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Citation: Price, Max et al. "Fodder, pasture, and the development of complex society in the Chalcolithic: isotopic perspectives on animal husbandry." *Archaeological and Anthropological Sciences* 12, 4 (March 2020): 95 © 2020 Springer-Verlag

As Published: <http://dx.doi.org/10.1007/s12520-020-01043-z>

Publisher: Springer Science and Business Media LLC

Persistent URL: <https://hdl.handle.net/1721.1/128382>

Version: Author's final manuscript: final author's manuscript post peer review, without publisher's formatting or copy editing

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Fodder, Pasture, and the Development of Complex Society in the Chalcolithic: Isotopic Perspectives on Animal Husbandry at Marj Rabba

Cite this article as: Max Price, Yorke M. Rowan, Morag M. Kersel, Cheryl A. Makarewicz, Fodder, Pasture, and the Development of Complex Society in the Chalcolithic: Isotopic Perspectives on Animal Husbandry at Marj Rabba, *Archaeological and Anthropological Sciences*, doi: [10.1007/s12520-020-01043-z](https://doi.org/10.1007/s12520-020-01043-z)

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Title: Fodder, Pasture, and the Development of Complex Society in the Chalcolithic:
Isotopic Perspectives on Animal Husbandry at Marj Rabba

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Abstract: The emergence of social complexity in the southern Levant during the Chalcolithic (c. 4500 – 3600 cal. BC) was intimately tied to intensification in animal management. For the first time, secondary products such as milk and wool were intensively exploited, supplying communities with increasingly diverse foodstuffs and raw materials for craft production and exchange, but the precise herding practices underlying these new production strategies are unknown. Here, we explore the role of

multi-species livestock pasturing through carbon and nitrogen isotopic analysis of animal bones from Marj Rabba in the Lower Galilee (ca. 4600-4200 cal. BC). Isotopic results suggest different pasturing/foddering of sheep compared to goats. Cattle were largely pastured locally, but high $\delta^{13}\text{C}$ values in some animals indicate access to the Jordan River Valley (the *Ghor* in Arabic), where major Chalcolithic settlements were situated. This may indicate some cattle were moved along regional Chalcolithic exchange networks established for other prestige objects, such as copper. Finally, we provide evidence for moderate ^{15}N enrichment in pigs relative to herbivorous livestock indicates. Possible interpretations include consumption of nuts (esp. acorns), household refuse containing animal protein, and/or fattening pigs on grain. Although an interpretation that requires further exploration, grain-foddering of pigs would complement the zooarchaeological data for early slaughter, which suggests intensive meat production at Marj Rabba. It might also help explain why pig husbandry, as a drain on grain stockpiles, was gradually abandoned during the Bronze Age. Taken together, the isotopic and zooarchaeological data indicate an economy in transition from a non-specialized, household-based Neolithic economy to one in which the production of agrarian wealth, including animal secondary products, was beginning to emerge.

Keywords: Zooarchaeology, Stable isotopes, Carbon, Nitrogen, Chalcolithic, Levant

Acknowledgments

We wish to thank the Oriental Institute of the University of Chicago for its support of the Galilee Prehistory Project and the excavations at Marj Rabba. Thanks also

to Andrea Dudek, Phil Graham, Austin (Chad) Hill, Michael Homan, Brittany Jackson, and Dina Shalem – senior members of the Marj Rabba excavations. Over six seasons, the bones were carefully recovered by student excavators; we are grateful for their dedication to the project. We also wish to extend our gratitude to the Israel Antiquities Authority for permission to excavate and export animal bones from Marj Rabba. We thank Bob Michener (Boston University) for assistance with mass spectrometry, as well as Richard Meadow (Zooarchaeology Lab) and Robert Ackert (Archaeology Multi-User Lab) at Harvard University. Karin Winter helped with graphics. Funding for the isotopic analysis was provided by the Alexander von Humboldt-Stiftung and the Archaeological Stable Isotope Laboratory (Kiel University).

Introduction

The Chalcolithic (c. 4500-3600 cal. BC) in the southern Levant was a critical moment in the evolution of complex societies. Population expansion, increased visibility of ritual architecture, greater social investment in ritual practice, and craft specialization all took place at this time (Rowan & Golden 2009). These changes coincided with – and were likely connected to – transformations in livestock management that sought to regularly exploit “secondary products” including milk, fiber, and traction power. Pigs, animals that generate no secondary products, provided a major source of meat and fat to Chalcolithic communities across the region (Grigson 1998; Price et al. 2013). Landscape use also appears to have shifted during the Chalcolithic. Abundant chipped stone axes recovered from Chalcolithic sites (Rowan & Golden 2009: 28) and a marked rise in the frequency of *Olea* pollen in lake cores (Litt et al. 2012; Schiebel 2013) suggest land clearance for agriculture and arboriculture. Additionally, small, ephemeral sites were established outside of the core settlement zones of the Jordan River Valley (colloquially referred to as the *Ghor*, the Arabic word for “valley”) and the northern Negev. This shift in settlement patterns, suggestive of mobile herding (Epstein 1978; Levy 1983, 1992; Bourke 2001), may reflect intensification in animal production and its coordination with intensive cereal agriculture. However, it remains to be seen how, if at all, animals were distributed across the landscape and what strategies livestock keepers employed to feed their herds.

Here, we explore Chalcolithic landscape use, in the form of livestock pasturing, through analysis of carbon and nitrogen isotopes from animal remains recovered from Marj Rabba. Carbon and nitrogen isotopes of collagenous tissues reflect animal dietary

intake, offering insight into habitat vegetation dynamics, mobility, habitat exploitation, and changes in foddering regimes (Makarewicz & Tuross 2012; Hamilton et al. 2009; Pickard et al. 2017). Marj Rabba is a roughly eight-hectare site located in the hilly Lower Galilee (Figure 1). The relatively well-watered landscapes of the Lower and, especially, Upper Galilee provided ideal pasturelands as well as opportunities for growing grains and fruits. To the south and east, the fertile Jordan Valley also supported large communities of agropastoralists. Marj Rabba's location, size, and robust faunal assemblage make it an ideal site to test questions related to landscape use and animal management in the Chalcolithic.

Animals and Socioeconomic Change in the Chalcolithic

The Chalcolithic period witnessed profound shifts in demography, economic organization, and ritual activities that, altogether, contributed to new forms of socio-political organization. After an extended period of settlement retraction during the Pottery Neolithic, large settlements of up to 10 hectares sprang up across the southern Levant, particularly in the Jordan River Valley and to its west (Finkelstein & Gophna 1993; Gibson & Rowan 2006; Shalem 2008). People settled in previously sparsely inhabited regions, such as the Negev and Golan (Epstein 1978; Levy 1992). At the same time, craft production became more specialized. Wheel-made pottery appeared for the first time (Kerner 2010) and concentrations of weaving tools at some sites (e.g., Gilat) suggest specialization of textile production (Levy et al. 2006). Metal production was also specialized. At the Chalcolithic-EB I sites of Tell Hujayrat al-Ghuzlan and Tell al-Magass in the Aqaba region, craftsman smelted and cast copper in considerable quantities

(Notroff et al. 2014). In a similar fashion, evidence for metalworking at northern Negev sites such as Shiqmim and Abu Matar included crucibles, slags, and ores yielding chemical compositions indicating Faynan ore sources (Golden et al. 2001).

Diversification and elaboration of ritual activity were likely tied to these demographic and economic changes. The archaeological record of the Chalcolithic is replete with an abundance of ritual material culture, such as miniature vessels, female figurines, and elaborate wall decorations depicting animals and people (Joffe et al. 2001; Lovell 2010; Drabsch 2015). Burial traditions diversified to include both primary and secondary burials, the latter of which were often interred in stylized ceramic ossuaries (Rowan & Golden 2009; Shalem et al. 2013; Ilan & Rowan 2019). People congregated at what some have argued were “cultic” centers or at sites with “temples.” Notable examples are Gilat, Tulaylat Ghassul (sometimes spelled “Teleilat al-Ghassul”), and Ein Gedi (Rowan & Golden 2009).

Debate persists over whether these ritual and economic changes represent a society that had developed a hierarchical (“chiefdom”) level of organization (Gopher & Tsuk 1996; Levy 1998), or whether Chalcolithic communities were egalitarian (Joffe et al. 2001). While direct evidence for elites and hierarchical organization is limited, some have suggested that elaborate rituals, perhaps coordinated by specialist religious practitioners (Levy 2006; Rowan & Ilan 2007; Ilan & Rowan 2012), served as an impetus towards greater economic specialization and coordination among increasing large and dispersed populations. Chalcolithic sites are also notable, especially in comparison to previous periods, for the presence of prestige goods, such as maceheads, palettes, and other objects made of ivory, copper, and polished stone (Rowan and Golden 2009: 9).

Again, it remains unclear if these objects functioned in ritual contexts defined by achieved status or whether emerging hereditary elites were attempting to accumulate prestige goods on their paths to political power.

Whatever their specific forms of sociopolitical organization, Chalcolithic societies were founded upon an agropastoral base that facilitated social elaboration. Accumulated foodstuffs fueled a more specialized economy, enabled feasts, and potentially may have been a source of elite economic power. Indeed, archaeobotanical and zooarchaeological data indicate substantial subsistence developments during the Chalcolithic. Pollen cores from the Dead Sea and macrobotanical evidence from Chalcolithic sites in the Jordan River Valley and the Galilee/Golan indicate extensive olive production beginning in the mid-5th millennium cal. BC (Epstein 1978; Bourke 2001; Litt et al. 2012; Graham 2018). Cereal cultivation also expanded, signaled by the high relative abundances of wheat and barley in archaeobotanical assemblages, the proliferation of sickle blades, and the high rates of caries and other dental pathologies in Chalcolithic skeletons (Smith et al. 2003; Rowan & Golden 2009; Graham 2018). Similarly, large-scale storage facilities at, for example, Tulaylat Ghassul might indicate control over distribution (Bourke 2001: 117).

In terms of animal production, the Chalcolithic has long been thought to herald the so-called “secondary products revolution” (Sherratt 1983; Grigson 1998). This is a somewhat hyperbolic term for the *intensification* of the exploitation of animals for non-meat products such as milk, traction, and animal fiber. It is important to recognize that, in contrast to Andrew Sherratt’s (1983) original hypothesis, the Chalcolithic was *not* the first time that secondary products were exploited (Vigne & Helmer 2007; Evershed et al. 2008). Rather, the Chalcolithic represents a period in which herders began to adjust their

management strategies to target and eventually maximize the production of milk, animal hair, and traction.

Several lines of evidence indicate the intensification of secondary product exploitation. Some faunal assemblages, such as Gilat (Grigson 2006) and Tulaylat Ghassul (Bourke et al. 2007), show increased survivorship of adult sheep/goat, a harvesting profile consistent with theoretical models that emphasize long-term herd security or meat production is visible at some sites. Evidence for milk and hair production also includes the proliferation of ceramic churns, spindle whorls, and an abundance of weaving implements made from animal bones (e.g., at Gilat: Commenge et al. 2006; Levy et al. 2006). There is also occasional evidence for traction pathologies on the distal limbs of cattle at some sites, indicating the use of these animals for plowing (Grigson 1995; Hill 2011; Price et al. 2013).

The abundance of pigs at Chalcolithic sites, on the other hand, indicates that secondary products were far from being the sole focus of Chalcolithic animal husbandry. The remains of pigs, animals that do not provide hair for textiles or abundant milk for dairy production, regularly exceed 25% of the fauna (by Number of Identified Specimens - NISP) in the Galilee, Coastal, and Jordan River Valley regions (Grigson 1995, 1998; Price et al. 2013). This pattern is consistent with animal exploitation at preceding Late Neolithic sites in the region (Horwitz 2002: 168; Marom & Bar-Oz 2013), but differs significantly from the low proportions of pigs found at sites dating to the Early Bronze Age and later. Beginning in the Early Bronze Age (3600-2000 cal. BC), the importance of pigs gradually declined, becoming an insignificant part of the typical Levantine diet by the second millennium BC (Allentuck 2013: 164-169). While some authors have

attributed this decline to climate change, specifically increased aridity (Allentuck and Rosen 2019), the retention of cattle in the Bronze Age and the addition/expansion of crops requiring significant amounts of water in the Early Bronze Age (e.g., grapes and flax; see Reihl 2008) strongly suggest that water scarcity was not the main reason for the decline of pig husbandry. Moreover, pig husbandry primarily declined during the EB II-III, a period characterized by relatively more rainfall than the preceding EB I (Bar-Matthews & Ayalon 2011). The demise of pig husbandry should be understood not so much in terms of climate change (though we do not deny that this may have played an important role in some contexts), but rather in the specific ways that people raised these animals in relation to other human-environmental interactions and economic activities. In that vein, we ask whether Chalcolithic pig husbandry practices might shed light on pork's gradual disappearance from the Levantine diet.

Semi-specialized or mobile pastoralism may have formed an important component of the Chalcolithic economy. Survey data from the Negev indicates the presence of ephemeral sites located outside the Nahal Besor floodplain, where major settlements and, presumably, cereal agriculture were concentrated (Levy 1983). However, the transient sites were located in proximity to ideal summer and winter pastures for ruminants. This might therefore reflect a more mobile system of pastoralism of sheep and goats designed to avoid competition between herding and grain production or to take advantage of seasonally-available pastures (Levy 1983). Others have contended that, since animals in all age classes were present in the bone assemblages of major settlements in the region, herding was localized and non-mobile (Grigson 1998).

Animal Management at Marj Rabba

Marj Rabba (32.844°N, 35.282°E, c. 450 masl) is one of about three dozen known Chalcolithic sites in the Galilee (Shalem 2008). The areal extent of the sherd scatter (c. 8 ha) and dense palimpsest of stone architecture revealed by ground-penetrating radar (Urban et al. 2014) indicates a sizable village, with four phases radiocarbon dated to 4600-4200 cal. BC. Excavations were carried out between 2009 and 2014 (Rowan & Kersel 2014; Urban et al. 2014). In addition to domestic architecture, the excavators uncovered two seemingly ritual features: a pit containing the articulated remains of two cattle (Hill et al. 2016) and a uniquely- and well-constructed building (Building 1) containing the remains of several gazelle feet as well as a human foot (Price et al. 2016).

Archaeobotanical and faunal data from Marj Rabba indicate a mixed agricultural economy. Among the plant remains, wheat and barley predominated, followed by lentils, olives, and peas (Graham 2018). The animal remains (Table 1) show a predominance of domestic livestock. Gazelle were also present, although the majority of these remains (N = 256) derive from the previously mentioned Building 1 and probably reflect ritual, not quotidian, activities.

Table 1. Main animal taxa from the Marj Rabba faunal assemblage. “Sheep/Goat” includes specimens identified specifically as “sheep” or “goat” in the subsequent lines.

Taxon	NISP	%NISP
Cattle (<i>Bos taurus</i>)	750	13%
Sheep/Goat	2855	50%
Sheep (<i>Ovis aries</i>)	(182)	
Goat (<i>Capra hircus</i>)	(239)	
Pig (<i>Sus scrofa</i>)	1685	30%
Gazelle (<i>Gazella gazella</i>)	373	7%

Ongoing research at Marj Rabba has examined secondary products exploitation. Collagen peptide fingerprinting (ZooMS) assigned 52 mandibles bearing age at death information to genus (*Capra* or *Ovis*), allowing computation of sheep and goat survivorship separately (Price et al. 2013). The demographic profiles between the two species were not significantly different (Kolmogorov-Smirnov test: $D = .333$, $P = .699$) and both demographic profiles were broadly comparable to risk-minimizing (or meat-focused) production models (Payne 1972; Redding 1981). On the other hand, sheep were slaughtered somewhat later than goats, with 25% of animals surviving past four years of age (Payne's age classes G-I) compared to 13% for goats (Table 2). In fact, this pattern of slightly older kill-off for sheep has been found repeatedly at Chalcolithic sites, including Bir es-Safadi (Grigson 1987) and Gilat (Grigson 2006) in the northern Negev as well as early 5th millennium Tel Tsaf (Hill 2011). This could be taken as evidence for a slight (or emerging) emphasis on wool exploitation.

Table 2. Sheep/goat suggested ages for Payne's age classes, published by Payne (1973: 293). *Ages in months.

Age Class	MNE Sheep/Goat	Sheep/Goat % Surviving	MNE Sheep	Sheep % Surviving	MNE Goat	Goat % Surviving	Est. Age*
A	1	99	0	100	0	100	0-2
B	1	98	1	95	0	100	2-6
C	23	73	5	70	8	75	6-12
D	16	55	3	55	8	50	12-24
E	12	42	2	45	4	38	24-36
F	15	25	2	35	8	13	36-48
G	12	12	4	15	2	6	48-72
H	5	7	2	5	2	0	72-96
I	6	0	1	0	0	0	>96

Total	91		20		32		
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For cattle, harvesting of young adults was consistent with a focus on meat production (Table 3). The presence on several distal limb bones of pathologies similar to those that develop on draught oxen, coupled with the high proportion of flint sickle blades and sickle blanks (35%) in the lithic assemblage and the presence of several stone circular features, tentatively interpreted as the bases of silos, suggest intensive grain production at Marj Rabba aided by oxen traction (Price et al. 2013).

Table 3. Cattle suggested ages for Halstead's age classes (Halstead 1985). Suggested ages for last four categories: Young Adult = 3-5 years; Adult = 5-10 years; Old = 10-14 years; Senile > 14 years.

Age Class	MNE	% Surviving	Est. Age
A	0	100	0-1 Month
B	1	93	1-8 Months
C	0	93	8-18 Months
D	2	79	18-30 Months
E	5	43	30-36 Months
F	1	36	Young Adult
G	1	29	Adult
H	2	14	Old
I	2	0	Senile
Total	14		

Swine exploitation at Marj Rabba focused on domesticated pigs, with very little or no contribution from wild boar (Price et al. 2013). Mortality data indicate an intensive husbandry system that targeted animals less than one year old (Table 4). The early age at death stands in contrast to other Chalcolithic sites in the Middle East, where the majority

of pigs were slaughtered after eight months of age – e.g., mid-late 4th millennium Hacinebi in southeastern Anatolia (Price 2016: 218), Çamlıbel Tarlası (Bartosiewicz et al. 2013), and “Early Chalcolithic” (late 6th millennium) Tel Tsaf (Ben-Shlomo et al. 2009). Early slaughter potentially indicates a management system designed to raise and fatten pigs quickly, providing pork for the inhabitants of the site on a regular basis.

Table 4. Pig suggested ages for Lemoine et al.’s “simplified-A” age classes (Lemoine et al. 2014: 186).

Age Class	MNE	% Surviving	Est. Age (months)
A	3	94	<1
B	32	30	3-8
C	6	18	8-12
D	6	6	12-16
E	2	2	18-52
F	1	0	52-96
G	0	0	>96
Total	50		

In sum, zooarchaeological, macrobotanical, and material culture records paint a picture of a community balancing its demands for the intensive production of grain and secondary products against an inherited tradition of risk-minimizing herding strategies. It remains ambiguous as to what role, if any, more mobile forms of pastoralism may have played. Similarly, while demographic data from pigs suggest an intensive management system, it is not understood how people at Marj Rabba managed food resources for these omnivores, which provided a sizable portion of the meat consumed at the settlement.

The Environment of Marj Rabba

The Lower Galilee is characterized by steep hills, typically less than 500 masl in height, and lies within the Mediterranean phytogeographic zone (Figure 2). The apex vegetation of this zone is dominated by woodlands/park forests of evergreen oak (*Quercus calliprinos*), deciduous oak (*Quercus ithaburensis*), and terebinth (*Pistacia palaestina*). These and other C₃ plants provide the vast majority of plant biomass, although some C₄ plants are also present (Hartman & Danin 2010). While not extant today, low carbon isotopic values exhibited in aurochsen may indicate moderately dense forests existed in this region in the early Holocene (Makarewicz et al. 2016), although additional isotopic and paleoenvironmental data are needed to more fully explore this hypothesis.

The Galilee, like the rest of the Levant, is characterized by moderate seasonality, with hot and dry summers and cool, moist winters. Today, precipitation falls during the winter and early spring in amounts ranging from 500-1000 mm along an east-west and north-south cline. The highest precipitation levels are found in the north in the Upper Galilee, where elevations reach as high as 1000 masl (Ziv et al. 2014). The area around Marj Rabba, the Lower Galilee, receives around 500-700 mm per year.

During the Chalcolithic, the Mediterranean zone extended further south than at present. The environmental carbon and oxygen isotopic recorded in speleothems from Soreq Cave, located 25 km west of Jerusalem, indicate that the Chalcolithic was somewhat wetter during the Middle Holocene, with a local peak in humidity around 4500 cal. BC (Bar-Matthews & Ayalon 2011). Similarly, Dead Sea pollen cores yielded high concentrations of *Q. calliprinos* and *Q. ithaburensis*; Litt et al. (2012: 100) contend that

this indicates the presence of these oak species further south into the Judean Hills than at present. Isotopic analysis of snail shells dating to the Middle Holocene (c. 6500-3000 uncal. BP) indicates that C₃-dominated plant communities with rainfall above 300 mm/year existed, on average, about 20 km south of their current terminus (Goodfriend 1990).

Marj Rabba's location places it in relatively close proximity to other environmental zones that are markedly different from the Mediterranean vegetation of the Galilee. Today, Sudano-Zambezian vegetation dominates the most southern part of the Jordan River Valley (Danin 2004; Schiebel & Litt 2018). Further north in the *Ghor*, and closer to Marj Rabba, mixed communities of Mediterranean and Saharo-Sudanian vegetation are present, with some flora typically found in an Irano-Turanian zone (Danin 2004). Additionally, the *Ghor*, which is the northern reach of the Great Rift Valley, represents a major depression in the landscape with elevations averaging -200 to -300 m asl. Here, mean rainfall is typically less than 200 mm/year (Ziv et al. 2014; Schiebel & Litt 2018), with C₄ vegetation more prominent below the 300 mm isohyet (Goodfriend 1990). The Saharo-Sudanian and Sudan-Zambezian phytogeographic zones support a higher abundance of C₄ flora, including grasses (Poaceae) and chenopods (Zohary 1982; Danin 1995).

Carbon and Nitrogen Isotope Ecology

Carbon isotopes shed light on plant ecology and, therefore, the diets of the animals who eat them. Several physiological and environmental variables influence floral carbon isotopic composition, including photosynthetic pathway, water availability, and

canopy cover. C_3 plants exhibit low $\delta^{13}C$ values, globally averaging around -26.5‰ , compared to C_4 plants, which average around -12‰ (Smith & Epstein 1971). Under conditions of water stress, plant stomata close to conserve moisture, a process that reduces the conductivity of CO_2 and, consequently, enriches leaf tissue in ^{13}C by as much as 3-6‰ (Stewart et al. 1995; Hartman & Danin 2010). Density of forest canopy cover and light intensity also influences the carbon isotopic composition of grasses, forbs, and arboreal taxa. The combination of decomposing plant litter releasing ^{13}C -depleted CO_2 , the recycling of atmospheric CO_2 , and/or low light levels that reduce photosynthetic rate can lead to a depletion in ^{13}C by as much as 5‰ (Vogel 1978; Van der Merwe & Medina 1991; Bonafini et al. 2013). Isotopic variation in the floral biome is incorporated into herbivore tissues with a roughly +5‰ offset in bone collagen $\delta^{13}C$ values relative to that of dietary intake (Koch et al. 1994).

The nitrogen isotopic composition of plants varies according to plant physiology, aridity, local source nitrogen pools, and plant part so that floral $\delta^{15}N$ values typically vary widely in semi-arid environments. Legumes and other plants that rely on symbiotic nitrogen-fixing bacteria are depleted in ^{15}N compared to those that assimilate nitrogen from non-biological sources, although this pattern can be reversed depending on the ^{15}N composition of the soil (DeNiro & Epstein 1981). Plants growing in hot and arid environments exhibit higher $\delta^{15}N$ values due to the inhibition of biological fixation of atmospheric N_2 – fixation discriminates against the heavier isotope (Bogaard et al. 2007). In the context of the southern Levant, plants in regions that receive around 500 mm/year rainfall, such as the Lower Galilee, are depleted c. 3-5‰ in ^{13}C relative to environments that receive around 200 mm/year, such as the southern Jordan Valley (Hartman & Danin

2010: 845). Finally, floral growth in soils characterized by high nitrogen isotope ratios exhibits higher $\delta^{15}\text{N}$ values (Rennie et al. 1976). Higher soil $\delta^{15}\text{N}$ values can occur due to denitrification (Högberg 1990). On the other hand, the addition of exogenous nitrogen, such as manure, would increase floral $\delta^{15}\text{N}$ values due to the loss of ^{14}N via gaseous ammonia that enriches the soil in ^{15}N (Choi et al. 2006; Bogaard et al. 2007). Different plant tissues also exhibit different nitrogen isotope ratios due to fractionation during the uptake and assimilation of ammonia or nitrate, with progressive enrichment of ^{15}N from roots to stems and leaves to seeds and fruits. Overall, seeds are enriched in ^{15}N about 1-2‰ compared to leaves and stems (Yoneyama et al. 1991; Bogaard et al. 2007).

Animal bone collagen is enriched approximately 3‰ in ^{15}N and 1‰ in ^{13}C for each trophic step up the food chain, with herbivores displaying lower values than omnivores and carnivores (DeNiro & Epstein 1981). Animals ingesting higher amounts of animal protein in their diet display higher $\delta^{15}\text{N}$ values. Similarly, suckling animals are enriched in ^{15}N relative to their mothers since their diet consists entirely of milk (Fogel et al. 1989; Hedges & Reynard 2007).

Methods

A total of 116 animal bones were sampled for carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$) isotopic analysis. Bones were identified on established morphological criteria as belonging to *Ovis aries* (n = 16), *Capra hircus* (n = 12), *Bos taurus* (n = 39), *Sus scrofa* (n = 40), and *Gazella* (n = 9). *Gazella gazella*, the only species of gazelle to inhabit the Galilee today and throughout the Holocene, is a territorial animal than maintains a small

home range (Martin 2000: 22). Gazelle specimens were analyzed in order to characterize the carbon and nitrogen composition of vegetation surrounding Marj Rabba.

Bones were exported to the United States for zooarchaeological analysis, during which time samples were cut using a diamond-tipped Dremel drill at the Zooarchaeology Laboratory at Harvard University. All faunal remains were returned to Israel and are currently stored at the W.F. Albright Institute of Archaeological Research in Jerusalem.

Demineralization was carried out at the Archaeological Stable Isotopes Laboratory at Kiel University. Samples were demineralized in 0.5 M EDTA (pH = 7.5) following Tuross et al. (1988). Demineralized samples were then rinsed seven times in dH₂O, soaked in 0.1 M NaOH overnight at 4°C to ensure removal of any residual humic acids, and then rinsed five more times in dH₂O. Samples were then sent for analysis to the Boston University Stable Isotope Laboratory. Samples were combusted at 1800°C in a Eurovector CN elemental analyzer, with H₂O removed by a chemical trap. They were then introduced into a continuous flow GVI IsoPrime isotope-ratio mass spectrometer. For calibration, ¹³C was calibrated against NBS 20, NBS 21, and NBS 22; ¹⁵N was against atmospheric N₂ and IAEA standards N-1, N2, and N-3. One lab reference (peptone or glycine) was run per 10 samples to ensure machine accuracy and precision. Measurement error on these amino acids was ±0.1‰ for δ¹³C and ±0.4‰ for δ¹⁵N. After the data had been generated, we followed the recommendations of van Klinken (1999) and included for statistical analysis only those collagen samples yielding C/N ratios of 2.9-3.6, %C of 30-47%, and %N of 10-18%.

Results

In total, 77 out of the original 116 samples yielded well-preserved collagen (Supporting Information 1; Table 5; Figure 3). Carbon isotope values for all samples ranged from -21.6 to -14.1‰ , with most specimens yield values between -21.6 and -18‰ indicating that most animals fed in a primarily C_3 biome. Gazelle ($n = 4$) on average $-19.2 \pm 0.9\text{‰}$ in $\delta^{13}\text{C}$ and were isotopically similar to goats ($n = 10$; $-19.4 \pm 0.3\text{‰}$) ($t = .414$, $df = 3.347$, $P = .703$) and sheep ($n = 10$; $-19.9 \pm 1.4\text{‰}$). Removal of a single outlier measuring -16.5‰ resulted in a lower mean value of -20.2‰ for sheep. This was significantly lower than goats ($t = 2.86$, $df = 10.67$, $P = .02$).

Pigs ($n = 29$; $-19.4 \pm 0.7\text{‰}$) were also similar in their carbon isotopic composition to sheep, goats, and gazelle ($t = .571$, $df = 38.782$, $P = .572$). However, cattle ($n = 24$; $-18.6 \pm 1.6\text{‰}$) were significantly enriched in ^{13}C by 0.9‰ compared to all other ruminant species grouped together ($t = 2.73$, $df = 38.87$, $P = .01$). While this average enrichment is modest in magnitude, inspection of the data revealed that cattle exhibited a particularly wide range values (-21.6 to -14.1‰), with one-third of sampled cattle exhibited $\delta^{13}\text{C}$ values $> -18\text{‰}$. These high $\delta^{13}\text{C}$ values contrast with those of the other species, with the exception of the single outlier sheep noted above (Figure 4).

Herbivores from Marj Rabba exhibited relatively low variation in nitrogen isotopes ranging from ca. 5 to 7‰ . Gazelle ($5.6 \pm 0.6\text{‰}$) as well as domesticated goats ($6.0 \pm 0.9\text{‰}$), sheep ($5.9 \pm 1.3\text{‰}$), and cattle ($5.8 \pm 1.1\text{‰}$) exhibited, on average, similar $\delta^{15}\text{N}$ values. A one-way ANOVA revealed no significance differences between the ruminants ($F(3, 44) = .18$; $P = .91$). However, pigs ($7.0 \pm 1.0\text{‰}$) were enriched in ^{15}N by an average of 1.2‰ compared to the combined ruminant species $\delta^{15}\text{N}$ ($t = 4.79$, $df = 60.0$,

$P < .01$). A single outlier displaying a particularly high $\delta^{15}\text{N}$ value of 10.6‰ was from a juvenile pig.

Table 5. Summary statistics of carbon and nitrogen isotopic data from Marj Rabba.

Taxon	N	Mean $\delta^{13}\text{C} \pm 1 \text{ sd}$ (‰)	Mean $\delta^{15}\text{N} \pm 1 \text{ sd}$ (‰)
Bos taurus	24	-18.55 ± 1.56	5.79 ± 1.08
Ovis aries	9	-19.85 ± 1.38	5.93 ± 1.26
Capra hircus	10	$-19.44 \pm .34$	$5.97 \pm .86$
Gazella gazella	4	$-19.23 \pm .90$	$5.60 \pm .56$
Sus scrofa	29	$-19.44 \pm .65$	6.98 ± 1.01

Mobility and Diversified Husbandry Strategies for Sheep, Goats, and Cattle

The carbon isotopic differences between sheep, goat, and cattle indicate dietary differences between these species. Turning first to the small sample of sheep and goats, slight differences in $\delta^{13}\text{C}$ values suggest different dietary preferences or, potentially, the exploitation of different pastures. Notably, goats were isotopically similar to gazelle, which suggests that goats were locally pastured in the vicinity of Marj Rabba as part of a village-based pastoral strategy.

Sheep isotopic data show a different pattern. First, the presence of an outlier with a $\delta^{13}\text{C}$ value of -16.5‰ indicates a diet that included C_4 plants and/or water-stressed C_3 plants. This suggests access to non-local biomes – likely pasturing in the Jordan River Valley, as will be discussed for cattle below. Once, this outlier is removed, sheep are significantly depleted .8‰ in $\delta^{13}\text{C}$ relative to goats ($t = 2.86$, $df = 10.67$, $P = .02$). Sheep tend to consume more graze than browse relative to goats, and while grasses tend to exhibit higher $\delta^{13}\text{C}$ values than browse, annuals can exhibit lower $\delta^{13}\text{C}$ values than shrubs

and trees (Hartman & Danin 2010: Fig 4). Another explanation is that herders took flocks of sheep to moister pastures located at higher elevations during the drier summer months, a scenario consistent with Levy's (1983) hypothesis for seasonal caprine herding in the Chalcolithic Negev. The Upper Galilee, about 20-30 km north of Marj Rabba and where several Chalcolithic sites are located (Shalem 2008), represents the closest location with higher average rainfall. By pasturing sheep on pastures with more abundant vegetation, especially during crucial summer months, herders may have been attempting to improve wool quality or output. Dry seasons and corresponding graze shortages limit exogenous amino acid intake, leading to reductions in wool staple length and fiber diameter (e.g., Liu et al. 1998).

For cattle, the combination of a wide range in carbon isotope values and the high proportion of specimens exhibiting values greater than -18‰ suggest two foddering/pasturing strategies were in use: one in which animals grazed locally, perhaps on field stubble as well as wild vegetation, and another that relied on higher amounts of C_4 graze and, in at least some cases, utilized pastures located in warmer and drier landscapes. One can certainly explain at least some of the isotopic variation in cattle due to grazing these animals on local pastures with a higher relative abundance of C_4 plants. Collection of winter fodder in mixed C_3/C_4 stands might also explain some of the variation. But at least a few of the cattle, along with the outlier sheep, most likely exploited pastures outside the Galilee region. This is especially the case for those exhibiting $\delta^{13}\text{C}$ values greater than -17‰ . Pastures that support higher density of ^{13}C -enriched C_4 plants and water stressed C_3 graze were present in the Jordan Valley some 40km away. Moving cattle down to the Jordan Valley would probably take several days

to one week, based on comparisons with 19th-century cattle drives in the American Southwest (Bell & Haley 1932).

The decision to move cattle from Marj Rabba to the more arid environments that supported less productive pastures may have been linked to the numerous regionally-important settlements located in the Jordan Valley that would have served as hubs of ceremonial activity, exchange, and communication in the Chalcolithic world (Rowan & Golden 2009: 16). Chalcolithic settlements in the Jordan Valley are unusual in that cattle were intensively exploited, demonstrated by the high proportion of *Bos* bones at Pella (30%) and Abu Hamid (33%) (Dollfus et al. 1988; Bourke et al. 2003). Later historical texts from the Levant and beyond depict cattle as valuable commodities that could be given as gifts, dowries, or bride prices, or taken as booty (Arbuckle 2014). Cattle were particularly high-value commodities among the elite from Anatolia to Egypt to Mesopotamia (Arbuckle 2014). Perhaps, then, the settlements in the Jordan Valley served as locations in which people from across the southern Levant met and, among other things, offered cattle as sacrifices, consumed them in feasts similar to the one found at Marj Rabba (Hill et al. 2016), or exchanged them for prestige objects or marital partners. If so, cattle may themselves be considered prestige objects – that is, beings uniquely situated to facilitate exchange in other prestige goods or as gifts accompanying marriage. We can, perhaps, draw rough parallels to the use of cattle among the Tiv, where Bohannan observed them exchanged almost exclusively for brass rods and other prestige goods (Bohannan 1955), or East African groups such as the Nuer, in which cattle function as bride-prices and facilitate many other forms of exchange (e.g., Hutchinson 1992).

Agricultural Intensification and Feeding Pigs

Cross-culturally, pig husbandry strategies vary widely. They include, on one end of the spectrum, free-ranging with minimal human oversight and, on the other, penning reliant on direct feeding by humans with household food refuse and grain fodder. At Marj Rabba, the significant 1.2‰ enrichment in ^{15}N visible in suids to herbivores suggests that pigs accessed either a ^{15}N -enriched plant food or ingested a higher proportion of animal protein in their diets. Interestingly, this pattern of higher nitrogen isotope ratios in pigs at Marj Rabba contrasts sharply with those observed for wild and domestic suids from other sites in the prehistoric Middle East, including Chalcolithic Çamlıbel Tarlası (Pickard et al. 2017), PPNA-PN Çayönü Tepesi (Pearson et al. 2013), and E-MPPNB Nevalı Çori (Lösche et al. 2006), where suids exhibited *lower* mean $\delta^{15}\text{N}$ values than cattle and similar or lower values than sheep/goats. At these sites, zooarchaeologists interpreted these and other data as indications of free-ranging (Lösche et al. 2006; Pearson et al. 2013; Pickard et al. 2017).

One possible explanation for the higher $\delta^{15}\text{N}$ in the Marj Rabba pigs is that they consumed household leftovers (“slop”) that contained at least some animal proteins in the form of dairy, meat, or feces. Alternatively, they may have been able to root for insects and annelids. Several scholars have put forth this as an explanation to account for higher $\delta^{15}\text{N}$ values in pigs (e.g., Hamilton & Thomas 2012; Balasse et al. 2018: 83). Another possible explanation is that pigs consumed large amounts of hardwood nuts, which are high in crude protein. Mast-feeding systems, in which pigs are allowed to pasture seasonally in beech or oak woodlands, are well known from historical and modern

ethnographic data in Europe (Hadjikoumis 2012; Halstead and Isaakidou 2011). The catchment area surrounding Marj Rabba likely included stands of evergreen (*Quercus calliprinos*) and deciduous oak (*Quercus ithaburensis*), both of which produce ripe fruit in the autumn. Ethnohistorical evidence from Greece indicates that acorns, especially of deciduous oak (anecdotally reported to preserve better) may have been collected in the autumn and used for fodder for penned pigs (Halstead and Isaakidou 2011:166).

A third possible explanation for the suid carbon and nitrogen isotopic patterns is that pigs consumed large volumes of grain, which is enriched ca.1-2‰ in nitrogen isotopes compared to other plant tissues (Bogaard et al. 2007). Ingestion of cereals grown in fertilized soils may have also contributed to nitrogen isotopic enrichment in pigs (Bogaard et al. 2007). Grain-feeding pigs as part of an intensive husbandry system would enable pigs to gain weight faster, achieve larger carcasses at slaughter, and produce larger litters (Halstead and Isaakidou 2011:166). Herders committed to creating a large supply of pork frequently devote a substantial portion of agricultural surplus to supporting pig fattening operations. In New Guinea, many highland villagers raise pigs on diets dominated by sweet potatoes cultivated by humans for the purpose of pigfeed (see Hide 2003: 55-78). Penned “household pigs” in modern Greece are said to consume about as much grain as an adult human (Halstead and Isaakidou 2011:167). Similarly, late 3rd millennium BC texts from Mesopotamia refer to so-called “grain-fed pigs” (šah-hi-a še), animals fattened on oats, bran, dates, and low-quality flour (Lion & Michel 2006; Owen 2006). These texts also document pig feed deriving in part from spent brewing grain, indicating that pig husbandry can complement other food production activities (Lion & Michel 2006: 94).

While grain was unlikely to have been the sole component of pig diets, limited as it is in essential amino acids such as lysine, it may well have been the dominant source of caloric intake. Modern Western farmers typically supplement pig diets with animal-protein additives (fishmeal, bone meal, or whey) and/or soybeans to achieve the full component of amino acids (National Research Council 1998: 17-25). In traditional pig husbandry systems, many herders supplement an essentially vegetarian pig diet with annelids (worms) or insects which are collected for pigfeed (e.g., Hide 2003: 57) or whey protein leftover from dairy production (Halstead and Isaakidou 2011:167). Nevertheless, animal protein, while highly variable, typically constitutes a small proportion of pig diet (c. 10% or less by dry weight). Moreover, vegetarian pig diets are possible as long as they contain high enough concentrations of essential amino acids (e.g., from legumes). Fully vegetarian diets have been shown to result in similar growth and carcass performance (Liesegang et al. 2002).

The isotopic data are not sufficient to test between these different hypotheses. It remains possible, perhaps likely, that pig herders at Marj Rabba pursued all three strategies: meat/milk supplemental feeding, acorn harvesting, and grain-foddering. Unfortunately, additional isotopic tests on seeds, which could test the grain-feeding hypothesis, are not possible given the low abundance and poor preservation of botanical remains at Marj Rabba (Graham 2018). The zooarchaeological and archaeological data, however, offer potential support to the grain-feeding hypothesis. Namely, the focused slaughter of 3-8-month-old pigs at Marj Rabba points to an intensive husbandry regime in which pigs achieved slaughter weight by the autumn or winter. Foddering with grain would allow pigs to grow and fatten quickly, reaching slaughter weight more quickly.

Grain production appears to have been intensive at Marj Rabba. This is attested to by the abundance of sickle blades and blanks in the lithic assemblage and the presence of several circular architectural evidence interpreted as silos.

If grain foddering was a central component of pig husbandry at Marj Rabba and in the Levant more widely, it might explain why pig husbandry declined in the Bronze Age. Sheep, goats, and cattle contributed secondary products and, at least by the Late Bronze Age, embodied wealth (e.g., Sapir-Hen 2019). The investment of grain resources in pig husbandry, which would not produce wealth, may have fallen out of favor. The use of grain as a commodity may also have redirected attention away from pig husbandry (Redding 1992). Thus, the transformation of pigs into a meat source in competition with wealth production may explain why swine declined in the importance in the southern Levant during the Early Bronze Age, despite the long tradition of pig husbandry in that region.

Security, Mobility, and Contradiction in Chalcolithic Economies

The isotopic data from the animals at Marj Rabba reveal several dietary patterns that, when compared to standard zooarchaeological datasets, enrich our understanding of Chalcolithic livestock production in the Galilee. For one, the $\delta^{13}\text{C}$ data suggest that while goats were raised in the environs of the site, herders took at least some sheep to pasturelands in the Jordan Valley and, potentially, the Upper Galilee. If so – and we stress the need for additional testing based on larger sample sizes – this differential treatment of sheep, when viewed alongside the demographic data, suggests that Chalcolithic herders adopted somewhat more specialized herding strategies to increase

the output of wool. This can be viewed as a small step on the road to more intensive fiber production in the Early Bronze Age.

The unexpectedly high $\delta^{13}\text{C}$ values in about a third of the cattle remains and one sheep indicates unique foddering/pasturing strategies. At least some cattle spent significant time in the Jordan Valley. While mobile sheep/goat husbandry has already been hypothesized for the Chalcolithic (Levy 1983), mobile cattle husbandry has not been previously considered as part of agro-pastoralist management strategies. Why move cattle? We suspect the reason may have to do with their connection to elite prestige. In other words, similar to ivory, copper, and stone maceheads cattle may have been another prestige good exchanged between, and desired by, emerging elites or ritual leaders. As embodiments of wealth, it is not hard to imagine that keeping these animals fed, exchanging them with other communities for goods or people, and even rustling herds from other villages may have made cattle some of the most mobile elements of the Chalcolithic animal economy.

While cattle, sheep, and goats would continue to play vital roles in southern Levantine economies, the role of pigs would diminish during the Early Bronze Age (Allentuck 2013). Further data are needed to test between different hypotheses for pig feeding regimes in the Chalcolithic. However, if grain-foddering was a regular feature of pig husbandry in the Levant, it might help explain the decline of swine husbandry in the Early Bronze Age. That is, if pig husbandry increasingly became reliant on cereal fodder, it would have found itself in competition both with efforts to produce large surpluses of grain and the foddering of other animals. In this new mode of production based on animal wealth, cereal-foddering of pigs may have become a contradictory element of the animal

economy. Additionally, pigs, lacking secondary products, could not possess the level of value that sheep, goat, cattle or grain could. Thus restricted from the sphere of commodities, pig husbandry became a victim of the secondary products revolution.

Figure Captions

Fig. 1 Map of the southern Levant showing sites mentioned in text and modern cities.

Fig. 2 Map of environmental vegetation zones of the southern Levant. Redrawn from Schiebel & Litt (2018:579). **M** = Mediterranean; **IT** = Irano-Turanian; **SA** = Saharo-Arabian; **S** = Sudano-Zambesian. Mixed zones indicated by sub-dominant vegetation type in parentheses (e.g., **SA(M)** = Sudano-Zambesian dominant with Mediterranean).

Fig. 3 Carbon and nitrogen isotopic data for animals from Marj Rabba. Star-shaped icons and black lines indicate mean $\pm$ one standard deviation for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values for each taxon.

Fig. 4 K-Means Clustering of carbon and nitrogen isotopic data from cattle from Marj Rabba, using `kmeans()` function in R with $k = 2$. Star-shaped icons and black lines indicate mean $\pm$ one standard deviation indicate calculated means of the two groups.

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Appendix. Isotopic data from Marj Rabba. Shaded cells not included in analysis due to poor collagen preservation. For mandibles, only bone was sampled. Note: MC34 = Metacarpal 3-4, MT34 = Metatarsal 3-4, MP34 = Metapodial 3-4.

Lab ID	Taxon	Locus	$\delta^{13}\text{C}$	%C	$\delta^{15}\text{N}$	%N	C/N*	Element	Age Info.**
13368	Bos	111 A	-20.1	35.8	4.6	13.0	3.2	Ilium Shaft	
12936	Bos	121 A	-21.6	36.3	4.7	12.7	3.4	MC34 Shaft	
15524	Bos	322 B	-17.6	36.8	5.0	13.6	3.2	Thor. Vert.	
11170	Bos	304 B	-20.0	37.4	5.8	14.1	3.1	Calcaneus	
11355	Bos	318 B	-16.8	37.4	6.6	14.5	3.0	Humerus Shaft	
11075	Bos	312 B	-17.1	37.7	7.2	14.4	3.1	Mand. w/o Teeth	
11088	Bos	312 B	-17.5	38.2	5.6	14.1	3.2	Ds. Radius	Fused
12694	Bos	119 A	-18.3	38.3	4.8	14.6	3.1	Tibia Shaft	
15305	Bos	312 B	-19.6	38.3	4.5	14.4	3.1	Ds. Radius	Unfused
12235	Bos	166 A	-19.6	38.4	5.6	14.5	3.1	Humerus Shaft	Fused (Ds.)
14241	Bos	353 B	-18.6	38.6	6.1	14.6	3.1	Mand. w/o Teeth	Unfused
11001	Bos	314 B	-19.2	38.9	5.2	14.9	3.1	MP34 Shaft	

11192	Bos	312 B	- 14. 1	39.0	8.9	15. 0	3.0	MP34 Shaft	
14232	Bos	360 B	- 19. 4	39.4	5.9	15. 0	3.1	Px. Radius	Fused
12487	Bos	556 C	- 19. 5	39.5	6.3	14. 7	3.1	MC34 Shaft	
12487 (rep.)	—	—	- 18. 2	40.4	5.9	15. 2	3.1	—	
14551	Bos	385 B	- 17. 0	39.9	5.3	14. 7	3.2	Ds. Humerus	Fused
14405	Bos	375 B	- 18. 8	40.1	7.0	15. 6	3.0	Ds. Radius	Unfused
14321	Bos	NA	- 20. 5	40.3	4.3	15. 5	3.0	Humerus Shaft	Fused
11321	Bos	314 B	- 17. 3	40.4	6.2	15. 4	3.1	Humerus Shaft	
12237	Bos	321 B	- 17. 5	40.6	4.7	15. 3	3.1	Thor. Vert	
10237	Bos	322 B	- 19. 8	40.6	7.2	15. 8	3.0	MT34 Shaft	
14029	Bos	364 B	- 18. 3	40.7	6.4	15. 3	3.1	MT34 Shaft	Fused
12486	Bos	556 C	- 18. 8	42.7	5.2	16. 3	3.0	MC34 Shaft	
11784	Capr a	385 B	- 19. 3	37.7	6.2	14. 5	3.0	Ds. Tibia	Fused
12742	Capr a	121 A	- 19. 1	37.8	5.5	14. 1	3.1	Ds. Humerus	Fused
10295	Capr a	323 B	- 19. 2	38.1	4.4	14. 3	3.1	Ds. Humerus	Fusing
10116	Capr	319	-	39.0	6.0	14.	3.1	Ds. Tibia	Fused

	a	B	19.1			9			
13444	Capra	107 A	- 19.9	39.1	6.7	15.1	3.0	Px. Radius	Fused
13203	Capra	117 A	- 19.5	39.7	4.8	15.3	3.0	Ds. Humerus	Fused
10443	Capra	314 B	- 19.0	40.0	6.5	15.4	3.0	Ds. Humerus	Fused
11099	Capra	314 B	- 19.7	40.2	7.1	15.7	3.0	Ds. Humerus	Fused
13351	Capra	107 A	- 19.9	40.2	5.9	15.6	3.0	Ds. Humerus	Fused
12613	Capra	556 C	- 19.7	40.4	6.6	15.8	3.0	Radius Shaft	Fused (Px.); Unfused (Ds.)
11463	Gazella	316 B	- 20.1	38.0	6.4	13.7	3.2	Ds. Humerus	Fusing
11340	Gazella	318 B	- 18.5	40.1	5.4	15.4	3.0	MT34 Shaft	
10214	Gazella	318 B	- 19.9	40.2	5.5	15.4	3.0	Ds. Tibia	Fused
13389	Gazella	109 A	- 18.4	40.2	5.1	15.8	3.0	MC34 Shaft	
13897	Ovis	378 B	- 21.3	30.8	4.0	11.0	3.3	Ds. Humerus	Fused
14065	Ovis	365 B	- 16.5	36.5	8.8	13.7	3.1	Ds. Tibia	Fused
13373	Ovis	111 A	- 21.2	36.9	5.7	12.7	3.4	Px. Radius	Fused
12674	Ovis	575 C	- 20.1	37.1	7.0	14.3	3.0	Px. Radius	Fused
13586	Ovis	331 B	- 20.	38.8	5.3	14.9	3.0	Ds. Humerus	Fused

			4						
13778	Ovis	366 B	- 19. 7	39.1	6.0	15. 0	3.0	Ds. Tibia	Fused
13778 (rep.)	—	—	- 19. 6	39.8	5.9	15. 2	3.1	—	—
13537	Ovis	331 B	- 20. 6	39.5	5.5	15. 0	3.1	Ds. Humerus	Fused
13006	Ovis	113 A	- 18. 9	39.5	5.2	15. 5	3.0	Px. Radius	Fused
14592	Ovis	554 C	- 20. 2	40.0	5.9	15. 4	3.0	Ds. Humerus	Fused
11909	Sus	179 A	- 20. 4	29.7	6.2	10. 9	3.2	Max. w/ Teeth	dP4 & M1 in wear
11800	Sus	385 B	- 19. 1	31.7	6.5	11. 7	3.2	Max. w/ Teeth	M2 in wear
12906	Sus	117 A	- 19. 4	32.8	6.3	12. 6	3.0	Frontal	
ASIL771 9	Sus	43	- 19. 6	33.6	6.9	12. 8	3.1	Mand. w/ Teeth	Age Class 7; 30-52 months
10273	Sus	325 B	- 19. 4	34.0	8.1	13. 0	3.0	Mand. w/ Teeth	Age Class 1; <1 month
14215	Sus	359 B	- 18. 3	35.1	8.5	13. 3	3.1	Max. w/ Teeth	dP4 & M1 in wear
12705	Sus	554 C	- 21. 2	35.1	10.6	13. 2	3.1	Max. w/ Teeth	Age Class 3; 6-8 months
13886	Sus	332 B	- 18. 9	36.6	7.4	13. 9	3.1	Maxilla	M3 in wear
14033	Sus	364 B	- 19. 9	36.8	6.6	13. 9	3.1	Px Ulna	
14353	Sus	352 B	- 19. 4	37.5	5.9	14. 3	3.1	Mand. w/ Teeth	Age Class 5; 12-16 months

14668	Sus	351 B	- 19. 0	37.7	7.4	14. 3	3.1	Mand. w/ Teeth	Age Class 2- 3; 3-8 months
14534	Sus	554 C	- 20. 4	37.8	6.4	14. 7	3.0	MC4 Shaft	
11145	Sus	310 B	- 18. 9	38.1	6.3	14. 7	3.0	Ph2	Unfused
14400	Sus	375 B	- 19. 2	38.2	7.0	14. 5	3.1	Mand. w/ Teeth	Age Class 5- 7; 12-30 months
13189	Sus	110 A	- 19. 1	38.5	7.1	14. 2	3.2	Px. Radius	Fused
12672	Sus	575 C	- 18. 6	38.5	6.9	14. 7	3.1	Ds. Scap.	Fused
13202	Sus	100 A	- 19. 6	38.6	6.5	14. 8	3.1	MC4 Shaft	Unfused
14137	Sus	362 B	- 20. 1	38.8	5.2	14. 7	3.1	Px Ulna	Unfused
13007	Sus	113 A	- 20. 7	38.9	7.3	15. 1	3.0	Mand. w/ Teeth	Age Class 3; 6-8 months
10438	Sus	314 B	- 19. 1	38.9	7.8	14. 7	3.1	Ds. Humerus	Fused
12671	Sus	575 C	- 19. 7	39.1	6.9	15. 0	3.1	Ds. Scap.	Fused
14708	Sus	356 B	- 19. 4	39.1	8.3	15. 3	3.0	Ds. Radius	Unfused
13194	Sus	100 A	- 18. 8	39.2	6.4	15. 0	3.1	Ds. Humerus	Fused
10115	Sus	322 B	- 19. 2	39.3	7.1	15. 0	3.1	Max. w/ Teeth	dP4 & M1 in wear
12365	Sus	168 A	- 19. 3	39.3	6.5	15. 3	3.0	Max. w/ Teeth	dP3 & dP4 in wear
14096	Sus	364	-	39.5	6.9	15.	3.0	Ds. Radius	Unfused

		B	19.0			3			
12603	Sus	556 C	- 19.1	39.5	6.9	14.9	3.1	Ds. Radius	Unfused
12066	Sus	176 A	- 18.9	39.6	6.7	15.2	3.1	Mand. w/ Teeth	Age Class 3; 6-8 months
12545	Sus	557 C	- 20.1	39.3	5.7	14.6	3.2	Ds Scap	Unfused
13435	Bos	110 A	- 25.0	12.0	5.4	3.1	4.6	Ilium Shaft	Unfused
110426	Bos	312 B	- 20.4	24.4	6.6	8.8	3.2	Calcaneus	Fused
12096	Bos	375 B	- 19.1	28.5	6.0	11.0	3.0	Ds. Humerus	Fusing
12933	Bos	121 A	- 25.0	31.4	5.1	6.6	5.5	Mand. w/ Teeth	Wear Stage 26-27; 2-3 years
12749	Bos	121 A	- 24.1	31.9	5.9	8.2	4.5	MC34 Shaft	
14394	Gazelle	352 B	- 22.8	37.8	5.6	11.4	3.9	Ds. Tibia	Fused
ASIL7808	Sus	927	- 19.9	15.4	7.0	5.8	3.1	Max. w/ Teeth	dP4 & M1 in wear, M2 erupting
ASIL7740	Sus	9	- 19.8	20.2	7.0	7.4	3.2	Mand. w/ Teeth	Age Class 3-4; 6-12 months
ASIL7735	Sus	161 A	- 19.7	22.3	6.9	8.5	3.1	Max. w/ Teeth	M2 in wear
ASIL7720	Sus	19	- 21.0	27.5	6.7	10.3	3.1	Mand. w/ Teeth	Age Class 3; 6-8 months
13037	Sus	110 A	- 25.9	28.8	5.4	9.1	3.7	Mand. w/ Teeth	Age Class 3; 6-8 months

*C/N reported as atomic ratio

** When applicable, age classes used for *Sus* mandibles following Lemoine et al.'s (2014) "specific system"; Grant (1982) used for *Bos*.

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