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The Southern Levantine pig from domestication to Romanization: A biometrical approach

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ABSTRACT

Zooarchaeological research has begun to expose the long and complex history of the pig in the southern Levant. In this paper, we present the first large-scale synthesis of biometrical data from pigs and wild boar in the southern Levant from sites dating from the Paleolithic through the Islamic period. We show broad morphological change over this multi-millennium period. We find the first evidence of morphological change associated with domestication in the Pre-Pottery Neolithic C (c. 7000-6400 cal. BC), at the site of Motza. This date is contemporaneous with the first evidence from kill-off patterns and relative abundance data indicating management of morphologically wild boar. Taken together, we argue for a process of local pig domestication. We also present tentative evidence for increased body size correlating with the genetic replacement in the Iron Age, when European-derived mitochondrial haplogroups replaced those of local origin. Finally, the data indicate variability in tooth size in the Roman period (c. 63 BCE – 330 CE), suggesting the exploitation of different populations of pigs. The data suggest sophisticated management techniques underwrote the upsurge in pig husbandry in the Levant in the Classical period.

1. Introduction

Today subject to powerful taboos in Judaism and Islam, pigs have experienced one of the more unusual trajectories among southern Levantine domesticates and have long attracted zooarchaeological attention. Zooarchaeologists have tended to focus on the domestication of pigs in the Neolithic (Haber and Dayan, 2004; Horwitz et al., 1999; Kusatman, 1991; Makarewicz, 2016; Marom and Bar-Oz, 2013; Munro et al., 2018) or the development of the pig taboo in the Iron Age (Faust, 2018; Hesse and Wapnish, 1997; 1998; Horwitz et al., 2017; Lev-Tov, 2000a; Price, 2022; Sapir-Hen et al., 2015; Sapir-Hen, 2018). Beyond domestication and taboo, there are other important episodes in pig-human relations in the southern Levant. They include a “genetic turnover” in mitochondrial DNA around 3000 years ago. Some have connected this genomic pattern to the development of the pig taboo: they argue that the arrival of exogenous suid mitochondrial lineages relates to the settling on the southern coast of (pork-eating) Philistines, a people identified in the Hebrew Bible as inveterate enemies of the (pork-avoiding) Israelites (Meiri et al., 2013, 2017). Another important change in the human-pig relations in the region was the institution of Roman political control and cultural domination, sometimes referred to as “Romanization.” This historical period coincided with an upsurge in pig husbandry, especially in military sites and settlements associated with Greek-speaking populations (Horwitz and Studer, 2005; Price, 2021, pp. 142–169).

In this paper, we present on biometrical data to reconstruct pig size and morphology in the southern Levant from the Paleolithic to the Islamic period. The data, collated from publications and collected in the course of our individual analyses of southern Levantine faunal assemblages, are based on linear measurements of bones and teeth taken with calipers. Such data are of great value to zooarchaeologists. Not only are the data relatively simple to collect and marked by limited rates of intersubjective error when standards (e.g., Payne and Bull, 1988) are followed, but they also directly relate to aspects of human-animal relations such as domestication, population turnover, breed improvement, sex-related culling patterns, among others (e.g., Albarella, 2002; Aniceti and Albarella, 2022; Harding et al., 2023; MacKinnon, 2023; Payne and Bull, 1988; Slim et al., 2020; Trentacoste et al., 2021; Wolfhagen, 2023).

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While we present the data in its entirety, spanning the Pleistocene to the Islamic period, and attend to the issue of long-term morphological change, we focus on three questions: 1) When do we see the first biometrical evidence for domestic pigs in the southern Levant and was the process endogenous? 2) Did the genetic turnover c. 3000 years ago correspond with changes in pig size? 3) How did pig morphology change in the Roman period, when pigs served as a major food source for legionnaires, Greek-speaking urbanites, and others in the region?

2. A brief history of swine: the southern levantine perspective

The story of pigs in the southern Levant (Fig. 1) is long and complex (Price, 2021). And while we will focus on the three processes outlined above, it is important to provide some context to these "moments" in human-pig relations. Much of the following history of pigs has been gleaned from relative abundance data (NISP); our biometrical data will provide further insights into these processes.

Wild boar hunting gave way to domestic pig husbandry towards the end of the Pre-Pottery Neolithic, somewhat later than that of other domesticates. Goat herding began in the MPPNB, and was joined by domestic sheep and perhaps cattle management by the LPPNB (Makarewicz and Tuross, 2012; Marom and Bar-Oz, 2013; Munro et al., 2018). At some point, swine management was added to the mix and morphologically domestic pigs first appear in the archaeological record. There is debate about how and when, exactly, this process took place. Some argue that the first morphologically domestic pigs can be dated to the PPNC (Makarewicz, 2016; Munro et al., 2018); others push for a date in the LPPNB (Marom and Bar-Oz, 2013) or even earlier (Helmer and Gourichon, 2008). It remains unclear if the southern Levant's first pigs were domesticated locally or were instead imported from northern Mesopotamia, where pigs were first domesticated around 8000-7500 cal. BC (Ervynck et al., 2001; Price and Hongo, 2020).

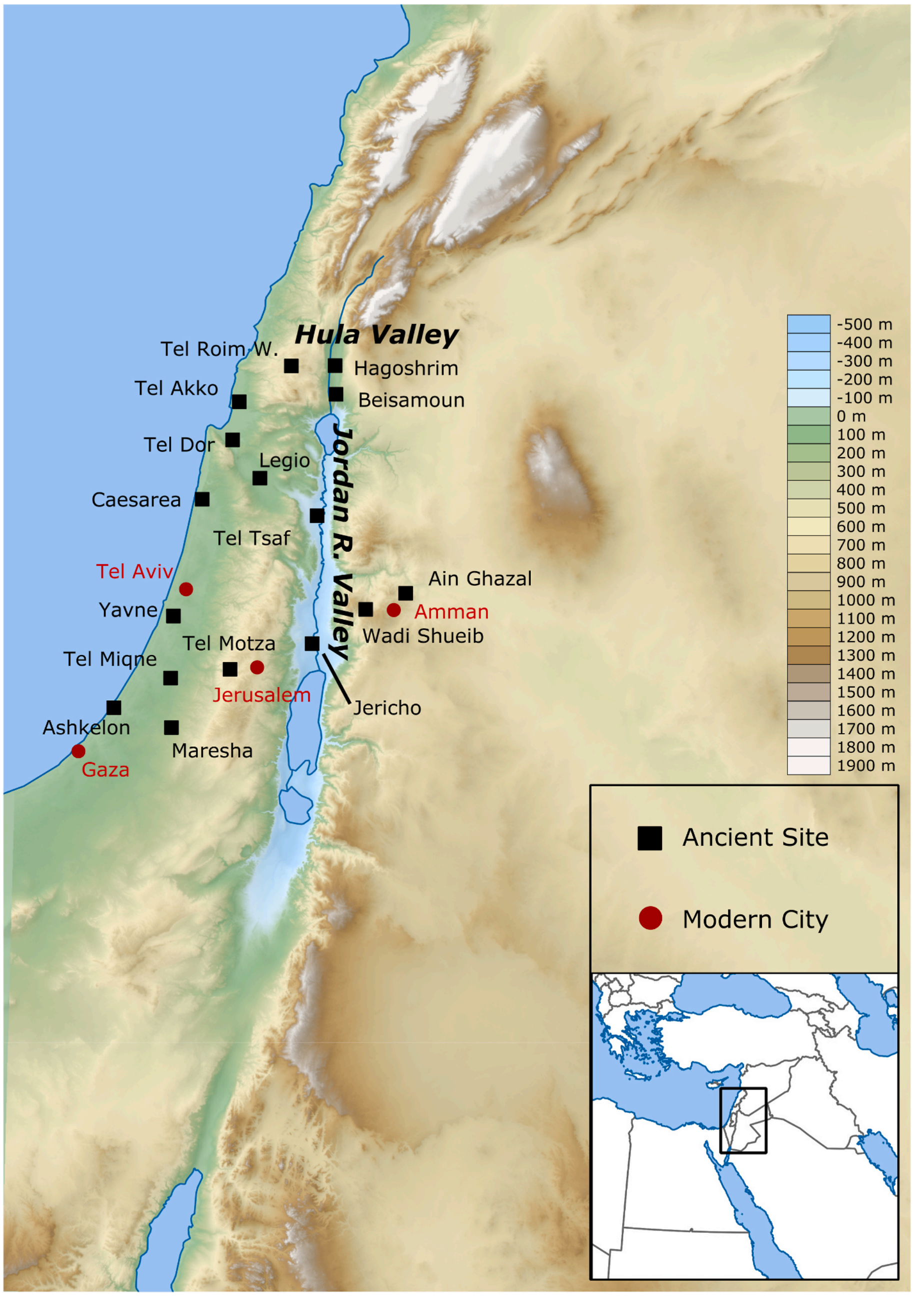

Fig. 1. Map of the region with sites mentioned in the text.

By the Late Neolithic, domestic pigs were an important feature of the southern Levantine agropastoral "package," particularly in the Mediterranean zone of northern Israel/southern Lebanon and in the Jordan River Valley. The marshy Hula Valley (Fig. 1), in particular, was a location where pork long played an important dietary role. But for reasons that remain unclear, the relative importance of pig husbandry declined in the southern Levantine diet over the Bronze Age. By the beginning of the Late Bronze Age (c.1600 BCE), *Sus* bones and teeth represent up to 5% or less of the total NISP of fauna at almost every southern Levantine site. Many if not most of the Late Bronze *Sus* remains derive from large-sized individuals, consistent in morphology with wild boar, not domestic pigs (Price, 2021, p. 74).

Modest amounts of morphologically domestic pig remains (c. 10–20% of NISP) in the Iron Age at sites located near modern-day Gaza have long invited contemplation of the biblical Philistines and their ostensible predilection for pork (although their affinity for pigs is nowhere referenced in the Hebrew Bible) as opposed to the Israelites, the cultural forebearers of the Jews, and their emerging taboo on pork (Faust, 2018; Hesse and Wapnish, 1998; Horwitz et al., 2017; Lev-Tov, 2000a; Price, 2021; Sapir-Hen et al., 2015). In addition, mitochondrial aDNA shows that by the Iron II period (c.950–600 BCE), local populations of domestic pigs had been largely replaced by European-derived ones (Meiri et al., 2013, 2017). This is, in fact, a pattern seen across the Near East, one tentatively linked to changes in pig molar morphology (analyzed via geometric morphometrics), namely the shortening of the distal cusp of the third molar and the relative (though not absolute) widening of that tooth's shape (Ottoni et al., 2012). Beyond the potential shape change in suid dentition, the phenotypic implications of this widespread genetic turnover remain unclear.

A third important change in human-suid relations accompanied the Roman annexation of Judea in 63 BCE, which brought Greek-speaking colonists and Roman legionnaires to the region. Pork was a celebrated feature of the Roman diet (Rosenblum, 2010). In marked contrast to the previous three millennia defined by declining NISP and the development of a taboo on pork, pig relative abundances shot up across the southern Levant (Horwitz and Studer, 2005) and the Near East more generally (King, 1999). Pigs would remain a major feature of the diet in the southern Levant through the Byzantine period (Kroll, 2012), declining only with the Muslim conquest in the 7th century AD. While the uptick in pig husbandry has been documented with NISP data, we know little about the morphology of pigs in this period, nor how they were raised.

2.1. *Morphological variation in pigs*

Biometrical data provide an important source of information on evolving human-suid relations. In the first place, biometrical data are relatively easy to collect and part of the standard zooarchaeological analytical protocol. Many data are therefore available in the literature. Biometrical data are also valuable because they reflect important aspects of suid population structures. Sex, age, and population (e.g., wild vs domestic) form important components of biometrical variation in suid bones and teeth (Payne and Bull, 1988).

In terms of sexual size dimorphism, piglets of both sexes are of equal size at birth and remain so through the first year of life (Moretti, 1995). After that point, males grow faster than females and by the beginning of their third year weigh 25–40% more than females, with most of this additional body mass concentrated in the front of the body (Payne and Bull, 1988; Price and Hongo, 2020, p. 568). Bone measurements from Payne and Bull (1988) indicate a c.7% difference in distal limbs between males and females. The difference in the forelimbs is more pronounced at 8–12% (Table 1). And while males possess continuously growing and much larger canines than females, post-canine teeth show little sexual size dimorphism (1–4%) (Table 1; see also Zeder and Lemoine, 2020). Age-related effects are also important to consider. Although this study used only fused bones, post-fusion growth does occur, sometimes over 10% (Payne and Bull, 1988, p. 30). Among teeth, molar lengths with age decrease as a result of interstitial wear (Evin et al., 2013; Zeder and Lemoine, 2020). Dental breadths, however, do not change.

Table 1
Sexual dimorphism in select measurements of molars and upper and lower limbs of wild boar from Turkey and Israel, excluding very young animals (Payne and Bull's Age Class 1). All animals older than ca. 19 months. Bp = proximal breadth; Bd = distal breadth; GLl = greatest length of lateral side; HTC = diameter of trochlear constriction. WA = anterior molar breadth.

Measurement	Female mean ± 1 sd (mm)	Male mean ± 1 sd (mm)	% Difference of Means
Turkish Wild Boar Postcranial Bones			
Humerus Bd	45.3 ± 2.1 (N = 11)	49.4 ± 2.0 (N = 4)	9.1%
Humerus HTC	20.9 ± .5 (N = 11)	23.0 ± .9 (N = 4)	10.0%
Radius Bp	31.8 ± 1.1 (N = 11)	34.9 ± 1.5 (N = 4)	9.7%
Tibia Bd	31.9 ± .7 (N = 11)	34.4 ± 1.5 (N = 4)	7.2%
Astragalus GLl	46.9 ± 1.5 (N = 11)	50.2 ± 1.9 (N = 4)	6.5%
Turkish Wild Boar Molars			
Lower M1 WA	11.2 ± .4 (N = 21)	11.6 ± 1.2 (N = 21)	3.6%
Upper M1 WA	15.2 ± .7 (N = 24)	14.9 ± .6 (N = 23)	2.0%
Lower M2 WA	15.0 ± .6 (N = 20)	15.5 ± 1.4 (N = 19)	3.3%
Upper M2 WA	19.2 ± .9 (N = 23)	19.4 ± .8 (N = 22)	1.0%
Lower M3 WA	17.9 ± .9 (N = 8)	18.3 ± .7 (N = 14)	2.2%
Upper M3 WA	21.2 ± 1.0 (N = 11)	22.0 ± .9 (N = 14)	3.8%
Israeli Wild Boar Molars			
Lower M1 WA	10.9 ± .4 (N = 54)	10.9 ± .5 (N = 46)	0.0%
Upper M1 WA	14.4 ± .4 (N = 48)	14.6 ± .7 (N = 47)	1.4%
Lower M2 WA	15.0 ± .6 (N = 36)	15.2 ± .7 (N = 41)	1.3%
Upper M2 WA	18.8 ± .8 (N = 33)	19.2 ± 1.1 (N = 40)	2.1%
Lower M3 WA	17.8 ± .8 (N = 19)	18.4 ± .8 (N = 30)	3.4%
Upper M3 WA	21.0 ± .8 (N = 21)	21.9 ± 1.2 (N = 38)	4.3%

Data: Molars: Turkey (Kusatman, 1991, p. 93), Israel (Kusatman, 1991, p. 95). Postcrania: (Payne and Bull, 1988).

There are some important limitations to a biometrical study of this scope, which relies on a large dataset of published measurements and measurements taken directly by the three authors in different projects. First, while measurement standards (e.g., Driesch, 1976; Payne and Bull, 1988) provide protocols for replicable data collection, inter-observer error remains a potential issue, one that has not been studied adequately. A second issue relates to uneven sample size and representation. Certain sites and periods have much larger collections of measurements. In particular, suid metrical data tend to be under-published from sites post-dating the Neolithic — likely a symptom of the implicit assumption that biometrical data are most useful/interesting in documenting domestication. For example, we have no biometrical data from the Persian period. Some periods are represented by single sites, thus allowing perhaps a handful of archaeological contexts to speak for several centuries of pig-human relations.

These issues notwithstanding, the biometrical data offer unique insight into human-pig relations over time. Dental metrics are particularly useful. Generally speaking, postcranial bones vary more by age and sex than post-canine teeth. Teeth measurements do not vary much by age and sex; they also tend to be heritable. Dental metrics are thus a reliable indicator of population (Albarella and Payne, 2005; Payne and Bull, 1988). That said, the conclusions reached here, especially for under-represented periods such as the Roman period, should be treated as a first glimpse into what is likely a more complex situation.

2.2. *Materials and methods*

Biometrical data were collected from faunal assemblages from archaeological sites in Israel and Jordan that date to the Pre-Pottery Neolithic B through the Byzantine period (Table 2). We focused on molar breadth metrics (WA and WP) (Payne and Bull, 1988). These measurements provide a good proxy for metrical variation within a

Table 2
Period and sites used in this study. Site names in **bold** indicate collections measured by the authors, whereas non-bolded site names indicate data deriving from the literature review. The superscripts "P" and "T" indicate whether postcrania or teeth were measured. Dates and terminology for Neolithic periods after Goring-Morris and Belfer-Cohen (2020) and (Banning, 2010). See Supplemental Information for raw data and bibliographical references.

Period	Calibrated Date	Sites
Mousterian & Upper Paleolithic	>21 k BC	Kebara^{PT}, Hayonim^{PT}
Kebaran	21 k-15 k BCE	Ein Gev^{PT}
Natufian	15k-9700 BCE	Hayonim^{PT}, Jericho^{T}, Hatoula^{P}
PPNA	9700-?8200 BCE	Gilgal I^{P}, el-Hemmeh^{P}, Jericho^{TP}, Salabiyah^{T}
MPPNB	8200–7500 BCE	Yiftahel^{TP}, **Motza**^{PT}, **Mishmar HaEmeq**^{PT}, Beidha^{P}, **Ain Ghazal**^{PT}, Abu Gosh^{PT}, Munhata^{T}
LPPNB	7500–7000 BCE	Tel Roim West^{PT}, **Ain Ghazal**^{PT}
PPNB (Not Determined)	(8200–7000 BCE)	Ard el Samra ^{PT}, Nahal Betzet^{T}, Tell Aswad^{PT}, Tel Teo^{PT}, Kebara^{P}
PPNC (or FPPNB)	7000–6400 BCE	**Motza**^{PT}, **Hagoshrim**^{PT}, **Ain Ghazal**^{PT}, Shaar Hagolan^{P}, Tel Ali^{P}, Tel Roim West^{P}, Tel Teo^{P}, Wadi Shueib^{P}, Yiftahel^{P}
LN 1 (Yarmoukian)	6400–5800 BCE	Tel Roim West^{PT}, **Mishmar HaEmeq**^{PT}, Nahal Zehora^{PT}, **Ein el Jarba**^{PT}, **Ain Ghazal**^{PT}, Munhata^{PT}, Ard el Samra^{P},
LN 2 (Jericho IX, Lodian)	5800–5500 BCE	**Hagoshrim**^{PT}, Nahal Zehora^{PT},
Wadi Raba	5500–5000 BCE	**Hagoshrim**^{PT}, **Mishmar HaEmeq**^{T}, Munhata^{T}, Nahal Zehora^{PT}, **Ein el Jarba**^{PT}, Amud Hamshal^{PT}, Arjoune^{PT}, Newe Yam^{PT}, Tel Teo^{PT}, Nahal Betzet^{T}, Tell Hreiz^{T}
Middle Chalcolithic	5000–4500 BCE	**Tel Tsaf**^{PT}
Late Chalcolithic (Ghassulian)	4500–3600 BCE	Gilat^{P}, Grar^{P}, Tel Ali^{P}, Tel Teo^{PT}, **Marj Rabba**^{PT}
Early Bronze Age	3600–2500 BCE	Tel Teo^{PT}, **Ein el Jarba**^{T}, Tel Lod^{PT}, Qiryat Ata^{PT}, Horvat Illin Tachtit^{P}, Tel Ali^{P}, Jericho^{P}
Intermediate Bronze Age	2500–2000 BCE	Horvat Rimonim^{PT}
Middle Bronze Age	2000–1600 BCE	**Ashkelon**^{PT}, Jericho^{PT}
Late Bronze Age	1600–1200 BCE	(None)
Iron Age	1200–500 BCE	**Ashkelon**^{PT}, Bet Shemesh^{P}, Tel Miqne/ Ekron^{P}, Tel Dor^{T}
Persian Period	500–333 BCE	(None)
Hellenistic	333–63 BCE	**Maresha**^{PT}, Tel Dor^{PT}, Tel Anafa^{P}
Roman	63 BCE – 330 CE	Tel Anafa^{P}, Tel Dor^{PT}, **Legio**^{PT}, Givaati Parking Lot^{P}
Byzantine	330 CE–636	Nahal Betzet^{T}, **Jerash**^{PT}, Jericho^{P}, Haliuza^{P}
Islamic Period (Umayyad-Abbasid)	63 CE6-c.1000	Nizzana^{PT}, **Yavne**^{PT}, **Jerash**^{PT}
Modern	>1900 CE	(Northern Israel)^{PT}

single population while minimizing the effects of interstitial wear. We also collected a restricted set of postcranial measurements: astragalus GLl, tibia Bd, radius Bp, and humerus HTC, Bd, and BT (Driesch, 1976). We focused on these specific measurements because they are relatively easy to take (and thus replicable between analysts) and frequently available in zooarchaeological assemblages due to the robustness of these elements. These are also the set of measurements recommended by Payne and Bull (1988, pp. 32) for examining population- and sex-related variation as these measurements do not vary much according to age-at-death. This fits with our focus on population-level size changes over time.

To supplement our dataset, we conducted a detailed literature review and recorded measurements published by other researchers. Kusatman's (1991) dissertation provided an invaluable dataset, including around 450 measurements of modern wild boar on specimens she accessed in the Department of Zoology at Hebrew University. Most of these specimens consisted of crania (and thus she collected many more tooth measurements than postcranial ones). By and large, they derived from animals from the Hula Valley and Upper Galilee (Kusatman, 1991, pp. 76–77). The full list of measurements, along with citations, is supplied in the Supplement Information.

Biometrical data were converted into log-size index values, of base 10 (LSI) (Meadow, 1999; Wolfhagen, 2020), using Payne and Bull's (1988, pp. 40–41) standard values, which are based on averages of male and female wild boar from Kizilcahamam, Turkey (see SI). For specimens with more than one measurement, the mean LSI was taken.

For analysis, unfused specimens were excluded and outliers were removed. In this case, outliers included any tooth or bone specimen with an LSI value greater than 0.20 or less than −0.20. Outliers also included 11 unusually small proximal radii measurements reported by Kusatman (1991) that lay four standard deviations below the first quartile and we assumed to be immature individuals, as the proximal radius fuses around 7–8 months of age (Zeder et al., 2015). Also excluded were measurements from mixed contexts or assemblages that could not be securely dated to period. This included a small number of cases for which it could not be determined whether measurements assigned to the "PPNB" referred to MPPNB or LPPNB. Additionally, Kusatman (1991) published a large number of measurements from Beisamoun, but unfortunately lumped those from LPPNB and LN1 deposits together. Due to the chronological mixing of periods relevant to the timing of domestication, Beisamoun's large dataset was excluded from analysis.

All statistical analysis and graphical plotting was conducted in R, using the base package v.4.2.0 (R Core Team, 2022), ggplot2 (Wickham, 2016), and ggdist (Kay, 2022).

3. Results

3.1. *Defining a "confidence zone" for wild boar size*

Most (86%) of the 448 dental measurements taken on modern Israeli wild boar fall above an LSI value of −0.05 and virtually all (>99%) fall above −0.075. The same holds true for tooth measurements of suids recovered from Pleistocene through PPNA deposits (Fig. 2), which average slightly larger (Mean $\text{LSI}_{\text{Pleistocene-PPNA}} = -0.005 \pm 0.023$; Mean $\text{LSI}_{\text{Modern}} = -0.023 \pm 0.024$) We therefore conservatively define −0.075 as the minimum LSI value for wild boar, or the lower end of a wild boar biometrical "confidence zone." Importantly, this does not constitute a concrete metrical barrier between wild and domestic suids; domestic pigs may show LSI values above −0.075, as might hybrids or recently feral populations. The −0.075 LSI should only be understood as the point above which fall 99% of "wild" animals (i.e., those from long-standing free-living populations). But one can argue with a high degree of confidence that tooth specimens bearing LSI values below −0.075 are unlikely to derive from morphologically wild boar.

3.2. *Long-term trends in suid morphology*

Tooth metrical data, presented graphically as LSI boxplots in Fig. 2, show a gradual diminution over time. Much of the morphological change occurred in the first 5000 years of the Holocene until the Late Chalcolithic. During that time, average tooth size declined on average about 14% (Mean $\text{LSI}_{\text{LChalco}} = -0.096 \pm 0.027$; Mean $\text{LSI}_{\text{PPNA-MPPNB}} = -0.029 \pm 0.027$; $t = 12.94$, $df = 51.39$, $p < .001$).

Suid molar size appears to have remained relatively stable from the Chalcolithic onward (Fig. 2).

One source of variation is the continued hunting of wild boar and the paucity of published measurements from certain periods. This causes some variation in the means, with wild-sized specimens "dragging up" the mean in certain periods. To overcome this, we removed specimens

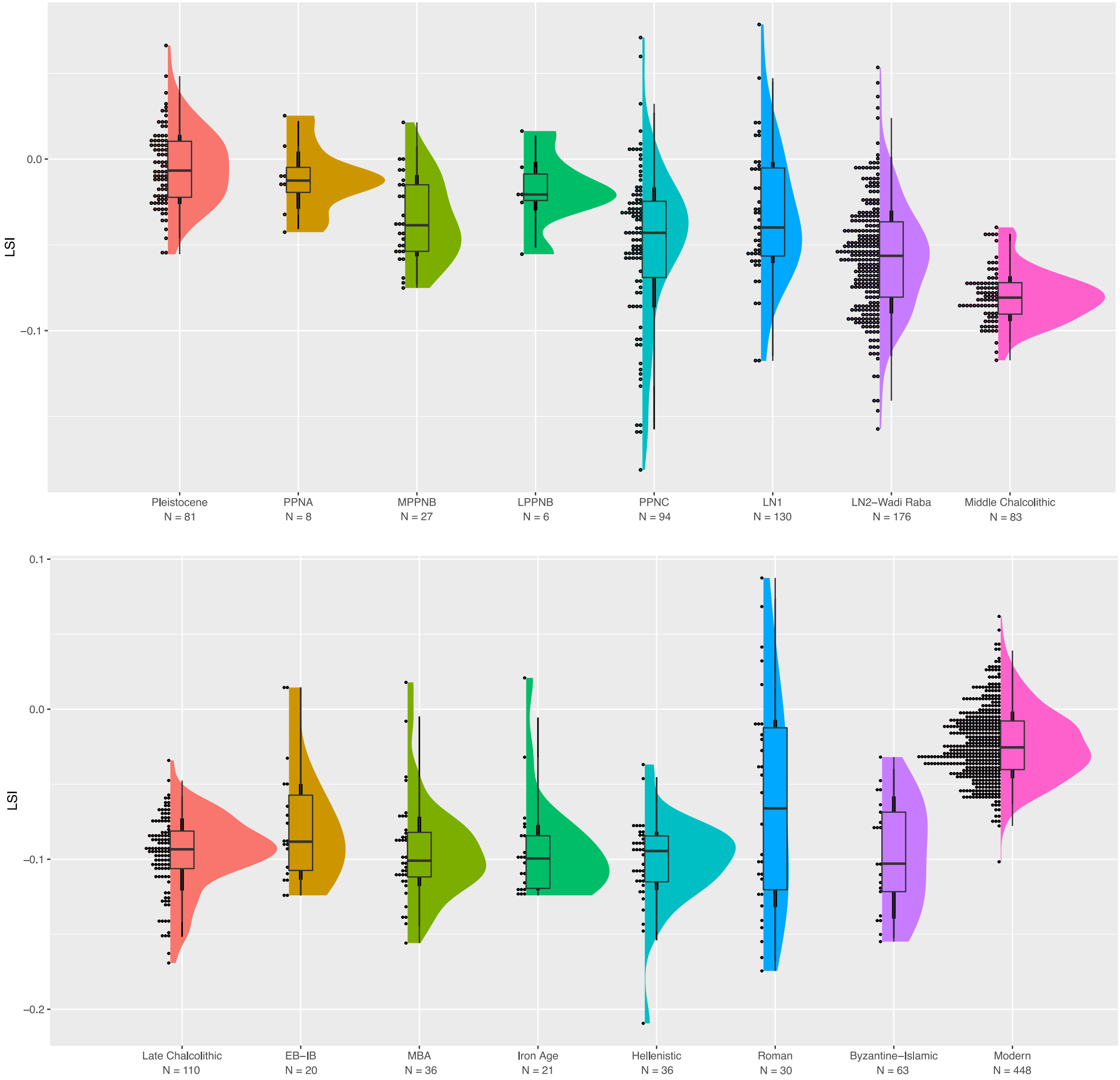

Fig. 2. LSI of tooth breadths (WA and WP) over time.

with LSI > −0.05, a point below which the vast majority of domestic-sized specimens fall and thus can be reasonably suspected of deriving from wild and hybrid individuals. Once done, there is relatively little change between the Late Chalcolithic (Mean LSI = −0.097), EB-IB (mean LSI = −0.096), MBA (mean LSI = −0.103), Iron Age (mean LSI = −0.103), Hellenistic (mean LSI = −0.102), Roman (−0.120), and Byzantine-early Islamic periods (mean LSI = −0.094). Nevertheless, a one-way ANOVA revealed a significant difference over this timespan (F (6,234) = 2.254; P = .039). A Tukey's post-hoc test revealed that the only significant differences (P < .05) were between the Roman and other periods.

Upon closer inspection, the LSI data in the Roman period exhibit a high degree of variance. If specimens > −0.05 are removed, there appears to be a slight dip in tooth size to a mean of −0.120. These specimens were assumed, in other periods, to be largely derived from wild boar. But specimens larger than −0.05 (N = 13) are almost as numerous as those less than −0.05 (N = 17) in the Roman period. If one adds the large-size specimens back in, the mean LSI increases to −0.063, which stands out in a diachronic perspective (Fig. 2). The high variance of the metrical data in the Roman period is a point to which we will return.

Postcranial bone measurements presented greater variance within periods than dental metrics (Fig. 3). This was expected given the greater variation according to age and sex in postcranial measurements. Like teeth, postcranial LSIs show a downward trend in average size over time. The general decline from the Pleistocene (mean LSI = −0.017 ± 0.056) and PPNA-MPPNB (mean LSI = −0.022 ± 0.045) continues until the Late Chalcolithic, at which point the mean LSI is −0.111 ± 0.053 — a 19% reduction. Unlike teeth, postcranial measurements then *increase* in the Hellenistic (mean LSI = −0.059 ± 0.041).

3.3. The first morphologically domestic pigs in the PPNC

The gradual decline in average tooth size in Fig. 2 can make it difficult to pinpoint a particular moment when morphologically domestic pigs first appeared in the archaeological record. Compounding the issue are small sample sizes, geographic variability, and possible variation stemming from different analysts working on separate collections. For instance, the PPNA is represented by only eight tooth measurements collected by Kusatman (1991) from Jericho and Salabiyah, both of which are east of Jerusalem in present-day Palestine. The LPPNB is represented by only six measurements taken by one of us (MP) on teeth from 'Ain Ghazal (near Amman, Jordan) and Said-Agha (2011) on a single tooth from Tel Roim West, which is just to the northwest of the Hula Valley in northern Israel. These issues aside, the PPNA through

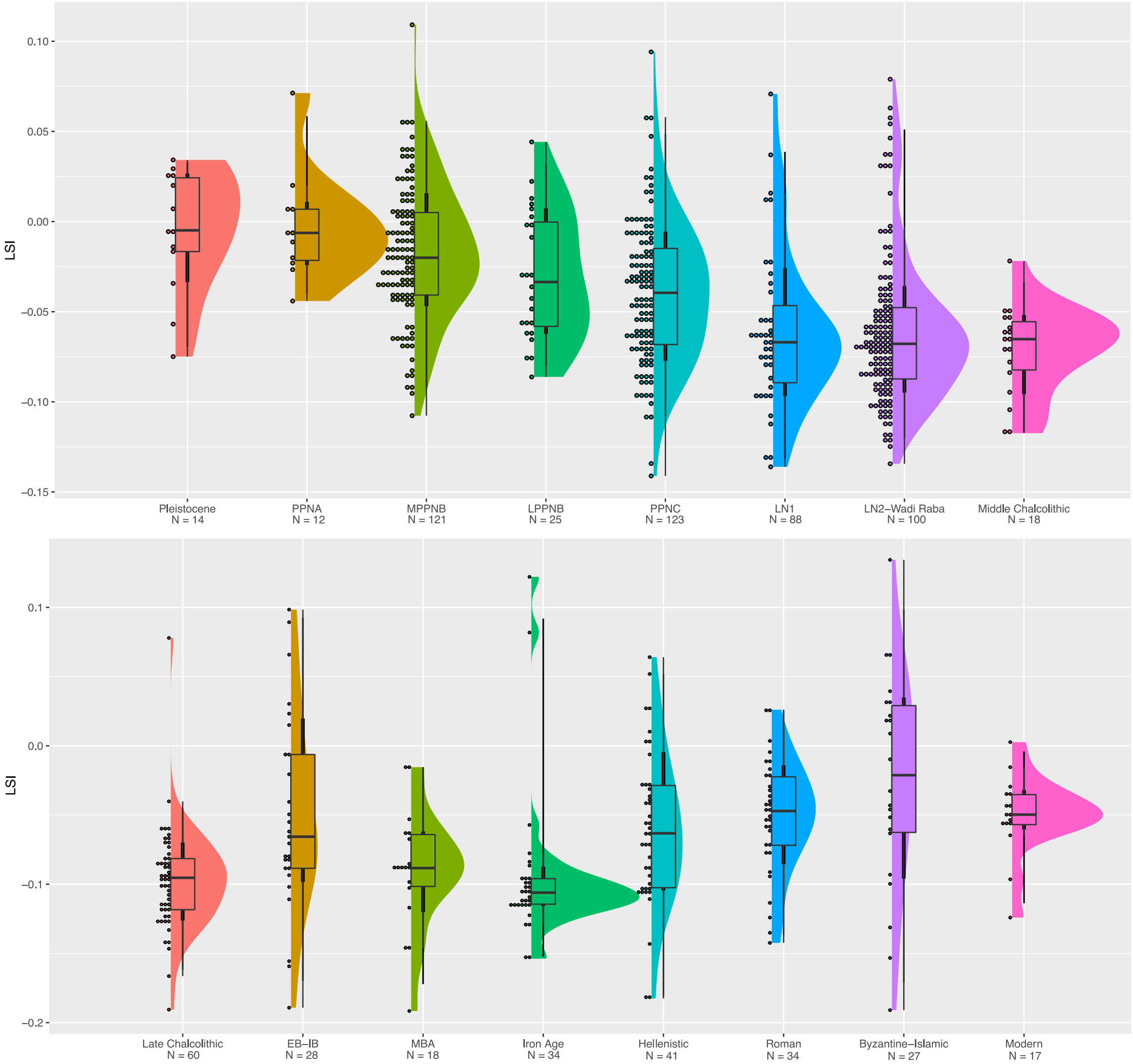

Fig. 3. LSI of postcranial measurements (Astragalus GLl; Tibia Bd; Radius Bp; Humerus Bd, BT, HTC) over time.

LPPNB dental metrical data are all consistent with Pleistocene wild boar.

A notable change appears in the PPNC, which is represented principally by the sites of Motza (n = 51), which lies west of Jerusalem and which was measured by one of us (HR; see Reshef, 2020) and Hagoshrim (n = 37) in the Hula Valley, which was published by Haber and Dayan (2004). While there is only a minor, though statistically significant, downward shift if mean LSI value in the PPNC (−0.049 ± 0.046; ANOVA: F(3,131) = 3.373, P = .020), many specimens are much smaller than the lowest LSI value for suids in the Pleistocene through LPPNB. These small specimens (LSI < −0.075) derive exclusively from Motza, where morphologically wild specimens were also present (Fig. 4). While many of the teeth from Motza cluster with morphologically wild boar, 21 out of 51 specimens presented LSI values less than −0.075 and about half of them fall within the size range of domestic pigs from the Chalcolithic period.

Fig. 5 shows a scatterplot of lower third molar lengths and anterior breadths (WA), measurements often used in the discrimination between wild and domestic pigs (e.g., Flannery, 1983; Price and Evin, 2019; Rowley-Conwy and Dobney, 2007). Four out of 13 PPNC lower third molars display lengths less than 34 mm — the smallest modern wild boar measured by Kusatman (1991) was 34.1 mm.

The suids from Motza exhibit a wide spread (Fig. 4). When considering all the dental metrics from all sites dating to the PPNC (n = 94; sd = 0.046) the spread is significantly larger than all the measurements from all sites dating from between the Mousterian and MPPNB (n = 113, sd = 0.026) (F-Test: F = 0.331, P < .0001). The large variance in the PPNC, which continues into the LN 1 and LN 2, indicates a mixed population of suids, i.e., wild and domestic pigs — and probably hybrid and feral individuals as well. As Fig. 4 clearly shows, the difference in the PPNC is driven by the Motza dataset.

3.4. Bigger bodies, unchanging teeth, and the genetic turnover 3000 Years ago

Although measurements are limited, there was no detectable shift in dental biometrical data coinciding with the mitochondrial DNA turnover. There was relatively little change in average tooth size of domestic pigs after the Late Chalcolithic (Fig. 2). When we focus in on the period from the Middle Bronze through the Hellenistic, there is no change in average tooth size ANOVA F(2, 91) = 0.583; P = .560). Fig. 6 shows that average tooth size was virtually identical between Middle Bronze Ashkelon (mean LSI = −0.105 ± 0.021), Iron I Ashkelon (mean LSI = −0.103 ± 0.017), and Hellenistic Maresha (−0.103 ± 0.020).

There is, however, a significant upward shift in postcranial size (ANOVA F(2, 60) = 2.434; P = .096) from a mean LSI of −0.089 in the Middle Bronze to −0.060 in the Hellenistic period. This represents a 7%

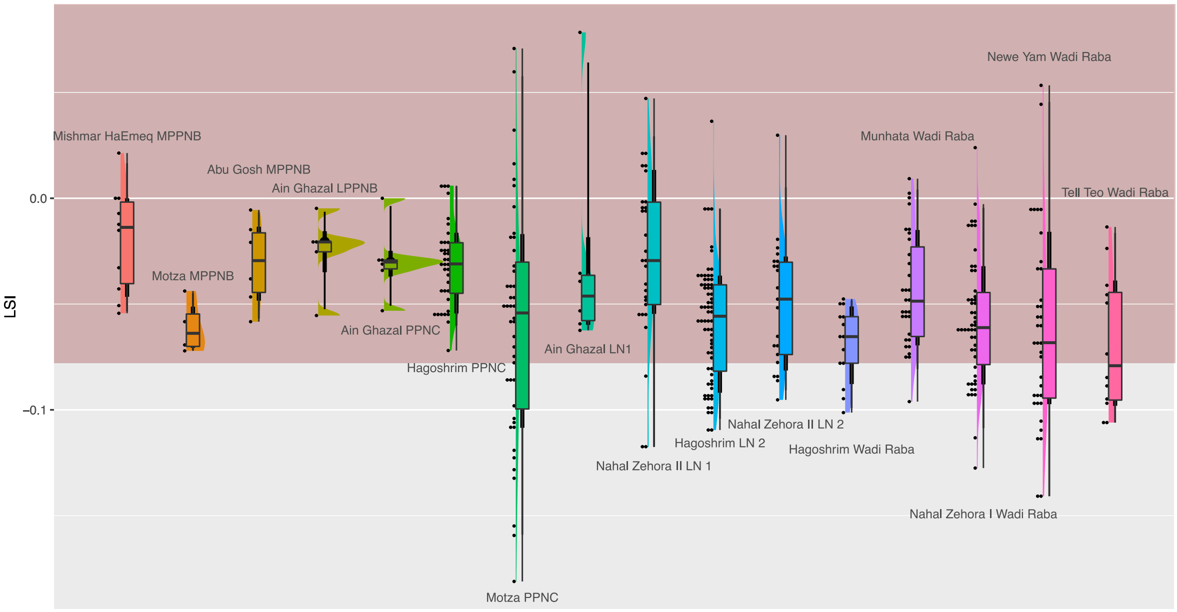

Fig. 4. LSI of tooth breadths (WA and WP) from MPPNB through Wadi Raba sites. Red shaded area represents range of modern and ancient wild boar. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

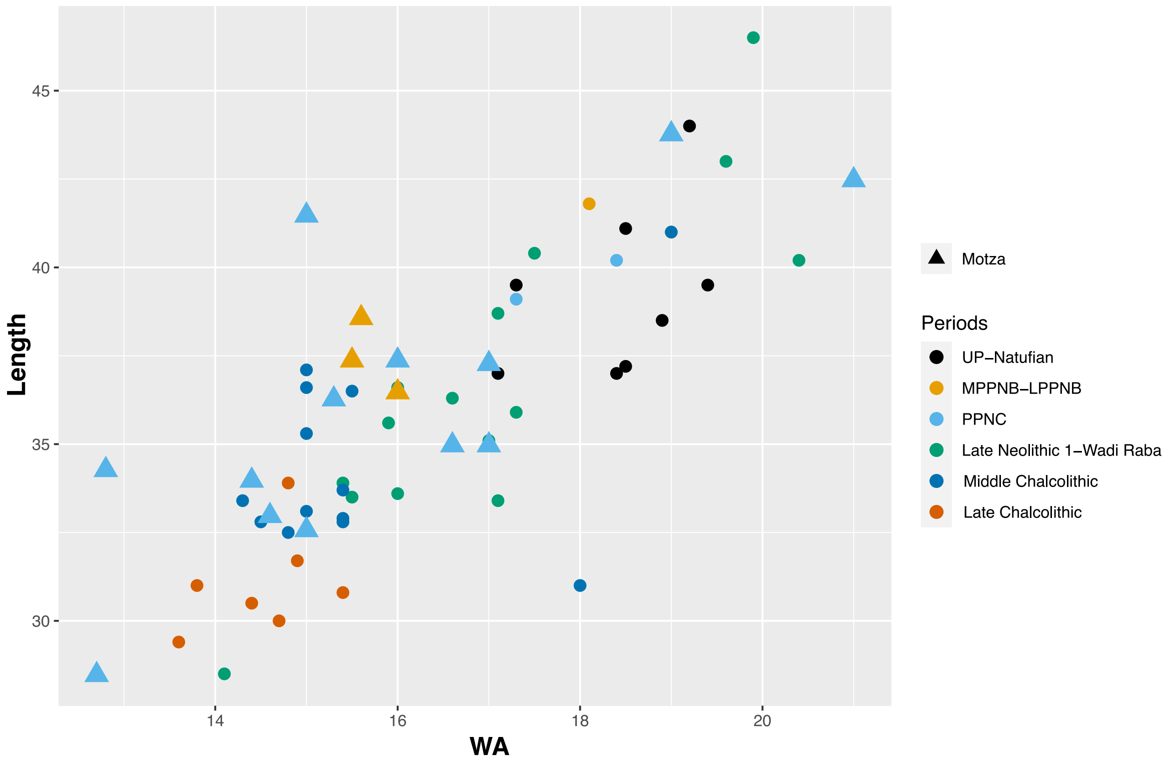

Fig. 5. Scatterplot of lower 3rd molar lengths and anterior breadths (WA), highlighting data from Motza (represented as triangles).

increase. Fig. 6 shows postcranial remains from Ashkelon, Maresha, and Tel Miqne (data from Justin Lev-Tov, personal communication). The plot indicates a positive shift from the Middle Bronze (mean LSI = −0.098) to Iron I (mean LSI = −0.110), to the Hellenistic period (mean LSI = −0.072) (ANOVA F(1, 45) = 5.346; P = .025).

3.4.1. *Multiple populations of Roman swine*

In the Roman period, dental biometrics show an extremely high variance (n = 32; sd = 0.088), much higher than that expected for a single population. By comparison, modern Israeli wild boar tooth measurements (n = 448; sd = 0.024) have a significantly lower variance (F-test: F = 0.075, P < .001). The Roman period pig teeth included in this study derive from two sites, Legio, a 2nd-4th century legionary fort near Tel Megiddo, and Tel Dor, a coastal city whose faunal data were published by Sapir-Hen (2010). Both sites show wide variances, indicating the exploitation of wild and domestic-sized pigs (Fig. 7). Legio, however, appears bimodally distributed, with a large-sized population (n = 10; mean LSI = 0 ± 0.045) — perhaps local wild boar, hybrid animals, or a

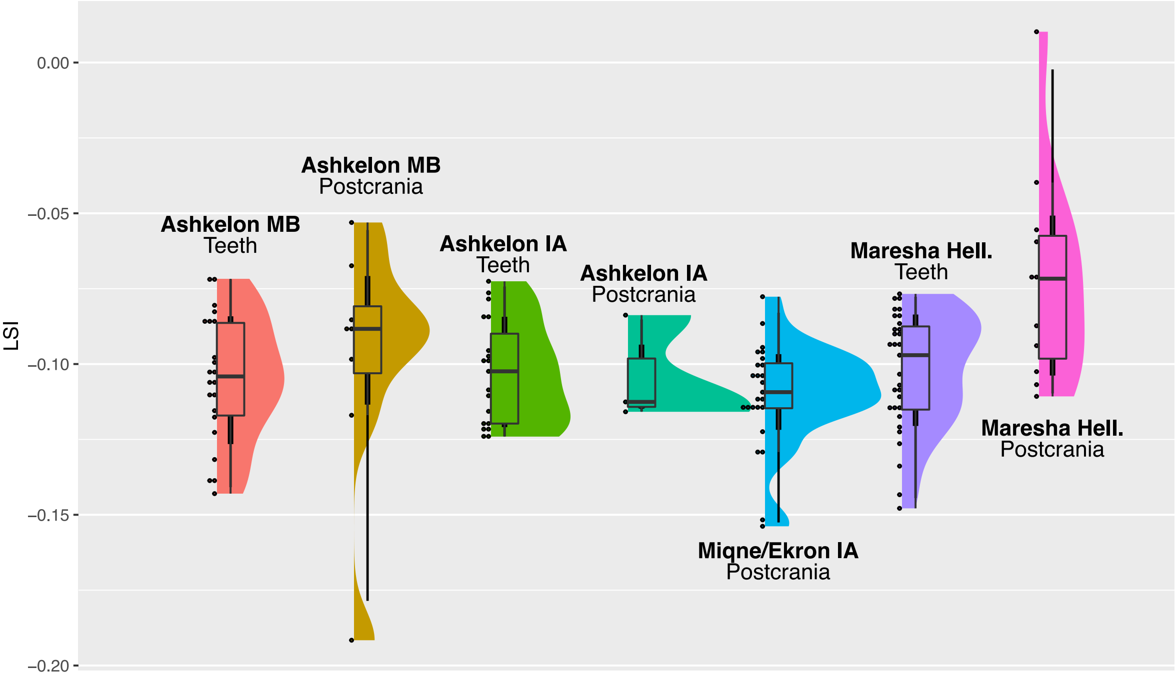

Fig. 6. LSI of dental breadths and postcranial measurements at Middle Bronze (MB), Iron Age (IA), and Hellenistic (Hell.) sites.

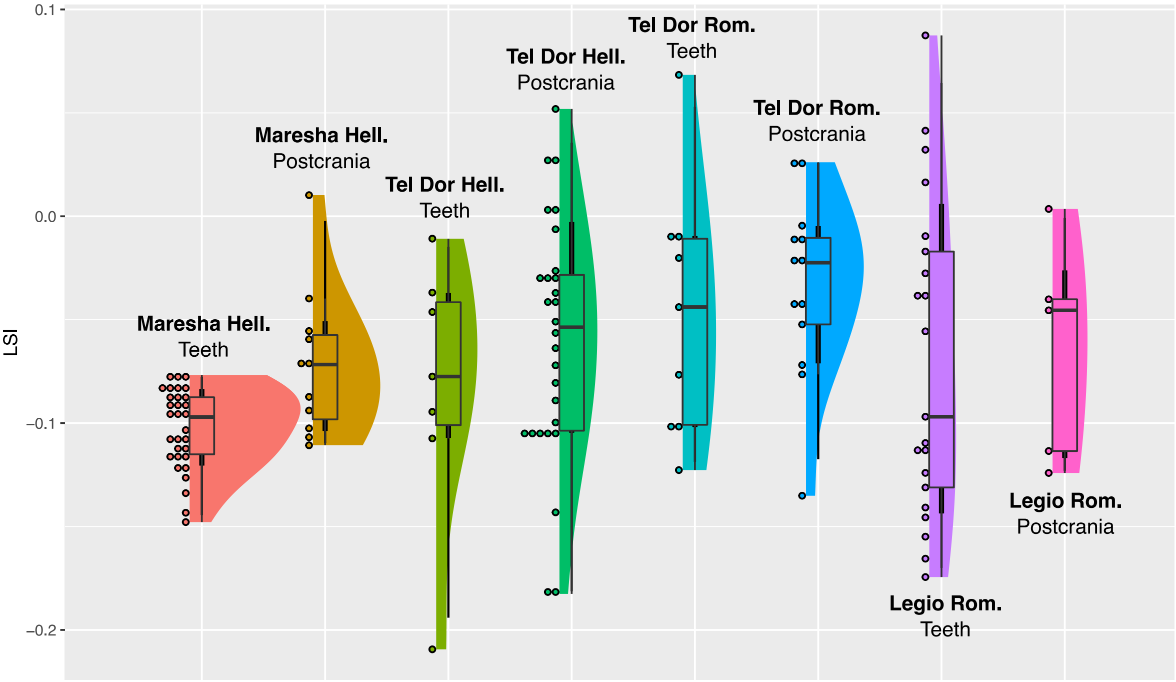

Fig. 7. LSI of dental breadths and postcranial measurements at and Hellenistic (Hell.) and Roman (Rom.) sites.

large-sized domestic introduced from elsewhere in the Roman empire — and a much smaller-sized one (n = 11; mean LSI = −0.133 ± 0.025) that averages a bit smaller than domestic pigs from earlier periods. The two population are found in roughly equal proportions (Fig. 7).

Postcranial biometrics from the Roman period were, on average, large (mean LSI = −0.054 ± 0.042). This may represent a continuation of the trend observed at Maresha of large-bodied suids that can be identified as domestic based on small tooth size. At the moment, however, it remains unclear if the large postcranial bones derive from a large-sized domestic population, hybrids, or wild boar. Interestingly, the exploitation of multiple populations of suids in roughly equal proportions continue into the Byzantine and Islamic periods, which is represented primarily by the site of Yavne, just south of Tel Aviv (Pery-Gal et al., 2022).

4. Discussion

The process of animal domestication and continued morphological change is sometimes described as a “long and winding road” (Evin et al., 2013; Peters et al., 2013). The metaphor is particularly apt for pigs in the southern Levant. The data here shed light on three important stops along this road: domestication, a known mitochondrial DNA turnover, and the resurgence of pig husbandry in the Roman period.

There is good evidence for management of suids beginning in the PPNC or perhaps earlier. There are a few MPPNB and LPPNB sites where *Sus* remains make up a significant proportion (>20% NISP) of the faunal assemblage, such as Jericho (Clutton-Brock, 1979), Tell Roim West (Agha et al., 2019), and Wadi Shueib (Makarewicz, 2016). But suids are much more common at PPNC sites, making up 20% or more of the faunal remains recovered from Beisamoun (Bocquentin et al., 2014; Khalaily et al., 2015), Wadi Shueib (Makarewicz, 2016), Hagoshrim (Haber and Dayan, 2004), Tel Ali (Lev-Tov, 2000b), and others. This spike in pork consumption coincides with the exploitation of young animals, as indicated by data derived from tooth eruption and wear patterns and epiphyseal fusion. There are several possible explanations for a young-skewed kill-off profile. For example, intensive boar hunting, perhaps killing whole sounders of females and their young, could account for it. But management of suid populations is a leading cause, especially if kill-off data can be corroborated by biometrical or other lines of evidence for management (see Price and Hongo, 2020). Thus, Makarewicz's (2016) detection of young kill-off of pigs at Wadi Shueib in the PPNC, but not the LPPNB, led her to conclude that pig domestication was underway by the PPNC in the Jordan Valley. Young kill-off was also evident in the Hula Valley at Beisamoun (Bocquentin et al., 2014, p. 82) and nearby at Tell Roim West (Agha et al., 2019) — although, interestingly, not at PPNC Hagoshrim, where *Sus* was extremely common (Haber and Dayan, 2004). The morphological data from these sites do not indicate size change in the dentition, a sign of morphological domestication. But at PPNC Motza, 21 of 51 measured teeth fall outside the range of modern and ancient wild boar (Fig. 4). At the moment, analysis of harvesting or management practices of suids at Motza is incomplete (for preliminary faunal results, see Reshef, 2020), but tentatively we suggest, based on the morphological data, that Motza provides the earliest evidence of morphologically domestic pigs in the southern Levant.

Between the PPNC and Chalcolithic, pigs continued to decline in average size, with average dental metrics falling at a rate of about 3–4% per millennium. To some extent, this is likely a result of continued selection pressures exerted on domestic pigs, which had by this point become an important part of the agropastoral package. Similar rates of dental size decline were seen in northern Mesopotamia from the 9th through 4th millennia cal. BC (Price and Evin, 2019). However, it also appears that a significant drop in the hunting of wild boar took place around the turn of the 5th millennium BC. Beginning with the Middle Chalcolithic, represented here by Tel Tsaf (Hill, 2011), morphologically wild boar remain scarce in faunal assemblages until the Roman period.

Investigation of pig biometry and husbandry practices is limited in later periods, but nevertheless has the potential to add insight to our understanding of the agropastoral dynamics of historical periods. Over a decade ago, archaeogenetics documented a mitochondrial genetic turnover that swept through Near Eastern pigs around 3000 years ago (Larson et al., 2007; Ottoni et al., 2012). In the southern Levant, the introduction of European-derived haplogroups has been speculatively associated with the settling along the Levantine coast of the Philistines (Meiri et al., 2013). Yet it remains unclear why this genetic turnover took place. Why, in other words, did European-derived mitochondrial haplogroups replace indigenous ones? Given how widespread the replacement was, covering Europe, Anatolia, northern Mesopotamia, and the Levant (Frantz et al., 2019; Ottoni et al., 2012), it is likely there European-derived pigs possessed phenotypes that were advantageous under (rather diverse) husbandry systems in a range of ecosystems. Obviously, these phenotypes might be zooarchaeologically invisible — e.g., higher teat counts, larger litter sizes, or neurochemical changes. Future ancient DNA work targeting specific genes associated with these traits is in order. In the meantime, it is worth examining whether suid size changed concurrently.

The available suid biometrical data from the Late Bronze and early Iron Age does not provide evidence of change in the dental metrical data coinciding with the genetic turnover, as one might expect if there were a new population of pigs being introduced to the region. There is, however, a significant increase in size in the postcranial data, indicating an uptick in suid body size, between the Iron I, which is represented principally by Ashkelon (Wapnish and Fulton, 2020) and Tel Miqne (Lev-Tov, 2000a), and the Hellenistic, which is represented by Maresha (Perry-Gal, 2017). As the published aDNA data suggest that the "turnover" accelerated in the Iron II period, the data here offer *tentative* evidence that the mitochondrial haplogroup turnover may be linked to larger-bodied or perhaps faster-growing pigs. We stress that this is a hypothesis — there are many possible alternative explanations. But a reasonable scenario entails such pigs having a selective advantage in the context of animal husbandry. Swineherds would likely prefer larger sows and boars for breeding. Larger sows may have also possessed other traits that could have led to a genetic turnover via natural selection: for example, they may have given birth to greater numbers of piglets per littler. If the uptick in suid body size is corroborated by future research, the turnover in the Levant might parallel the situation observed in Italian wild boar, where the "A-side" mitochondrial haplogroup, which was associated with larger body size and faster growth rates, became more prevalent over time relative to the slower-growing and smaller "C side" (Lega et al., 2017).

The relatively sudden upsurge in pig husbandry (indicated by an increase in %NISP) in the Classical period was the final process we investigated. The expansion of pig husbandry, especially in the Roman period, represented a significant change in Levantine agropastoralism, with pork becoming as or more common than it was in the Late Neolithic and Chalcolithic. We know relatively little, however, about how this expansion took place or how pigs were raised in this period. The data from Legio suggest that small-toothed domesticates, smaller even than the Hellenistic pigs, were exploited alongside larger-toothed suids, perhaps local wild boar. One possibility, to be explored with additional data, including genomic data, is that Roman soldiers and colonists introduced new populations ('breeds') of pigs. Intentional introductions would be in keeping with Roman agropastoral practices, which, among other things, involved livestock improvement (Trentacoste et al., 2021). Within the realm of pig husbandry, textual, zooarchaeological, and artistic data indicate that Roman swineherds kept different 'breeds' of pigs (MacKinnon, 2001). Perhaps one of these populations of swine was introduced to the southern Levant, in spite of the controversies it would have incited among the Jewish population.

We can connect these to patterns across the Mediterranean. Interestingly, Trentacoste et al. (2021) found only a slight increase in pig width measurements and a corresponding minor decline in dental breadths in the Roman period in northern Italy. Outside Italy, there are more obvious biometrical changes. In a broad study of pig biometrical data from North Africa, MacKinnon (2023) found that width measurements increased from the 3rd century BC onwards, with a notable increase in the Roman period. In his dataset, he also showed variation in size in the Egyptian pigs during the Roman period, matching the variation in the southern Levant. Slim and Çakırlar (2023) also found evidence for increasing width measurements of pig remains in central and western Anatolia over the latter half of the 1st millennium BC, with larger postcranial and dental measurements across Anatolia in the Roman period. This biometrical change coincided with an uptick in relative frequencies of pig remains at archaeological sites and a reduction in the diversity of slaughter practices that suggest, to Slim and Çakirlar (2023, p. 57) a "Roman pig 'ideal' in Anatolia."

5. Conclusion

Biometrical data, viewed in the *longue durée*, allow zooarchaeologists to investigate broadscale changes in human-animal relations. There are important limitations to this dataset — especially, the uneven representation in certain time periods and the attendant issue of relying on a single faunal assemblage (which may or may not reflect the "normal" situation) to represent an entire period. Nevertheless, the data presented here allow us to revisit the domestication question, providing evidence that the PPNC (early 7th millennium cal. BC) is the earliest period in which there is clear evidence for morphologically domestic pigs in the region. The morphological evidence derives exclusively from Motza. But other PPNC sites provide evidence for management of morphologically wild boar. Taken together, this suggests a process of pig domestication *occurred locally* in the southern Levant.

Our data also shed light on the genetic turnover in the Iron Age and its potential significance. While there is no evidence for dental size change, postcranial metrical data potentially indicate an increase in body size. We admit our dataset is limited, but this could be an indication that individuals of European-derived mitochondrial haplogroups were able to grow faster and achieve larger body sizes than their Near Eastern counterparts. This may well explain the rapid evolutionary success of European mitochondrial haplogroups. Moreover, we tentatively see the pattern of increasing body size continue into the Byzantine period, perhaps suggesting improved pig breeding practices.

Finally, our data indicate Roman pig husbandry in the Levant was far more complex than previously thought, involving the exploitation of multiple populations of suids — perhaps intentional hybridization, large-scale hunting of wild boar, or the introduction of new ‘breeds’ of domestic swine. Such an exciting find resonates with our understanding of Roman agricultural innovations across the Mediterranean. We hope that future genetics analysis of Roman-period suids will shed even further light on this pattern.

Declaration of competing interest

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

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jas.2023.105828.

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