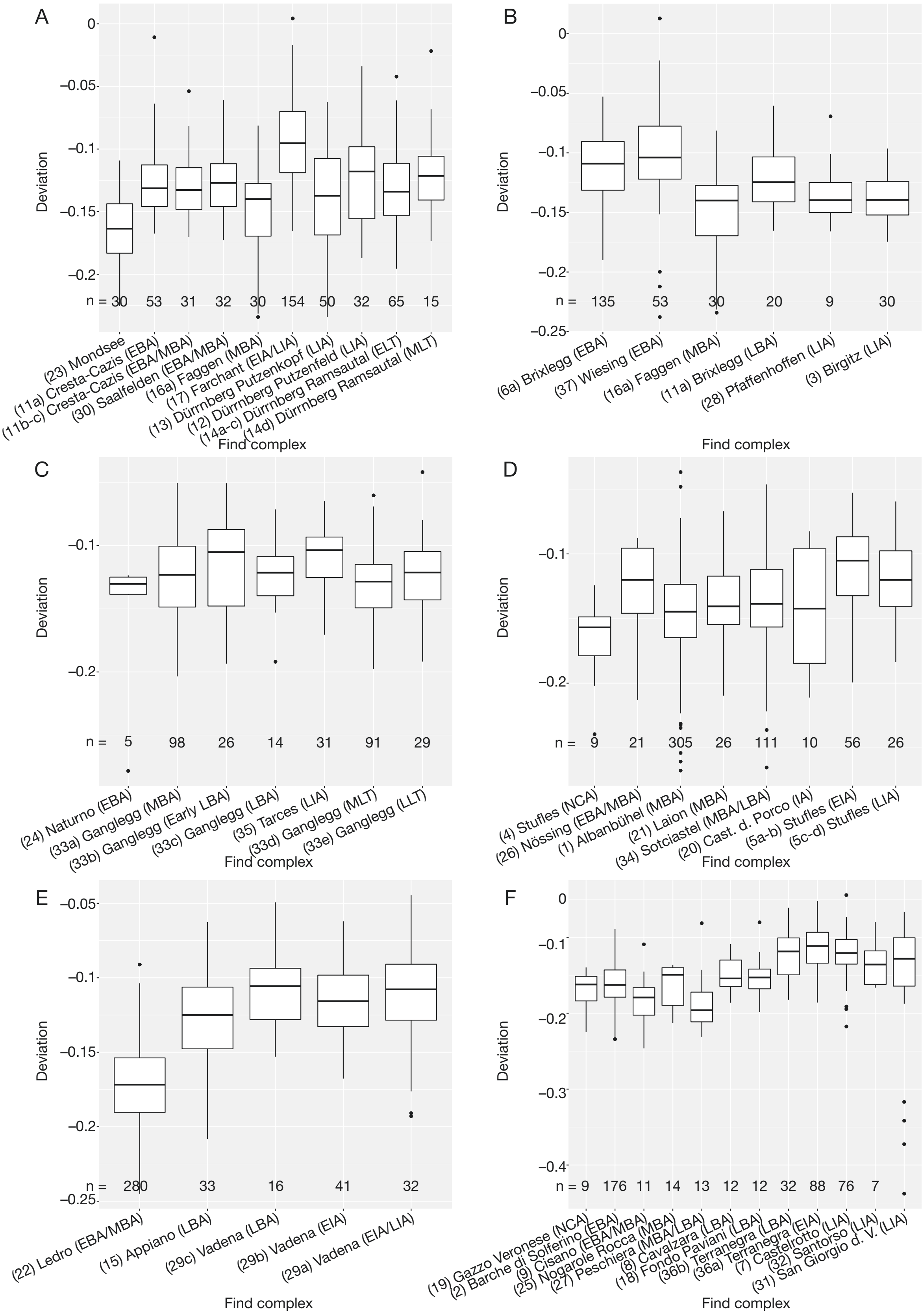


Fig. 6. — LSI of sheep bone width measurements in several micro-regions (for the results of the significance test see Table 3). The sites are arranged in chronological orders and numbering refers to Table 1. Abbreviations: **a**, Northern Pre-Alps and Limestone Alps; **b**, Inn Valley; **BA**, Bronze Age; **c**,Val Venosta; **d**, Isarco Valley; **e**, Adige Valley and surroundings; **EBA**, Early Bronze Age; **EIA**, Early Iron Age; **ELT**, Early La Tène Period; **f**, Southern drop of the Alps with Lessinian Mountains and Northern Padanian Plain; **IA**, Iron Age; **LBA**, Late Bronze Age; **LIA**, Late Iron Age; **LLT**, Late La Tène Period; **MBA**, Middle Bronze Age; **MLT**, Middle La Tène Period; **NCA**, Neolithic/Copper Age.

significant deviation between Early Bronze Age Brixlegg and the Late Iron Age assemblage from Birgitz (Distr. Innsbruck, Austria; Trixl 2019). Interestingly, the breadth measurements of the latter correspond exactly to the data obtained at the contemporaneous site of Pfaffenhofen-Hörtenberg (Distr. Innsbruck-Land, Austria; Trixl pers. comm.). This indicates that during the late Iron Age sheep of unique phenotype were kept in the Tyrolean Inn Valley (Fig. 6B). However, it is quite likely that the decline in size was not due to a phenotypic change but to a shift in the sex ratio from the Bronze Age to the late Iron Age; while in Early Bronze Age Brixlegg both males and females were well represented (Riedel 2003: 221), in Birgitz (Trixl 2019: 59) and Pfaffenhofen (Trixl pers. comm.) ewes dominated to a high degree. This is also supported by the lower dispersion of the LSI values within the Iron Age datasets (Fig. 6B), which implies a form of sheep exploitation focussing on one sex.

However, it is rather unclear when this change took place, since already bone measurements from Late Bronze Age layers in Brixlegg (Boschin & Riedel 2011) indicate a certain decrease in breadth measurements compared to the Early Bronze Age data (Fig. 6B), even if neither the differences between the two Brixlegg phases nor those between the Late Bronze Age and the Iron Age assemblages are statistically significant. At the same time, an increasing uniformity of the values, which could indicate changes in the sex distribution, becomes not evident in the Late Bronze Age sheep remains from Brixlegg. It is therefore quite possible that during the Late Bronze Age a slight decline in body size independent of shifting sex ratios took place.

Val Venosta

As one of the main Alpine rivers, the Adige forms a wide, initially east-west running valley directly south of the main Alpine ridge. Despite its central Alpine location, this region of Val Venosta has favourable climatic conditions and was therefore an important prehistoric settlement area, where sheep breeding has played a major economic role at least from the Bronze Age onwards (Fig. 1).

According to the LSI results, body size of the Val Venosta sheep underwent a different evolution than in the two regions already discussed. In the boxplot graph (Fig. 6C) the medians of most assemblages from the Early Bronze Age up to the Late Iron Age are at a unique level and diachronic changes between c. 2200 and 15 BCE do not become apparent. Also, statistical testing shows hardly any significant deviations between these datasets (Table 3).

The few exceptions include the data from the Late Iron Age sites Tartscher Bichl near Tarces/Tartsch and Ganglegg near Sluderno/Schluderns (Distr. Bolzano, Italy; Schmitzberger 2007). Despite overlapping chronologically and being located only a few kilometres apart, the sheep from Tartscher Bichl were significantly more strongly built than those from Ganglegg (Fig. 6C; Table 3). On the other hand, the shoulder height of the two populations equalises. Thus, the animals from Tartscher Bichl were comparatively more robustly built than the contemporaneous conspecifics from the multi-period hilltop settlement Ganglegg (Fig. 4.33D, E, .35). With the Late Bronze Age occupation phase of the Ganglegg, however, one single assemblage from Val Venosta is similar to the exceptional sheep remains from Tartscher Bichl with regard to bone breadth and length measurements. The reason for the morphological differences between the sheep from Late Iron Age Tartscher Bichl and Late Bronze Age Ganglegg on one hand and the conspecifics in all further Val Venosta assemblages on the other is unclear. Different patterns in sex distribution are not the likely explanation, since the proportion of ewes and rams was diachronically balanced as far as we know (Schmitzberger 2007: 631, 632, 642, 663). The import of an allochthonous sheep type in the beginning of the Late Bronze Age cannot be excluded. This would also explain an increasing inhomogeneity in case of the Late Bronze Age Ganglegg data (Fig. 6C). Since during the following occupation phase of this hilltop settlement the median of the sheep bone measurements decreases again to the level common in the Val Venosta obviously from the Early Bronze Age onwards, a sheep type of allochthonous origin would have been quickly replaced again by the phenotype traditionally common in prehistoric Val Venosta. A continuous development from the robust Bronze Age animals evidenced for the Ganglegg to the Late Iron Age sheep from Tartscher Bichl can also be ruled out, since the two populations are separated by some 800 years.

The Isarco Valley

East of Val Venosta stretches the Isarco Valley, which still plays an important role as a transalpine trading route, connecting the Inn Valley via the Brenner Pass and the Wipp Valley with the Adige Valley and finally to the Padanian Plain. Therefore, in the Isarco Valley there is also ample archaeological evidence for settlements of several Pre- and Protohistoric periods, especially in the Bressanone Basin (Table 1).

Judging from the archaeozoological data recorded from these locations, in contrast to Val Venosta the phenotypic development of the regional prehistoric sheep population is characterised by clear chronological trends. From the LSI boxplot graph (Fig. 6D), we can conclude that the width measurements of Middle to Late Bronze Age sheep flocks such as those from Laion/Lajen (Distr. Bolzano, Italy; Tecchiati *et al.* 2010) and Sotciastel near Badia/Abtei are at a uniform level, while during the Iron Age the values obviously increase. This is at least partially confirmed by the statistical test, proving that some Bronze Age sheep bone assemblages, such as Albanbühel near Bressanone/Brixen (Distr. Bolzano, Italy; Rizzi 1997), deviate significantly from two large Iron Age find units (Riedel 1986; Table 3).

The sheep remains of the Iron Age sacrificial site Castel del Porco/Burg Greifenstein (Distr. Bolzano, Italy; Riedel *et al.* 2002) and the Early to Middle Bronze Age hilltop settlement of Nössing near Varna/Vahrn (Distr. Bolzano, Italy; Riedel & Tecchiati 1999) fall somewhat outside this pattern. The reason for this is unclear. However, the small sample size may bias the LSI results calculated for these sites. This seems all the more likely since the statistical comparison of the measurements from Nössing with those from Albanbühel showed no statistically significant deviation despite the visual difference (Table 3).

The chronological trends observed of breadth measurements are also reflected in the withers height development; as can be seen from Figure 4, apart from small find units with severely limited sample size, the increase in body height and joint width behave proportional to each other.

In the Isarco Valley we also gain insights into the osteometry of the pre-Bronze Age sheep population; despite the small sample size, the values from the Neolithic site Bressanone-Stufles/Brixen-Stufels (Distr. Bolzano, Italy; Tecchiati & Zanetti 2013) show a similar distribution as the Bronze Age measurements from this region (Fig. 6D). This also agrees with the results of the Wilcoxon rank-sum test, which excludes statistically significant differences. This leads to the assumption that the sheep of the Isarco Valley were not affected by any phenotypic change until the Iron Age.

The Adige Valley

At today's Merano/Meran (Distr. Bolzano, Italy), the Adige River bends south and forms an increasingly wide valley, which finally merges into the Padanian Plain near Lake Garda. The prehistoric sheep of this region underwent a development similar to that of the Isarco Valley sheep, as shown by the LSI analysis, even if slightly chronologically misaligned, since sheep breadth measurements were already increasing before the Iron Age. This becomes evident from the partially statistically significant differences between the osteometric data from Early to Middle Bronze Age Ledro (Distr. Trento, Italy; Riedel 1976a) and Late Bronze Age assemblages such as Vadena/Pfatten (Distr. Bolzano, Italy; Riedel 2002) and Appiano/Eppan (Distr. Bolzano, Italy; Riedel 2002) (Fig. 6E; Table 3). According to the distribution patterns in Figure 4, the increase in joint width in this region perfectly corresponds to a growth in withers height. Therefore, the osteometric transformation can be seen as shift in body size and not in stature. Explaining this development as representing the increasing economic importance of wethers or rams is not plausible, as at Vadena/Pfatten, for instance, females outweighed males (Riedel 2002).

Another characteristic of the sheep bone measurements recorded in the Adige Valley sites is the consistently low data dispersion (Fig. 6E). If the increase in size during the Late Bronze Age had been due to the import of a phenotypically different livestock type, greater osteometric variability would have to be expected (e.g., Trixl & Peters 2019: 551). Accordingly, the increase in withers height is likely to be due to a change in the local sheep type without crossbreeding of allochthonous individuals.

The southern Alpine Fringe

Analogous results emerge by applying the LSI technique on sheep width measurements from prehistoric sites in the southernmost of the six separately considered regions. Although the majority of faunal assemblages from this region contain only a comparatively small number of osteometric data for the sheep, from Figure 6F it becomes obvious that the joint width in sheep increased from the Late Bronze/Early Iron Age onwards. Furthermore, the osteometric results from the Early Bronze Age settlement of Barche di Solferino (Distr. Mantova, Italy; Riedel 1976b), which can be considered valid due to the broad material basis of 176 values, prove that this is not a sample size bias. Those width measurements rank somewhat below the values from Late Bronze Age Cavalzara (Distr. Verona, Italy; Riedel 1979) and Fondo Paviani (Distr. Verona, Italy; Riedel 1979). Even more striking is the difference relative to the Late Bronze Age data from Terranegra. Finally, the medians of the bone measurements recorded for Iron Age sheep populations almost entirely range at a significantly higher level than those of the Bronze Age assemblages. The only exception is the archaeofauna of Santorso (Distr. Vicenza, Italy; Cassoli & Tagliacozzo 1991). However, with only seven datasets, this is by no means a statistically reliable sample.

The graphical LSI results (Fig. 6F) are mostly confirmed by applying the significance test (Table 3); sheep populations with large sample sizes such as Terranegra and Castelrotto (Distr. Verona, Italy; Riedel 1985a) show significant deviations from their Early and Middle Bronze Age conspecifics. In addition, phenotypic continuity between the Copper Age and Early Bronze Age sheep becomes obvious from the test results. Contradictions between the LSI graph and the p-values calculated by using the Wilcoxon rank-sum test emerge, especially in comparing small archaeofaunas such as Peschiera (Distr. Verona, Italy; Riedel 1982). This may be due to sample sizes and thus a data dispersion differing strongly from the normal distribution.

For the southernmost zone of the working area, we can furthermore note that other than in assemblages with small sample size, width measurements and average shoulder height of the prehistoric sheep flocks behave approximately proportional to each other (Fig. 4). Thus, between the Copper Age and the end of Prehistory, the sheep kept in this area were not affected by noticeable changes in body shape, even though body size increased significantly.

Identifying the reasons for these chronological alterations in the shoulder height of southern Alpine sheep is difficult. It is interesting, in this regard, to observe that at Late Bronze Age Terranegra, where the size increase appears earliest, the data are more dispersed than in Early Bronze Age Barche di Solferino. This could be the result of crossbreeding local sheep and allochthonous conspecifics of different phenotype. However, it remains uncertain if this assumption is correct, because the increasing inhomogeneity of width measurements is only evidenced in one single sheep population so far. Changing sex distribution patterns seem a rather unlikely explanation in this case, since in Early Iron Age Castelrotto (Riedel 1985a: 60) and Late Bronze/Early Iron Age Terranegra (Depellegrin *et al.* 2018: 185) the ratio between rams and ewes is rather balanced. This only applies to a limited extent to Barche di Solferino, where based on the horn cores a slight predominance of ewes becomes apparent, while based on Ossa coxae both sexes are almost equally frequent (Riedel 1976a: 258). Due to these ambiguous observations, it is advisable to recheck the sex distribu-

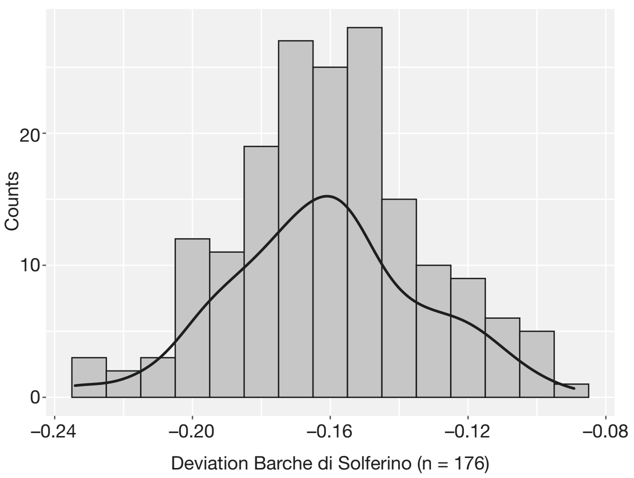


Fig. 7. — LSI of sheep bone width measurements in Early Bronze Age Barche di Solferino.

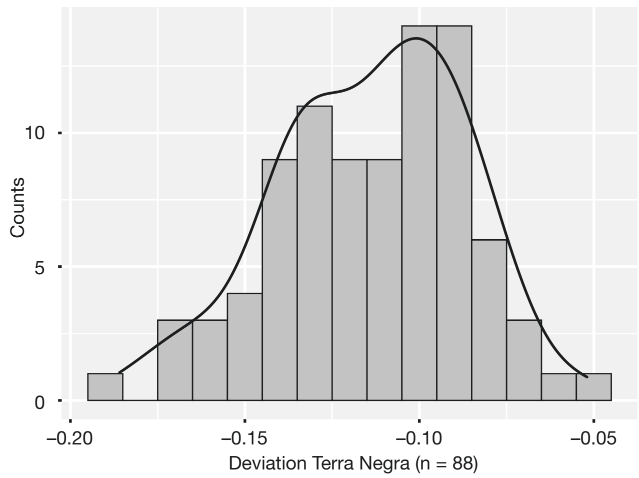


Fig. 8. — LSI of sheep bone width measurements in Early Iron Age Terra Negra.

tion by means of osteometry. The LSI values of Terranegra and Barche di Solferino are analysed for this purpose, by means of a histogram with density distribution curve (Figs 7, 8); among the Early Iron Age values, an emphasis on stout animals (deviation of –0.14 to –0.11) becomes evident, which does not appear in the Early Bronze Age. This cluster could represent a new surplus of stoutly built males. However, the LSI also shows that the whole Iron Age dataset has shifted significantly towards the positive range, scattering mostly between –0.14 and –0.07, while the Early Bronze Age data cluster ranges predominantly between only –0.20 and –0.09. Thus, sex distribution seems unlikely to be the sole explanation for the changing sheep biometry. These changes could also be the result of intentional breeding selection at the regional level or through improved conditions for sheep husbandry.

Spatio-temporal patterns

We can conclude, from the foregoing, that in the course of Prehistory different phenotypic developments occurred within the sheep populations of the working area; already during the Late Bronze Age, body size had increased in sheep herds kept in the Padanian plain, the southern Alpine ridge and the Adige Valley. In the Iron Age, this development also reached the Isarco Valley, but did not extend further north to Val Venosta and the areas beyond the main Alpine ridge. In the latter region several small-scale developments took place, with the sheep of the lower Inn Valley becoming smaller, possibly from the Late Bronze Age onwards. At the same time, local growth types with different body proportions seem to have emerged at the Northern Alpine ridge, as the sheep remains from Farchant in particular demonstrate.

This region-specific development of prehistoric Alpine sheep triggered the coexistence of different phenotypes within the mountain region, with alterations in shoulder height and partly also in body shape. Whether these patterns were already rooted in the Neolithic and originate from the introduction of different domestic animal types via a western and an eastern route (e.g., Pucher & Engl 1997) remains open to question for the area investigated in the present study. Even if certain alterations in biometry seem to occur between Neolithic/Copper Age sites located in different areas such as Mondsee and Bressanone-Stufles/Brixen-Stufels (Fig. 9), the reliability of such an observation must be doubted due to a small database.

At the latest from the Early Bronze Age onwards, however, there is a clear phenotypic difference between the sheep from the Inn Valley and their conspecifics from Barche di Solferino (Fig. 4.2, .6, .37); the latter were of significantly smaller body size than the former population. Between these two populations are scattered the measurements recorded for Early Bronze Age flocks from the Northern Pre-Alps and Limestone Alps, as well as for those from Val Venosta. For the Early to Middle Bronze Age assemblages similar patterns become apparent, when sheep north of the main Alpine ridge and in the Isarco Valley were of noticeably larger size than the animals in settlements further south, such as Ledro and Cisano (Distr. Verona, Italy; Riedel 1990). During this period, phenotypic differences also existed between the Val Venosta and the Isarco Valley sheep; the osteometric data from the largest Middle Bronze archaeofaunas in these regions, Ganglegg near Sluderno/Schluderns and Albanbühel near Bressanone/Brixen, differ statistically significantly from each other (Table 3).

These patterns became increasingly blurred and diversified, with the various regional changes in sheep biometry that occurred on both sides of the main Alpine ridge from the Late Bronze Age onwards. Examples are the Iron Age sheep of the southern Alps and the transitional zone to the Padanian Plain, reaching significantly higher values in both width and length measurements than the Iron Age Inn Valley population; the picture observed for the Early Bronze Age has thus virtually been reversed.

DISCUSSION

Overview of research history

Just as faunal remains from Alpine sites became the focus of archaeozoological research early on, the discussion about regional sheep breeding history also reaches back to at least the first half of the 20th century (e.g., Schlosser *et al.* 1910; Amschler 1939; Rueger 1942), and led to the emergence of numerous hypotheses on the phenotypic development of this indispensable livestock species. Although the volume of postcranial osteometric data was still relatively small, first regional patterning in width and breadth measurements was observed even in this time (e.g., Rueger 1942: 260, 263). As an increasing number of faunal assemblages from Northern Italy, Austria and Switzerland began to be published from the 1960s onwards, the picture of sheep biometry also grew more detailed, which is especially true for our knowledge of regionally specific developments. Among others, Riedel and colleagues observed metrical alterations between sheep populations north and south of the main Alpine ridge from the Bronze Age onwards (e.g., Riedel 1994: 73; 2003: 221; Boschin & Riedel 2011: 600, 601, 608). Another well-documented feature are size differences between Bronze Age sheep of the mountainous region and populations of the Alpine foothills, as has been demonstrated for present-day Austria (e.g., Schmölcke *et al.* 2018: 111, 112) and Northern Italy (e.g., Riedel 1984b: 272). An increase in withers height among the sheep populations of South Tyrol, Trentino, the southern Alpine fringe and the Padanian Plain, probably starting in the Late Bronze Age and during the Iron Age in particular, has also been confirmed in several archaeozoological studies (e.g., Riedel 1985a: 60; 1986: 199; 1994: 53, 54, 73; Schmitzberger 2007: 677; Depellegrin *et al.* 2018: 186).

The existence of strong regional characteristics in the biometry of prehistoric sheep was also the result of a study by Plüss (2007) on the faunal remains from the Bronze Age settlement of Cazis near Cresta, one of the largest faunal assemblages investigated in the Alpine region so far. Plüss noticed an extensive similarity of this sheep population from the area of present-day Grisons to contemporaneous conspecifics of South Tyrol, while the sheep from the Inn Valley were of larger and those of the southern Alpine region of smaller body size. She furthermore assumes that differences in stature also occurred between highland and lowland populations, with the latter being of more gracile body shape.

This brief review demonstrates that some of the results obtained by LSI and withers height analysis in the present paper confirm the outcome of previous works, even if the latter applied partly different methods. Other aspects, as for example the Iron Age size reduction north of the main Alpine ridge as well as a number of previously unknown local peculiarities as observed in the Farchant and Val Venosta populations, modify and complete our picture of the biometry in prehistoric Alpine sheep.

As mentioned in the Introduction, in addition to investigating such spatio-temporal patterns in sheep morphology, a second aim of this study is to identify the reasons behind

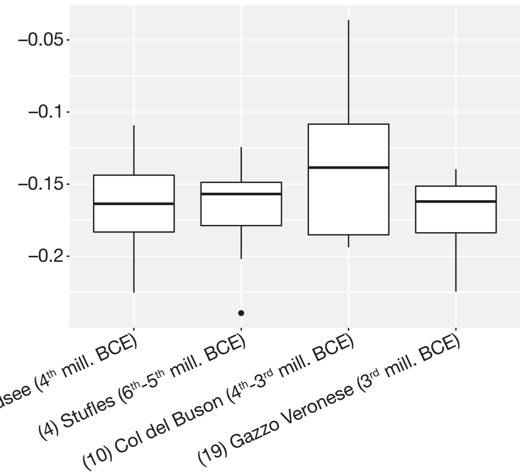


Fig. 9. — LSI of sheep bone width measurements in Neolithic/Copper Age archaeofaunas. For the results of the significance test, see Table 3.

these diverse phenotypic developments. In this regard, altering conditions for sheep husbandry, including aspects such as nutrition and livestock mobility, are discussed. These prerequisites can depend on environmental conditions such as climate and orography on the one hand and anthropogenic effects such as the emergence of improved feeding strategies on the other, even if ecological shifts and human impact are closely entangled with each other. Another possible influencing factor is the primary economic goal of sheep exploitation, which can be the production of meat, milk and wool. Even though in many pre-modern societies with rather self-sufficient subsistence systems livestock exploitation was versatile and served several goals synchronously in the sense of today's three-purpose breeds, a specialisation in one product is also evidenced in some rare cases in Prehistory, such as meat provision at mining sites (e.g., Saliari *et al.* 2020). This specialisation in one animal product such as meat or wool may have required distinct physical characteristics obtained by targeted breeding selection or crossbreeding with allochthonous livestock types, which may be reflected in the osteometric data. In addition, specialised exploitation patterns could also have led to striking one-sided sexual distribution features within the sheep flocks, which can also result in shifts of bone length and breadth measurements. Furthermore, cultural transfer triggered by the emergence of new exchange networks or human migration movements can also have an impact on sheep biometry by forming new husbandry systems or by establishing new livestock in the Alpine region.

Which of these factors may have had effects on Alpine sheep osteometry is discussed in the following paragraphs.

The question of climatic influences

In addition to environmental settings such as orography and soil quality, climate significantly shapes the conditions for livestock farming; rainfall and temperature influence the extent of potentially pasturable land and affect the quality and quantity of summer and winter fodder. Thus, climate change can cause massive systemic changes not only in present-day agriculture (e.g., Cai *et al.* 2015), but may have done so in pre-modern subsistence strategies, too (e.g., Huntley *et al.* 2002). Since the extent and quality of fodder can further influence the size and stature of animals (e.g., Fritz 1928), the question arises if the phenotypic development in Alpine sheep reflects nutritional alterations caused by climatic fluctuations.

Several forms of regional bioarchaeological records such as pollen diagrams as well as lake level and tree boundary fluctuations, combined with global data, provide insight into the climate history of the Alps. By means of this interdisciplinary approach, a period of climatic instability has been observed for the timespan between c. 3700 and 3200 BCE (Rotmoos II fluctuation). The Early Bronze Age (c. 2200-1550 BCE) was characterised rather by stable and mild climatic conditions, followed by a phase of high precipitation and lower annual average temperatures during the Middle Bronze Age (c. 1550-1300 BCE). The warmer Period of the Late Bronze Age, which is also referred to as Urnfield Period (c. 1300-850 BCE), was also followed by a cooling from about 850 BCE onwards (e.g., Nicolussi *et al.* 2005; Magny *et al.* 2009; Oeggl & Nicolussi 2009).

Since the archaeozoological record synchronous with the Rotmoos II fluctuation is scanty for the working area (Table 1), considerations about connections between climate, fodder supply and phenotypic development of sheep are limited to the Bronze and Iron Ages. However, for the period between c. 2200 BCE and 100-15 BCE, patterns in the distribution of osteometric data do not show any alterations, which could be paralleled with the climatic variations described above. A good example of this is the development of the Early to Middle Bronze Age sheep population of the Northern Limestone Alps and Upper Inn Valley. As indicated by Figure 6A, for these animals a decrease in joint width measurements, which could be expected in the case of a significant deterioraion of the nutritional situation, is not evidenced in the course of the 2nd millennium BCE. This also applies to the sheep populations synchronously reared in Val Venosta (Fig. 6C) as well as the Isarco Valley (Fig. 6D), and is even more true of the southern Alpine bone assemblages, where no negative trend is to be observed in length and width measurements (Figs 4; 6F).

From this, we can conclude that a drop in average temperature had no apparent effect on the size and stature of Alpine sheep. However, this is not surprising when one considers that decreasing temperatures did not necessarily mean a deterioration in the conditions for Alpine livestock farming; one major effect of climatic cooling is a lowering of the Alpine tree line, through which naturally treeless pasture areas in the uplands expanded. Indeed, an increasing number of high-altitude archaeological sites dating to the Middle Bronze Age indicate that an intensification of human economic activities was linked to the spread of potentially pasturable land (e.g., Pindur *et al.* 2007). In some regions, the additional food supply may therefore even have improved the nutrition of Alpine sheep during the middle of the 2nd millennium BCE. Furthermore, Bronze Age settlement activity in the Alps in general did not obviously decline at all during the climatic fluctuations (Oeggl & Nicolussi 2009: 81-83). Under these conditions, in terms of economic resilience, even an increasing focus on livestock farming in the high mountains could have compensated for possible economic losses in the valley areas.

Physiological adaption to alpine pasturing?

Assuming an intensified exploitation of high-altitude zones from the Bronze Age onwards leads to another aspect to be considered as potentially influencing the biometry of Alpine sheep: the emergence of mobile forms in livestock farming, such as transhumance or Alpine pasturing, when domestic ruminants were seasonally driven from the permanently settled valleys to high altitude pastures during the summer. Rueger (1942: 260) already supposed that the stout stature of the Bronze Age sheep from the Crestaulta site (Distr. Grisons, Switzerland) could be an adaptation to roaming in steep mountainous areas. Plüss (2007) suggested a similar explanation in view of the phenotypic differences between lowland and Alpine sheep populations. In addition to this archaeozoological record, Mysterud (1999) worked out that a diversification in forage supply associated with the seasonal change of altitudinal zones might have a positive effect on diet and thus on body size of present-day wild ruminants. Therefore, seasonal vertical mobility might have had similar effects on the shoulder height of prehistoric domestic livestock (Plüss 2007).

Among the numerous concepts of mobile livestock farming, Alpine pasturing and transhumance in particular are significant for the (Pre-) history of Central European mountain areas. Transhumance refers to the seasonal movement of livestock over long distances, which serves to relieve the economic pressure on areas close to the home estates and to generate additional production surpluses (e.g., Reitmaier 2010: 222-224). Both horizontal and vertical transhumance are known. Seasonal vertical mobility is also of central importance for the concept of Alpine pasturing. However, in this form of Alpine livestock farming, the high pastures visited in spring and summer are usually much closer to the home farms where the herds are kept during the advanced autumn, winter and early spring months. This implies a very close economic connection between the home farms and the high-altitude grassland zone (e.g., Werner 1981: 10; Reitmaier 2010: 222-224; Trixl 2019: 197, 198).

The origin and history of mobile livestock farming in the Alps is still the subject of lively discussion. A Copper Age glacial mummy recovered in the Ötztal Alps in particular gave reason to assume transhumance occurring in the Alps as early as the 4th millennium BCE (e.g., Spindler 2005). However, this view has been increasingly criticised in recent years. Various aspects, such as the absence of any compulsion for long-distance herding, militate against this form of animal husbandry in Alpine Prehistory (e.g., Plüss 2007; Putzer & Festi 2014: 68; Trixl 2019: 200). However, even if transhumance in the narrower sense may be proven to have been rather unlikely in Prehistory, the results of research in different archaeological disciplines nevertheless suggest that in parts of the Alps seasonal use of high pastures was already taking place in the Neolithic or Copper Age (e.g., Kühn & Hadorn 2004: 348; Walsh & Mocci 2011: 109). As already mentioned, Alpine pasturing intensified during the Middle Bronze Age which, apart from climatic changes, could also have been due to an increased demand for animal products in the context of large-scale copper and salt mining (e.g., Mandl 2006; Pindur *et al.* 2007). Apparently, after human impact at high altitudes had declined somewhat during the Late Bronze Age, the Iron Age witnessed an increased economic presence of humans in the upland zones (e.g., Steiner *et al.* 2009: 500).

If frequent and regular grazing in high altitude zones really had a significant effect on sheep morphology, one would expect on one hand phenotypic changes during periods characterised by an intensification of Alpine pasturing, and on the other hand general morphological differences between lowland and upland populations.

In fact, mountainous livestock farming appears to affect sheep biometry, whether through improved nutrition in the course of seasonal mobility (Mysterud 1999) or through an adaptation of the locomotor system. This becomes obvious by osteometrically comparing Alpine sheep and those of the Northern Alpine foreland, which demonstrates that the mountainous populations differ from their conspecifics kept in Bronze and Iron Age lowland sites such as Manching (Distr. Pfaffenhofen, Germany; Boessneck *et al.* 1971), Hochdorf (Distr. Ludwigsburg, Germany; Schatz 2009), Freising (Distr. Freising, Germany; Manhart 2004) and Heuneburg near Hundersingen (Distr. Sigmaringen, Germany; e.g., McEneaney-Schneider 1984). It becomes apparent from Figure 4 that with regard to width measurements the sheep from the three first-mentioned lowland sites rank below those from Bronze and Iron Age assemblages in the Alpine region. The comparison of withers height and breadth measurements indicates that these differences were limited to body size, while the stature of most Alpine and lowland populations is comparable. The situation in the area of present-day Northern Italy is quite similar, as becomes apparent from the data obtained in the lowland assemblage of Barche di Solferino, where Bronze Age sheep were decisively smaller than in the Southern Alps (Fig. 4.2). An exception to this pattern is the Heuneburg sheep population; despite its location far north of the Alps, this Iron Age assemblage includes sheep remains which suggest a morphotype of above-average size and also strikingly slender stature (Fig. 4O). However, this could be due to a high percentage of castrated males. This approach is discussed in greater detail below.

The question of how far back morphological differences between Alpine and lowland sheep go has to remain open, as an osteometric comparison is not possible for the Neolithic and Copper Age due to a lack of data from the Alpine foothills. It is furthermore difficult to evaluate if an intensification of human impact in high altitude zones, occurring for example in the Middle Bronze Age, had an impact on the size or stature development of Alpine sheep. The LSI results at least do not show any supra-regional increase in body size during this period (Fig. 6A-F). Rather, local morphological developments prevail, as explained in the Results section. In this regard, it is important to bear in mind that, even if we can reconstruct large-scale trends in the history of Alpine pasturing, small-scale palaeo-economic or palaeo-ecologic developments in the surroundings of most archaeofaunas considered here are difficult to grasp. Thus, we can assume that numerous factors influenced livestock farming in general and the significance of seasonal animal mobility in particular, on a micro-regional level.

This is well illustrated by the Iron Age sheep population from Farchant in North Alpine Loisach Valley, which is characterised by an exceptionally robust stature (Figs 4.17; 6A). Another distinctive feature of this sheep bone assemblage is the high degree of exostosis occurring at joint ends of long bones and phalanges in particular (Trixl in press). Archaeozoological evidence for similar lesions comes from the Upper Palaeolithic site grotte de la Vache (Distr. Charente, France; Lignereux *et al.* 1995), which stands out due to a high number of ibex individuals of quite advanced age. Those animals show comparable exostoses at their joint ends, which bear evidence of a strong strain on the locomotor system due to lifelong roaming on precipitous terrain (Lignereux *et al.* 1995). From this comparison one can conclude that grazing in steep mountainous zones played an extraordinary role for the sheep kept in the Iron Age Loisach Valley also. This could be the explanation for the remarkably robust body shape of this local sheep type, as Rueger (1942: 260) also supposed for the conspecifics from Crestaulta. The reason for an extraordinary importance of high-altitude grazing may be the topography of the Loisach Valley; its bottom, dominated by the Loisach River, offered few permanently cultivable areas in Prehistory. Furthermore, in contrast to most valleys considered in this study, large terraces at low mountain levels are also missing. Therefore, areas suitable for grain farming and settlements were largely limited to some alluvial fans piled up by streams flowing sideways into the valley. Under these circumstances, extensive use of the high pastures was necessary in order to guarantee a secure supply of plant and animal products.

Patterns in sex distribution

As outlined above, economic specialisation in meat, milk or wool exploitation can require distinct sexual distribution patterns in sheep herds. Due to biometric sexual dimorphism, the dominance of either rams or ewes in prehistoric sheep flocks can also have an effect on osteometric data.

For livestock systems focussing on dairy farming, a dominance of females can be assumed, whereas wool farming requires a balanced presence of both sexes. For the males, castration is also an option, as it results in some advantages such as a calmer temperament and higher fattening potential. A high proportion of castrated males is also the characteristic of a population primarily serving meat provision. This is all the more true for settlement communities, which were supplied with commercial surpluses from specialised producer sites (e.g., Pucher 1999b; Grömer & Saliari 2018: 137). This supply includes above all the male livestock, as these were needed to a lesser extent for herd maintenance than females (e.g., Pucher 1999b: 124).

Osteometric evidence for the latter supply system comes from the sheep remains recovered at the Iron Age site of Dürrnberg; according to LSI results and withers height calculation, these animals were characterised not only by their remarkable body size, but also by an extraordinarily slender build (Figs 4.12-14; 6A). Since castration and the resulting delay in epiphyseal fusion prolong the growth in length of some skeleton elements (Davis 2000), a high shoulder height together with slender build can be characteristic of gelded males. Thus, from the distribution of width and breadth measurements recorded for the Dürrnberg sheep, we can conclude that the proportion of neutered rams was above average at this site. This reflects the exceptional economic role of this place (e.g., Grömer & Saliari 2018: 137). Being specialised in salt mining, the inhabitants of this large Late Iron Age settlement did not maintain their own system of food production, but were primarily provided with livestock from surrounding producer sites. This may also explain the exceptional morphology of the Heuneburg sheep in the Northern Alpine foreland; as central place of proto-urban character, the supply of animals from the wider surroundings probably also played an important role for the Heuneburg, as evidenced for cattle also by stable isotope analysis (Stephan 2009: 72).

Returning to the Alps, the Early Bronze Age had already witnessed large-scale mining activities, as extensive evidence of copper exploitation in the Inn Valley demonstrates (Schibler *et al.* 2011). According to the archaeological and zooarchaeological records, food supply by external producers is also evident for the Bronze Age mining communities (e.g., Schibler *et al.* 2011: 1273, 1274), as detected at Brixlegg, for example. Young animals predominantly were slaughtered at this site, and the ratio between males and females is balanced, indicating an economic emphasis on the consumption rather than production of animal goods (e.g., Riedel 2003: 221). In the late Iron Age, mining activities in the Inn Valley had stopped, and highly specialised production was replaced by subsistence strategies relying on self-sufficient supply, in which dairy farming played a greater role. This is evident from the fact that in Late Iron Age assemblages females prevail, and slaughter age had shifted in favour of aged individuals (Trixl 2019: 59; Trixl pers. comm.). At the same time, a strong decrease in average sizes compared to the Bronze Age can be observed (Figs 4.3, .28; 6B). Obviously, the transformation of the economic system caused a change in the ratio between rams and ewes, which finally resulted in a significant decrease of length and width measurements.

The strong differences between the Copper and Bronze Age sheep populations of the Northern Pre-Alps and Limestone Alps (Figs 4.11, .23, .30; 6A) could also be related to a similar process; for the 4th millennium BCE archaeofauna from Mondsee, Pucher & Engl (1997: 24) noticed a massive predominance of females among the small domestic ruminants. In Bronze Age settlements such as Cresta Cazis (Plüss 2007) and Saalfelden (Pucher 2019: 49), a balanced sex ratio or even a dominance of males became apparent. The reason for this is elaborated below.

Wool economy: an influencing factor on sheep biometry?

Wool economy also comes into the reckoning as an influencing factor in the phenotypic development of Alpine sheep; earlier studies have explained increasing body size in sheep of different periods as being due to the enhanced importance of wool and the consequent introduction of wool sheep to Central and Eastern Europe. Bökönyi (1974: 169-171), for example, assumed this for parts of Hungary, where a sudden increase in withers height became apparent during the second half of the 4th millennium BCE. For the Alpine region, however, the latest archaeozoological investigations have cast doubt on the import of allochthonous phenotypes. Using osteometric data, they conclude that wool sheep developed from autochthonous populations by local breeding selection (e.g., Grömer & Saliari 2018: 135, 136; Schmölcke *et al.* 2018: 107).

According to age and sex distribution patterns in sheep in combination with textile archaeological results, the use of wool in the Central Alps and their foothills started at the end of the Neolithic and the initial phase of the Bronze Age. Subsequently, wool exploitation intensified until the Middle Bronze Age (e.g., Deschler-Erb *et al.* 2015: 368, 369; De Grossi Mazzorin & Solinas 2018: 196, 197; Grömer & Saliari 2018: 139; Schmölcke *et al.* 2018: 126). After wool had advanced to become the most important textile material in the course of the Bronze Age, fine wool fibres also increasingly appeared, especially in the Hallstatt Period, which could be obtained either through targeted breeding selection from local stocks or through the introduction of allochthonous sheep types (Grömer & Saliari 2018: 147, 148).

The use of their fleece may possibly have affected the biometry of the sheep in the study area in three ways: firstly, the emergence of wool sheep, whether by introducing non-local individuals or by local breeding selection, could have led to changes in the physical characteristics of Alpine populations, for example by raising the average shoulder height (e.g., Bökönyi 1974: 169-171). Secondly, a connection with nutrition must also be discussed, as wool growth rates depend decisively on fodder quantity and quality; for example, a protein-rich diet has a positive effect on the formation of wool fibre (Winder *et al.* 1995). Since nutrition also influences body size development (e.g., Fritz 1928), it is conceivable that new approaches to animal nutrition, which may have developed in the context of wool farming, might have had an effect on sheep biometry. Thirdly, we also have to consider that a shift in sex distribution patterns, as described above, could have occurred with the emergence of a wool economy (Halstead & Isaakidou 2011: 68).

The results on the development of length and breadth measurements (Fig. 4) confirm that the emergence of the Alpine wool economy from the Early and Middle Bronze Age onwards was not based on the introduction of allochthonous sheep of different physical qualities. This implies the sparse Neolithic and Copper Age data from the areas south of the main Alpine ridge (Fig. 6D, F), which indicate a continuous development rather than a progressive size increase

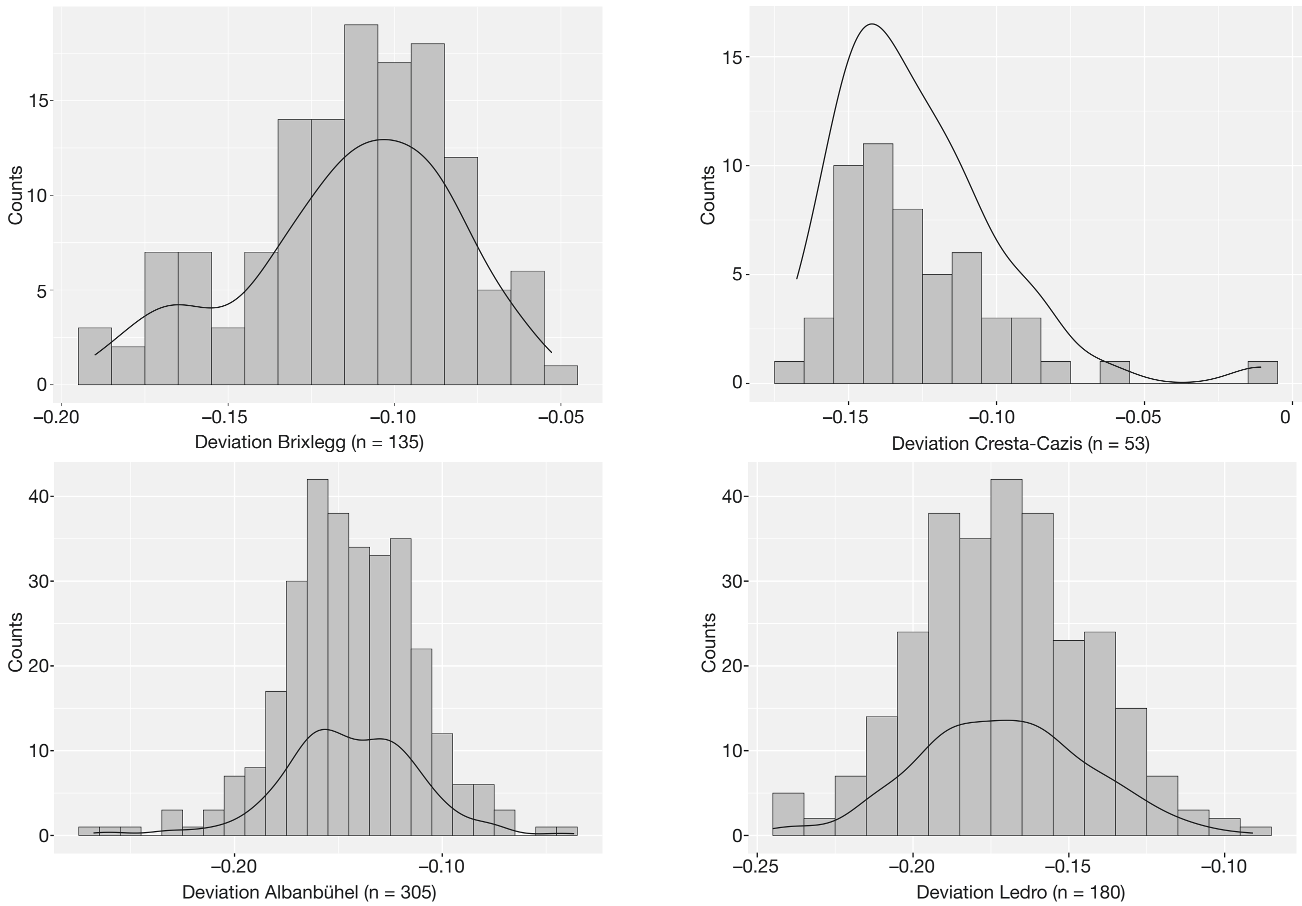


Fig. 10. — LSI of sheep bone width measurements in statistically meaningful Early/Middle Bronze Age find complexes. For Barche di Solferino, see Figure 7.

between the 5th-4th millennia BCE and the Middle Bronze Age. At the Northern edge of the Alps, the situation seems different (Fig. 6A); the Copper Age values from the Mondsee site rank significantly below the sheep bone measurements of all Bronze and Iron Age faunal assemblages of this region. However, as explained above, this probably results from an increasing proportion of males in Bronze Age sheep flocks. Thus, even if the occurrence of allochthonous sheep seems implausible, the enhanced importance of rams or wethers could in fact reflect the additional role of sheep as providers of textile fibre.

Moreover, in the Bronze and Iron Ages there is no supra-regional trend in the phenotypic development of the sheep that would suggest the importation of allochthonous morphotypes (Fig. 6A-F). Osteometrically, such a process would manifest itself in trans-local and synchronous changes in body size or stature. Furthermore, intra-site distribution in osteometric data argues against the extensive import of a morphologically different type of wool sheep: a detailed examination of significant find complexes of the Early to Middle Bronze Age by using histograms with density distribution curves reveals that neither to the north nor to the south of the main Alpine ridge do specific distribution patterns occur that can be interpreted as the co-existence of different phenotypes (Figs 7; 10). Nevertheless, it cannot be ruled out that local breeding efforts were undertaken in order to enhance the quality or quantity of fleece of single sheep populations. This is conceivable in the case of spatially and temporally isolated morphological patterns, such as those evident in Nössing (Fig. 6D), in the Late Bronze Age occupation phase of the Ganglegg near Sluderno/Schluderns and at the Iron Age site Tartscher Bichl near Tarces/Tartsch (Fig. 6C). In this context, it is important to bear in mind that wool was the most important raw material for textiles in the Bronze and Iron Ages, which in turn were an essential component of the Metal Ages' clothing (e.g., Grömer & Mautendorfer 2008). Although due to poor preservation conditions for organic material insights into regional peculiarities of prehistoric dressing styles are usually limited to metal dress components such as brooches, it seems conceivable that characteristic types of fabric were also part of distinctive regional costumes. Therefore, as raw material also wool could show regional characteristics in terms of fibre length or the ratio of coarse awn hairs to finer undercoat, which may also explain different breeding efforts in individual micro-regions.

As for the initial phase of the wool economy, earlier studies have discussed a connection between the development of textile production and sheep morphology for the Iron Age also (e.g., Riedel 1986, 1994); in the course of the

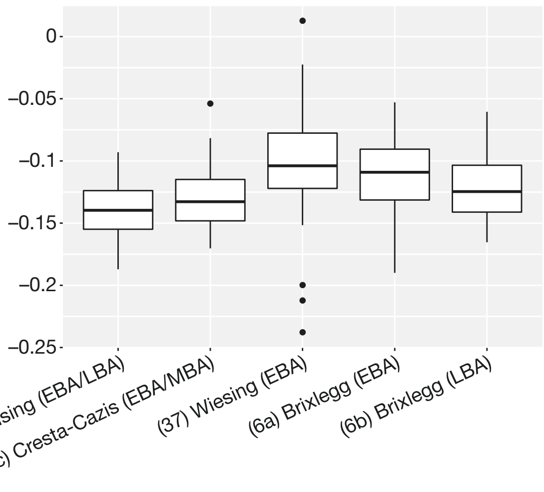


Fig. 11. — The Bronze Age sheep populations of the Northern Alpine Foreland and the Inn Valley in LSI comparison. For the results of the significance test, see Table 3.

1st millennium BCE, a size increase was noted for sheep in the Padanian Plain and the southern Alps. One explanation was the import of a large-grown and fine-wooled phenotypes from Etruria or from the Greek colonies in Upper Italy (Riedel 1986). However, the now much broader data base for Central and Northern Italy as well as the Alpine region allows different conclusions. In fact, as discussed earlier, the sheep population of the Isarco Valley grew in body size during the Iron Age (Fig. 6D). Further south in the Adige Valley, however, this size increase had already occurred in the Late Bronze Age and thus long before the establishment of Greek and Etruscan settlements in Upper Italy (Fig. 6E, F). Furthermore, the homogeneity observed in osteometric data, which is especially evident in the find complexes of the Adige Valley, indicates that an influence of non-local sheep types is implausible during the periods of growing shoulder height.

This size increase in Alpine sheep south of the main Alpine ridge could be part of a development of much greater regional significance, as shown by extensive osteometric studies on the prehistoric sheep of the Apennine Peninsula: an increase in withers height apparently also occurred in Northern and Central Italy, which, as in the Adige Valley, started as early as the Late Bronze Age or even at the end of the Middle Bronze Age (De Grossi Mazzorin & Solinas 2013; Trentacoste *et al.* 2018; De Grossi Mazzorin & Minniti 2019a, b). The biometric data reveal that the phenotypic changes also in these areas were more the result of local breeding efforts than due to the introduction of non-local sheep types. However, the reason for the supra-regional morphological change remains unclear. Besides altering husbandry conditions, new economic demands on the animals in terms of increased milk yield have already been discussed (e.g., Trentacoste *et al.* 2018: 24). Also, an intentional improvement in sheep nutrition in the light of an increased demand for (finer) wool cannot be excluded. However, this hypothesis needs to be tested in future studies.

The influence of allochthonous sheep types

Even if the introduction of allochthonous phenotypes seems a rather unlikely explanation for the alteration in sheep morphology during the Bronze and Iron Ages in the southern Alps, there could have been at least a supra-regional exchange of single individuals without lasting impact on local Alpine populations. One such example is known from the Iron Age occupation phase of the Ganglegg near Sluderno/Schluderns, where Schmitzberger (2007: 678) assumes that a single Talus of exceptional size may signify an individual imported from Roman Italy. Also, the few positive outliers in the LSI graphs (Fig. 6) could indicate the presence of single large-sized individuals of non-local origin. A good example for this is the Iron Age site of Castelrotto in the Lessinian Mountains (Fig. 6F), whose archaeological find material reveals strong connections to the Etruscan and Greek networks of Upper Italy (Riedel 1985a: 55). One single breadth measurement, which represents a strikingly large individual, indicates that exchange activities possibly not only included ceramics but also animals from time to time.

In contrast, hints of a large-scale transfer of sheep come from Bronze Age bone assemblages in the Inn Valley. As described above, a massive reduction of average body dimensions becomes apparent for the Iron Age sheep of this region, a development for which not phenotypic changes but rather a shift in the sexual distribution is responsible. However, a certain decline in withers height had apparently already set in during the Late Bronze Age, as demonstrated by a comparison of Early and Late Bronze Age sheep remains from the mining site of Brixlegg (Fig. 6B). Since, in contrast to the Iron Age, no shift in subsistence strategies from specialised supply structures to self-sufficient production is discernible in this case (Boschin & Riedel 2011), it is unlikely that shifting sex distribution patterns are the reason for the decrease in breadth measurements. A more likely explanation may lie in the cultural change during the Late Bronze Age, when a strong influence from the Northern Alpine foothills is assumed in the Inn valley, which could be based on cultural transfer, migration or a combination of both models (e.g., Grupe *et al.* 2017: 233-241). Interestingly, an LSI comparison between the Bronze Age sheep of the Inn Valley and the contemporaneous site of Freising, which is located in the Northern Alpine foreland, reveals good correspondence between both populations (Fig. 11; Table 3). It can therefore be hypothesised that the introduction of a new sheep type from the region north of the Alps also constituted a part of the Late Bronze Age cultural change in the Inn Valley. A similar assumption has already been made for cattle in earlier studies (e.g., Boschin & Riedel 2011: 599, 600, 608).

CONCLUSION

As demonstrated in the discussion, a large variety of factors underlie osteometric patterning in prehistoric Alpine sheep populations, some of which have an effect only at very micro-regional levels. In addition to physiological adaptations to Alpine environments and improvements in livestock nutrition, we also have to consider alterations in the ratio of ewes and rams, which are independent of real morphological changes. Also, the exchange and mobility of livestock may have played a role in phenotypic developments, as shown by the Bronze Age data from the Inn Valley archaeofaunas.

In many cases, however, it is difficult to find a clear explanation for spatial or temporal patterns in Alpine sheep biometry. This is not least due to close interactions between the influencing parameters, which are often hardly comprehensible by means of the archaeological or archaeozoological records. A good example of this is the question of the wool economy; it has been shown above that although it is unlikely that the introduction of phenotypically different wool sheep contributed significantly to establishing wool exploitation in the Alps (see also Schmölcke *et al.* 2018: 107), nevertheless we can note a shift in the osteometric data from the Neolithic/Copper Age to the Bronze Age in the Northern Alps. This may be due to increasing numbers of males kept for wool production. At the same time, we cannot rule out that nutrition in connection with the emergence of wool exploitation also had an influence on sheep biometry, since herders had to provide their animals with a sufficient amount of protein-rich fodder in order to gain satisfactory wool quality and quantity (e.g., Winder *et al.* 1995). However, it is also conceivable that livestock nutrition improved not only as a result of intensifying wool exploitation, but also for other reasons, such as an expansion and diversification of grazing lands due to enhanced access to pastures at high altitude consequent upon climatic alterations. It even seems possible that climate and wool exploitation were directly related, in that the expansion of high-altitude pastureland as a result of the Middle Bronze Age cooling resulted in improved fodder supply for the sheep, which contributed to enhancing the amount and quality of wool.

In addition to the possibility of such complex entanglements between several human and environmental factors, an overall picture of the biometry in Alpine sheep is furthermore difficult to draw due to the local and micro-regional variability of osteometric patterns; long-term continuous developments contrast with different forms of phenotypic changes in neighbouring populations, as a comparison of the situation in the Inn Valley, Val Venosta and Isarco Valley shows.

Even if an exchange between some sheep populations may have taken place in rare cases, such as between the Inn Valley and the Northern Alpine foreland, locally based breeding efforts or shifts in economic structures are most probably the explanation for the numerous processes of osteometric changes in Alpine sheep. The sheep can therefore be seen as a livestock animal perfectly adapted to local conditions and needs, whose breeding generally did not require large-scale genetic exchange. This resulted in region-specific phenotypes. In the case of the Middle Bronze Age Inn Valley, it is apparent that the morphological differences between the sheep populations may even correspond to regional patterns in material culture; the population of the Upper Inn Valley resembles the animals kept in the area of present-day Grisons much more than the conspecifics of the Lower Inn Valley (Fig. 6A, B), which were of significantly larger body size. At the same time, the material culture shows that the Upper Inn Valley was more strongly connected to the Inner Alpine Bronze Age culture of Grisons than to the region in the immediate vicinity of today's Innsbruck (Rageth 1986).

If we want to understand the history of the Alpine sheep in its entirety, it is therefore necessary to first obtain as precise a picture as possible of the development in individual micro-regions. Even if this is already possible to some extent, as demonstrated by the present study, there are still large gaps in both spatial and chronological terms in our knowledge of sheep breeding history in the Alps. It is therefore to be hoped that future material analysis will further improve the state of archaeozoological research in the areas that have so far been only rudimentarily scientifically explored. However, also applying methods beyond osteometrics promises new results. In the case of Bronze Age sheep populations in Central Asia, for example, geometric morphometrics on the Talus recently made it possible to distinguish sheep populations kept in mountainous regions from lowland flocks (Haruda *et al.* 2019). Such an approach could also help to evaluate the influence of high-altitude grazing on sheep morphology in the Alps, beyond mere body size alterations. Building on the results of osteometrics and morphometrics, invasive molecular-biological approaches such as aDNA and stable isotope analysis too have the potential to provide more detailed insights into the role of allochthonous breeding lines, changing patterns of sheep exploitation and alterations in animal husbandry conditions (e.g., Valenzuela-Lamas *et al.* 2021). Thus, we may expect further archaeozoological results on prehistoric Alpine sheep, which will contribute to understanding the human-animal relationship in one of the most important transit and cultural regions in Europe.

Acknowledgements
I am very grateful to the Bavarian Academy of Sciences and Humanities for funding this study. I also owe gratitude to the following persons for the detailed discussions, which contributed greatly to the success of this project: Anna-Sophie Buchhorn (Institute of Prehistory and Early History Archaeology and Provincial Roman Archaeology, University of Munich), Ivica Međugorac (Population Genomics Group, University of Munich), Carola Metzner-Nebelsick (Institute of Prehistory and Early History Archaeology and Provincial Roman Archaeology, University of Munich), Joris Peters (Institute of Palaeoanatomy, Domestication Research and the History of Veterinary Medicine, University of Munich), Simone Reuß (Institute of Prehistory and Early History Archaeology and Provincial Roman Archaeology, University of Munich) and Markus Wild (Bavarian Academy of Sciences and Humanities). Finally, I would like to express my thanks to the referees for their valuable comments.

REFERENCES

AMSCHLER W. 1939. — Die Haustiere von der Kelchalpe bei Kitzbühel, Tirol. Mitteilungen der Prähistorischen Kommission der Akademie der Wissenschaften 3: 96-120.

BOESSNECK J., MÜLLER H. & TEICHERT M. 1964. — Osteologische Unterscheidungsmerkmale zwischen Schaf (Ovis aries Linné) und Ziege (Capra hircus Linné). Kühn-Archiv 78: 1-129.

BOESSNECK J., DRIESCH A. VON DEN, MEYER-LEMPPENAU U. & WECHSLER-VON OHLEN E. 1971. — Die Tierknochenfunde aus dem Oppidum von Manching. Steiner (coll. Die Ausgrabungen in Manching; 6), Wiesbaden, 332 p.

BÖKÖNYI S. 1974. — *A* History of Domestic Mammals in Central and Eastern Europe. Akadémiai Kiadó, Budapest, 598 p.

BÖKÖNYI S. 1984. — Animal Husbandry and Hunting in Tác-Gorsium. The Vertebrate Fauna of a Roman Town in Pannonia. Akadémiai Kiadó (coll. Studia archaeologica; 8), Budapest, 238 p.

BOSCHIN F. 2006. — La fauna protostorica del sito di Bressanone-Elvas (BZ), in TECCHIATI U. & SALA B. (eds), Archäozoologische Studien. Festschrift für Alfredo Riedel. Autonome Provinz Bozen, Bozen: 131-142.

BOSCHIN F. & RIEDEL A. 2011. — Ein spätbronzezeitlicher Tierknochenfundkomplex aus der Kupferbergbausiedlung Brixlegg-Mariahilfbergl (Tirol). Annalen des Naturhistorischen Museums Wien Serie A 113: 591-618.

CAI X., ZHANG X., NOËL P. H. & SHAFIEE-JOOD M. 2015. — Impacts of climate change on agricultural water management: a review. Wires Water 2 (5): 439-455. https://doi.org/10.1002/wat2.1089

CASSOLI P. & TAGLIACOZZO A. 1991. — La fauna degli scavi 1983-1986 a Santorso, Vicenza (Età del Ferro). Preistoria Alpina 25: 165-216.

CLARK G. 1984. — The faunal remains from the Neolithic contexts at Casalmoro. Preistoria Alpina 20: 249-254.

DAVIS S. J. 1996. — Measurements of a group of adult female Shetland sheep skeletons from a single flock: a baseline for zooarchaeologists. Journal of Archaeological Science 23 (4): 593-612. https://doi.org/10.1006/jasc.1996.0056

DAVIS S. J. 2000. — The effect of castration and age on the development of the Shetland sheep skeleton and a metric comparison between bones of males, females and castrates. Journal of Archaeological Science 27 (5): 373-390. https://doi.org/10.1006/jasc.1999.0452

DE GROSSI MAZZORIN J. & MINNITI C. 2019a. — Caprine varieties in Italy during the Iron Age. The evidence from zooarchaeological data, in BUSANA M. S., GLEBA M., MEO F. & TRICOMI A. R. (eds), Textiles and Dyes in the Mediterranean Economy and Society. Proceedings of the 6th Purpurae Vestes international symposium on textiles and dyes in the Ancient Mediterranean World (Padova – Este – Altino, Italy, 17-20 October 2016). Libros Pórtico, Zaragoza: 107-116.

DE GROSSI MAZZORIN J. & MINNITI C. 2019b. — Variabilità dimensionale e sviluppo dei caprovini in Italia durante l'età del Ferro, in DE GROSSI MAZZORIN J., FIORE I. & MINNITI C. (eds), Atti dell'8° Convegno Nazionale di Archeozoologia. Università del Salento, Salento: 127-138.

DE GROSSI MAZZORIN J. & SOLINAS A. M. 2013. — L'analisi dei resti faunistici provenienti dai settori A ed E della palafitta di Lavagnone, in DE GROSSI MAZZORIN J. CURCI A. & GIACOBINI G. (eds), Economia ed Ambiente nell'Italia padana dell'età del Bronzo. Edipuglia, Bari: 21-102.

DE GROSSI MAZZORIN J. & SOLINAS A. M. 2018. — The analysis of faunal remains from sectors A and E of the pile dwellings at Lavagnone, in BAIONI M., MANGANI C. & RUGGIERO M. G. (eds), The Pile Dwellings: Investigation, Conservation, Enhancement. SAP Società Archeologica, Quingentole: 195-203.

DEPELLEGRIN V., TECCHIATI U. & SALZANI L. 2018. — Die bronze- und eisenzeitlichen Tierknochenfunde von Terranegra (Legnago, Verona). Annalen des Naturhistorischen Museums Wien, Serie A (120): 177-193.

DESCHLER-ERB S., GINELLA F. & HÜSTER PLOGMANN H. 2015. — Archäozoologische Untersuchungen zu den prähistorischen und mittelalterlichen Funden vom Kiechlberg, in TÖCHTERLE U. (ed.), Der Kiechlberg bei Thaur als Drehscheibe zwischen den Kulturen nördlich und südlich des Alpenhauptkammes. Ein Beitrag zum Spätneolithikum und zur Früh- und Mittelbronzezeit in Nordtirol. Habelt (coll. Universitätsforschungen zur Prähistorischen Archäologie; 261), Bonn: 361-396.

DRIESCH A. VON DEN 1976. — A Guide to the Measurement of Animal Bones from Archaeological Sites. Harvard University Press (coll. Peabody Museum Bulletin; 1), Cambridge, 138 p.

FESTI D., TECCHIATI U., STEINER H. & OEGGL K. 2011. — The Late Neolithic settlement of Latsch, Vintschgau, Northern Italy: subsistence of a settlement contemporary with the Alpine Iceman, and located in his valley of origin. Vegetation History and Archaeobotany 20: 367-379. https://doi.org/10.1007/s00334-011-0308-0

FONTANA A., TECCHIATI U., BIANCHIN CITTON E. & MONDINI C. 2015. — I resti faunistici dell´età del Rame del Col del Buson, Valle dell´Ardo (Belluno). Aspetti archeozoologici e paleoeconomici, in THUN HOHENSTEIN U., CANGEMI M., FIORE I. & DE GROSSI MAZZORIN J. (eds), Atti del 7° Convegno Nazionale di Archeozoologia. Università degli Studi di Ferrara, Ferrara: 51-56.

FRITZ O. 1928. — Wachstumsstudien am Karakulschaf im Vergleich mit Karakulkreuzungen und Merinos. Kühn-Archiv 18: 1-8.

GRÖMER K. & MAUTENDORFER H. 2008. — Einfache Fetzen und prunkvolle Stoffe, in KERN A., KOWARIK K., RAUSCH A. W. & RESCHREITER H. (eds), Salz – Reich. 7000 Jahre Hallstatt. Naturhistorisches Museum Wien, Vienna: 106-111.

GRÖMER K. & SALIARI K. 2018. — Dressing Central European Prehistory – the sheep's contribution. An interdisciplinary study about archaeological textile finds and archaeozoology. Annalen des Naturhistorischen Museums Wien Serie A (120): 127-156.

GRUPE G., GRÜNEWALD M., GSCHWIND M., HÖLZL S., KRÖGER P., LANG A., MAYR C., MCGLYNN G., METZNER-NEBELSICK C., NEUBERGER F., PETERS J., REUSS S., SCHMAL W., SÖLLNER F., SOMMER C. S., STEIDL B., TRIXL S. & WYCISK D. 2017. — Current synthesis and future options, in GRUPE G., GRIGAT A. & MCGLYNN G. (eds), Across the Alps in Prehistory: Isotopic Mapping of the Brenner Passage by Bioarchaeology. Springer, Cham: 229-250.

GUEM F. 1956. — Vorgeschichtliche Tierreste aus Tirol. Eine naturwissenschaftlich-kulturhistorische Untersuchung an späträtischen Knochenfunden aus Birgitz, Ranggen und Himmelreich in Volders. Thesis Philosophische Fakultät. Leopold-Franzens-Universität, Innsbruck, Austria, 137 p.

HALSTEAD P. & ISAAKIDOU V. 2011. — Revolutionary secondary products: the development and significance of milking, animal-traction and wool-gathering in later prehistoric Europe and the Near East, in WILKINSON T. C., SHERRATT S., BENNET J. & SHERRATT A. (eds), Interweaving Worlds: Systemic Interactions in Eurasia, 7th to the 1st Millennia BC. Oxbow, Oxford: 61-74. https://doi.org/10.2307/j.ctvh1dr2k.10

HAMILTON N. E. & FERRY M. 2018. — ggtern: ternary diagrams using ggplot2. Journal of Statistical Software, Code Snippets 87 (3): 1-17. https://doi.org/10.18637/jss.v087.c03

HARUDA A., VARFOLOMEEV V., GORIACHEV A., YERMOLAYEVA A. & OUTRAM A. 2019. — A new zooarchaeological application for geometric morphometric methods: distinguishing Ovis aries morphotypes to address connectivity and mobility of prehistoric Central Asian pastoralists. Journal of Archaeological Science 107: 50-57. https://doi.org/10.1016/j.jas.2019.05.002

HUNTLEY B., BAILLIE M., GROVE J., HAMMER C., HARRISON S., JACOMET S., JANSEN E., KARLÉN W., KOÇ N., LUTERBACHER J., NEGENDANK J. & SCHIBLER J. 2002. — Holocene palaeoenvironmental changes in North-West Europe: climatic implications and the human dimension, in WEFER G., BERGER W., BEHRE K.-E. & JANSEN E. (eds), Climate Development and History of the North Atlantic Realm. Springer, Berlin, Heidelberg: 259-298. https://doi.org/10.1007/978-3-662-04965-5_17

Kühn M. & Hadorn P. 2004. — Pflanzliche Makro- und Mikroreste aus Dung von Wiederkäuern, in Jacomet S., Leuzinger U. & Schibler J. (eds), Die jungsteinzeitliche Seeufersiedlung Arbon Bleiche 3. Umwelt und Wirtschaft. Kantonsarchäologie Thurgau (coll. Archäologie im Thurgau; 12), Frauenfeld: 327-350.

Lignereux Y., Peters J. & Alzieu J. 1995. — Lésions et pathologie dentaires et locomotrices des ruminants chassés de la grotte de la Vache (Tardiglaciaire, Alliat, Ariège, France). Revue de Médecine Vétérinaire 146: 829-846.

Magny M., Peyron O., Gauthier E., Rouèche Y., Bordon A., Billaud Y., Chapron E., Marguet A., Petrequin P. & Vannière B. 2009. — Quantitative reconstruction of climatic variations during the Bronze and early Iron ages based on pollen and lake-level data in the NW Alps, France. Quaternary International 200 (1-2): 102-110. https://doi.org/10.1016/j.quaint.2008.03.011

Mandl F. 2006. — Almen und Salz. Hallstatts bronzezeitliche Dachsteinalmen. Jahrbuch des Oberösterreichischen Musealvereins 151: 7-36.

Manhart H. 1998. — Die vorgeschichtliche Tierwelt von Koprivec und Durankulak und anderen prähistorischen Fundplätzen in Bulgarien aufgrund von Knochenfunden aus archäologischen Ausgrabungen. Documenta Naturae, München, 341 p.

Manhart H. 2004. — Naturwissenschaftliche Untersuchungen: Archäozoologie, in Bankus M. (ed.), Der Freisinger Domberg und sein Umland. Untersuchungen zur prähistorischen Besiedlung. Leidorf (coll. Freisinger Archäologische Forschungen; 1), Rahden: 218-254.

McEneaney-Schneider E. 1984. — Tierknochenfunde von der Heuneburg einem frühkeltischen Herrensitz bei Hundersingen an der Donau (Grabungen, 1966 bis 1979): Wiederkäuer ohne die Bovini. Thesis Tierärztliche Fakultät. Ludwig-Maximilians-Universität, Munich, 88 p.

Meadow R. 1999. — The use of size index scaling techniques for research on archaeozoological collections from the Middle East, in Becker C., Manhart H., Peters J. & Schibler J. (eds), Historia animalium ex ossibus. Festschrift für Angela von den Driesch. Leidorf (coll. Studia Honoraria; 8), Rahden: 285-300.

Metzner-Nebelsick C., Lang A., Sommer C. S. & Steidl B. 2017. — Transalpine mobility and trade since the Mesolithic, in Grupe G., Grigat A. & McGlynn G. (eds), Across the Alps in Prehistory. Isotopic Mapping of the Brenner Passage by Bioarchaeology. Springer, Cham: 1-26.

Mysterud A. 1999. — Seasonal migration pattern and home range of roe deer (Capreolus capreolus) in an altitudinal gradient in southern Norway. Journal of Zoology 247: 479-486. https://doi.org/10.1111/j.1469-7998.1999.tb01011.x

Nicolussi K., Kaufmann M., Patzelt G., Van der Plicht J. & Thurner A. 2005. — Holocene tree-line variability in the Kauner Valley, Central Eastern Alps, indicated by dendrochronological analysis of living trees and subfossil logs. Vegetation History and Archaeobotany 14: 221-234. https://doi.org/10.1007/s00334-005-0013-y

Oeggl K. & Nicolussi K. 2009. — Prähistorische Besiedlung von zentralen Alpentälern in Bezug zur Klimaentwicklung, in Schmidt R., Matulla C. & Psenner R. (eds), Klimawandel in Österreich: Die letzten 20.000 Jahre… und ein Blick voraus. Innsbruck University Press (coll. Alpine space – man & environment; 6), Innsbruck: 77-86.

Oeggl K., Schmidl A. & Kofler W. 2009. — Origin and seasonality of subfossil caprine dung from the discovery site of the Iceman (Eastern Alps). Vegetation History and Archaeobotany 18: 37-46. https://doi.org/10.1007/s00334-008-0188-0

Patzelt G., Kofler W. & Wahlmüller B. 1997. — Die Ötztalstudie: Entwicklung der Landnutzung, in Oeggl K., Patzelt G. & Schäfer D. (eds), Alpine Vorzeit in Tirol. Forschungsinstitut für Alpine Vorzeit, Institut für Botanik, Forschungsinstitut für Hochgebirgsforschung, Innsbruck: 46-62.

Pindur P., Schäfer D. & Luzian R. 2007. — Nachweis einer bronzezeitlichen Feuerstelle bei der Schwarzsteinalm im Oberen Zemmengrund, Zillertaler Alpen. Mitteilungen der Österreichischen Geographischen Gesellschaft 149: 181-198.

Pisoni L. & Tecchiati U. 2010. — La fauna della recente età del Ferro di Laion/Lajen-Wasserbühel (BZ), Settore L-N. Notizie Archeologiche Bergomensi 18: 179-106.

Plüss P. 2007. — Archäozoologische Untersuchungen der Tierknochen aus Cresta-Cazis (GR) und ihre Bedeutung für die Umwelt-, Ernährungs- und Wirtschaftsgeschichte während der alpinen Bronzezeit. Thesis Philosophisch-Naturwissenschaftlichen Fakultät, University of Basel, Switzerland, 236 p.

Pucher E. 1984. — Bronzezeitliche Tierknochen vom Buchberg, OG Wiesing, Tirol. Fundberichte aus Österreich 23: 209-220.

Pucher E. 1999a. — Archäozoologische Untersuchungen am Tierknochenmaterial der keltischen Gewerbesiedlung im Ramsautal auf dem Dürrnberg (Salzburg). Leidorf (coll. Dürrnberg-Forschungen; 2), Rahden, 129 p.

Pucher E. 1999b. — Archäozoologische Ergebnisse aus zwei norischen Salzbergbausiedlungen, in Kokabi M. & May E. (eds), Beiträge zur Archäozoologie und Prähistorischen Anthropologie 2. Wais & Partner, Stuttgart: 121-128.

Pucher E. 2010. — Sechs Jahrtausende alpine Viehwirtschaft. Mitteilungen der ANISA 12: 1-28.

Pucher E. 2019. — Die Tierknochen der mittelbronzezeitlichen Fundstelle Saalfelden-Katzentauern im Salzburger Pinzgau. Annalen des Naturhistorischen Museums Wien Reihe A (121): 35-81.

Pucher E. & Engl K. 1997. — Die Pfahlbaustationen des Mondsees. Tierknochenfunde. Verlag der Österreichischen Akademie der Wissenschaften (coll. Mitteilungen der Prähistorischen Kommission der Österreichischen Akademie der Wissenschaften 33), Wien, 150 p.

Putzer A. & Festi D. 2014. — Nicht nur Ötzi? – Neufunde aus dem Tisental (Gem. Schnals/Prov. Bozen). Prähistorische Zeitschrift 89: 55-71. https://doi.org/10.1515/pz-2014-0005

R Core Team 2020. — R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Wien. https://www.gbif.org/fr/tool/81287/r-a-language-and-environment-for-statistical-computing, last consultation on 21 March 2022.

Rageth J. 1986. — Die wichtigsten Resultate der Ausgrabung in der bronzezeitlichen Siedlung auf dem Padnal bei Savognin (Oberhalbstein GR). Jahrbuch der Schweizer Gesellschaft für Ur- und Frühgeschichte 69: 63-103.

Reitmaier T. 2010. — Auf der Hut. Methodische Überlegungen zur prähistorischen Alpwirtschaft in der Schweiz, in Mandl F. & Stadler H. (eds), Archäologie der Alpen. ANISA, Ennstal: 219-238.

Riedel A. 1976a. — La Fauna del villagio preistorico di Ledro. Archeo-zoologia e paleo-economia. Studi Tridentini di Scienze Naturali 53 (5B): 3-120.

Riedel A. 1976b. — La fauna del villagio preistorico di Barche di Solferino. Atti del Museo Civico di Storia Naturale Trieste 29: 215-318.

Riedel A. 1979. — La fauna di alcuni insediamenti preistorici del territorio Veronese. Atti del Museo Civico di Storia Naturale Trieste 31: 41-73.

Riedel A. 1982. — Die Fauna einer bronzezeitlichen Siedlung bei Peschiera am Gardasee. Rivista di Archeologia 6: 23-27.

Riedel A. 1984a — Die Fauna der vorgeschichtlichen Fundstätte von Moletta bei Arco im Trentino. Preistoria Alpina 20: 131-138.

Riedel A. 1984b. — Die Fauna der Sonnenburger Ausgrabungen. Preistoria Alpina 20: 261-280.

Riedel A. 1985a. — The fauna of the Iron Age site of Castelrotto (Verona). Padusa 21: 55-95.

Riedel A. 1985b. — Die Fauna einer bronzezeitlichen Siedlung bei Eppan (Südtirol). Rivista di Archeologia 9: 9-25.

Riedel A. 1986. — Die Fauna einer eisenzeitlichen Siedlung in Stufels bei Brixen. Preistoria Alpina 22: 183-220.

RIEDEL A. 1990. — La fauna dell´età del Bronzo di Cisano (Verona), in SALZANI L. (ed.), Nuovi Scavi Della Palafitta di Cisano. Commune di Bardolino, Bardolino: 53-59.

RIEDEL A. 1992. — The Bronze Age animal bone deposit of Nogarole Rocca I Camponi (Verona). Padusa 28: 87-104.

RIEDEL A. 1994. — Archaeozoological investigations in Northeastern Italy: the exploitation of animals since the Neolithic. Preistoria Alpina 30: 43-94.

RIEDEL A. 2002. — Die Fauna der vorgeschichtlichen Siedlung von Pfatten. Museo civico di Rovereto (coll. Pubblicazione del Museo civico di Rovereto; 90), Rovereto, 146 p.

RIEDEL A. 2003. — Die frühbronzezeitliche Fauna von Brixlegg in Tirol. Atti dell'accademia roveretana degli Agiati 253: 197-281.

RIEDEL A. & RIZZI J. 1996. — Die faunistischen Reste der Megalithstruktur, in MULTSCHERMUSEUM & STADTMUSEUM STERZING (eds), Archäologie. Feldthurns und südliches Wipptal. Multschermuseum, Stadtmuseum, Sterzing: 13-14.

RIEDEL A. & RIZZI-ZORZI J. 2006. — La fauna dell´età del rame di Gazzo Veronese "Il Cristo" (VR). Padusa 41: 153-176.

RIEDEL A. & TECCHIATI U. 1999. — I resti faunistici dell´abitato d´altura dell´antica e media età del bronzo di Nössing in Val d´Isarco (Com. di Varna, Bolzano). Atti dell'Accademia Roveretana degli Agiati 249: 285-327.

RIEDEL A. & TECCHIATI U. 2000. — La fauna dell'antica etá del Bronzo di Naturno-Naturns, Loc. Schnalserhof (Bolzano), *in* MALERBA G., CILLI C. & GIACOBINI G. (eds), *Atti del 2° Convegno Nazionale di Archeozoologia*. Abaco Edizioni, Forlì: 225-230.

RIEDEL A., RIZZI J. & TECCHIATI U. 2002. — La fauna del luogo di culto dell'età del ferro di Castel del Porco/Greifenstein (S. Genesio), in TECCHIATI U. (ed.), Der Heilige Winkel. Der Bozner Talkessel zwischen der späten Bronzezeit und der Romanisierung (13.-1. Jh. v. Chr.). Südtiroler Archäologiemuseum, Bozen: 379-388.

RIZZI J. 1997. — Lo studio della Fauna dell´età del Bronzo medio di Albanbühel-Bressanone (Bolzano). Thesis Scienze Naturali, University of Padova, 88 p.

RUEGER J. 1942. — Die Tierreste aus der spätbronzezeitlichen Siedlung Crestaulta (Kanton Graubünden) nach den Grabungen 1935-1938. Revue suisse de Zoologie 49: 251-268.

SALIARI K., PUCHER E. & KUCERA M. 2016. — Archaeozoological investigation of the La Tène A-C1 salt-mining complex and the surrounding graves of Putzenkopf Nord (Bad Dürrnberg, Austria). Annalen des Naturhistorischen Museums Wien Serie A 118: 245-288.

SALIARI K., PUCHER E., STAUDT M. & GOLDENBERG G. 2020. — Continuities and changes of animal exploitation across the Bronze Age – Iron Age boundary at mining sites in the Eastern Alps. Archaeofauna 29: 77-106.

SALVAGNO L. & TECCHIATI U. 2011. — I resti faunistici del villaggio dell'età del Bronzo di Sotćiastel. Economia e vita di una comunità protostorica alpine (ca. XVII-XIV sec. a.C.). Institut Ladin Micurà de Rü (coll. Ladinia monografica 3), San Martin de Tor, 239 p.

SALVAGNO L. & TECCHIATI U. 2017. — I resti faunistici dell'abitato del Neolitico Tardo, dell'Età del Bronzo e di Età medievale, moderna e contemporanea di Castelrotto-Grondlboden (BZ). Preistoria Alpina 49: 37-50.

SCHATZ K. 2009. — Die Tierknochenfunde aus der frühlatènezeitlichen Siedlung Eberdingen-Hochdorf „Reps" – Archäozoologische Untersuchungen zur Wirtschaftsweise, Landnutzung und Ernährung der frühen Kelten im mittleren Neckarraum, in SCHATZ K. & STIKA H.-P., Hochdorf VII. Archäobiologische Untersuchungen zur frühen Eisenzeit im mittleren Neckarraum. Theiss (coll. Forschungen und Berichte zur Vor- und Frühgeschichte in Baden-Württemberg; 107), Stuttgart: 17-123.

SCHIBLER J., BREITENLECHNER E., DESCHLER-ERB S., GOLDENBERG G., HANKE K., HIEBEL G., HÜSTER PLOGMANN H., NICOLUSSI K., MARTI-GRÄDEL E., PICHLER S., SCHMIDL A., SCHWARZ S., STOPP B. & OEGGL K. 2011. — Miners and mining in the Late Bronze Age: a multidisciplinary study from Austria. Antiquity 85 (330): 1259-1278. https://doi.org/10.1017/S0003598X00062049

SCHLOSSER M., BIRKNER F. & OBERMAIER H. 1910. — Die Bärenoder Tischoferhöhle im Kaisertal bei Kufstein. Abhandlungen der II. Klasse der Königlichen Bayerischen Akademie der Wissenschaften 24: 387-503.

SCHMITZBERGER M. 2007. — Archäozoologische Untersuchungen an den bronze-, eisen- und römerzeitlichen Tierknochen vom Ganglegg bei Schluderns und vom Tartscher Bichl, in STEINER H. (ed.), Die befestigte Siedlung am Ganglegg im Vinschgau/Südtirol. Temi (coll. Forschungen zur Denkmalpflege in Südtirol; 3), Trento: 617-742.

SCHMITZBERGER M. 2012. — Die Tierknochen vom Ramsaukopf, Putzenkopf und Putzenfeld – neue Funde vom keltischen Dürrnberg bei Hallein. Annalen des Naturhistorischen Museums Wien Serie A 114: 79-138.

SCHMÖLCKE U., GROSS D. & NIKULINA E. 2018. — The history of sheep husbandry in Austria from the Neolithic to the Roman Period. Annalen des Naturhistorischen Museums Wien Serie A 120: 101-126.

SPINDLER K. 2005. — Der Mann im Eis und das Wanderhirtentum, in HOLZNER J. & WALDE E. (eds), Brüche und Brücken – Kulturtransfer im Alpenraum von der Steinzeit bis zur Gegenwart. Folio, Wien: 22-41.

STEINER H., PUTZER A., OBERRAUCH H., THURNER A. & NICOLUSSI K. 2009. — Vorgeschichtliche Moorfunde auf der Schöllberg-Göge in Weissenbach (Gde. Ahrntal/Südtirol). Archäologisches Korrespondenzblatt 39: 489-508.

STEPHAN E. 2009. Rekonstruktion eisenzeitlicher Weidewirtschaft anhand archäozoologischer und isotopenchemischer Untersuchungen, in BENECKE N. (ed.), Beiträge zur Archäozoologie und Prähistorischen Anthropologie 7. Beier & Beran, Langenweißbach: 65-79.

TECCHIATI U. 2006. — La fauna del II-I secolo a. C. di San Giorgio di Valpolicella – via Conca d´Oro (VR), in TECCHIATI U. & SALA B. (eds), Archäozoologische Studien. Festschrift für Alfredo Riedel. Autonome Provinz Bozen, Bozen: 181-216.

TECCHIATI U. 2012. — Die Tierknochen aus der bronze- und eisenzeitlichen Siedlung auf dem Kiabichl bei Faggen (Tirol, Österreich). Annalen des Naturhistorischen Museums Wien Serie A 114: 21-78.

TECCHIATI U. & ZANETTI A. L. 2013. — I resti faunistici dell´abitato della prima fase dei Vasi a Bocca Quadrata di Bressanone – Stufles (BZ). Atti dell'Accademia Roveretana degli Agiati 263: 193-264.

TECCHIATI U., FONTANA A. & MARCONI S. 2010. — Indagini archeozoologiche sui resti faunistici della media-recente età del Bronzo di Laion-Wasserbühel (BZ). Annali del Museo Civico di Rovereto: Sezione Archeologia, Storia, Scienze Naturali 26: 105-131.

TEICHERT M. 1975. — Osteometrische Untersuchungen zur Berechnung der Widerristhöhe bei Schafen, in CLASON A. T. (ed.), Archaeozoological Studies. Elsevier, Amsterdam, New York: 51-69.

TRENTACOSTE A., NIETO-ESPINET E. & VALENZUELA-LAMAS S. 2018. — Pre-Roman improvements to agricultural production: evidence from livestock husbandry in late prehistoric Italy. PLoS ONE 13 (12): e0208109. https://doi.org/10.1371/journal.pone.0208109

TRIXL S. 2019. — Zwischen Wandel und Beständigkeit. Die Entwicklung der späteisenzeitlich-frührömischen Viehwirtschaft im Alpenraum und dem nördlichen Alpenvorland. Leidorf (coll. Documenta Archaeobiologiae; 14), Rahden, 374 p.

TRIXL S. (in press). — Lebensgrundlage seit Jahrtausenden: Die Viehwirtschaft in Ammergebirge und Loisachtal im Spiegel archäologischer Knochenfunde.

TRIXL S. & PETERS J. 2019. — Viehwirtschaft und Kulturwandel – zur Archäozoologie der späten Eisen- und frühen römischen Kaiserzeit im nördlichen Alpenraum, in ZANIER W. (ed.), Kulturwandel um Christi Geburt: Spätlatène- und frühe römische Kaiserzeit in den mittleren Alpen zwischen Südbayern und Gardasee. Likias, Friedberg: 545-565.

TRIXL S., BEN TAHAR S., RITTER S. & PETERS J. 2020. — Wool sheep and purple snails. Long-term continuity of animal exploitation in ancient Meninx (Jerba/Tunisia). International Journal of Osteoarchaeology 30 (6): 811-823. https://doi.org/10.1002/oa.2911
VALENZUELA-LAMAS S., ORENGO H. A., BOSCH D., HALSTEAD P., NIETO-ESPINET A., PELLEGRINI M., TRENTACOSTE A., JIMÉNEZ-MANCHÓN S., LÓPEZ-REYES D. & JORNET-NIELLA R. 2021. — Shipping amphorae and shipping sheep? Livestock mobility in the north-east Iberian peninsula during the Iron Age based on strontium isotopic analyses of sheep and goat tooth enamel. PLoS ONE 13 (10): e0205283. https://doi.org/10.1371/journal.pone.0205283
WALSH K. & MOCCI F. 2011. — Mobility in the mountains: late third and second millennia Alpine societies' engagements with the high-altitude zones in the southern French Alps. European Journal of Archaeology 14 (1-2): 88-115. https://doi.org/10.1179/146195711798369427
WERNER P. 1981. — Almen. Bäuerliches Wirtschaftsleben in der Gebirgsregion. Callwey, Munich, 220 p.
WICKHAM H. 2016. — ggplot2: Elegant Graphics for Data Analysis. Springer, New York, 260 p.
WINDER L. M., SCOBIE D. R., BRAY A. R. & BICKERSTAFFE R. 1995. — Wool growth rate in vitro is independent of host animal nutrition, season, and the potential mediators of photoperiod, melatonin and prolactin. The Journal of Experimental Zoology 272 (6): 446-454. https://doi.org/10.1002/jez.1402720606
WÜRGLER F. 1962. — Veränderungen des Haustierbestandes während der Bronze- und Eisenzeit in zwei schweizerischen „Melauner"-Stationen, Montlingerberg und Mottata Ramosch. Zeitschrift für Tierzüchtung und Züchtungsbiologie 77: 35-46.

Submitted on 26 February 2021;
accepted on 26 August 2021;
published on 25 March 2022.