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Hoofprints in the sand: A study on domestic sheep (*Ovis aries*) from Iron Age southern Phoenicia using traditional biometric methods

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ABSTRACT

The majority of research to date on the translocation of livestock in the premodern (before 1500 CE) Mediterranean Basin has focused on expansive movements out from geographic origins of domestication or from colonizer-to-colonized territories. Fewer zooarchaeological studies have investigated the lateral trajectories of distinct varieties of domesticated animals around the post-Neolithic eastern Mediterranean, partially due to the difficulty in detecting intra-species variation osteologically. The research conducted in the present study sought to improve understanding of the human-mediated mobility of domestic sheep (*Ovis aries*) from Iron Age settlements in the southern Levant. Variability in body size and a greater variety of morphotypes were expected from coastal flocks in southern Phoenicia in comparison to inland herds, possibly due to the dynamic influence of maritime trade. Biometric data analysis of zooarchaeological materials using log size index and astragalar dimension index methods revealed evidence for the possible optimization of coastal sheep for wool production and a potential introduction event in the Persian period. The Aegean region could be a source for this introduction; however, further research is needed to specify the geographic origin of this phenomenon.

1. Introduction

The Mediterranean Basin was an epicenter of ancient maritime activity, where sea-voyaging facilitated the movement of people, goods, ideas, and animals between distinct cultural communities in subregions around the basin since at least the Neolithic (Horden and Purcell, 2000; Broodbank, 2006, 2013; Strasser et al., 2010; Paschou et al., 2014). Based on the archaeological and palaeozoological records (Vigne, 1992, 2007: 271, Fig 125, 2012; Zilhao, 2001; Guilaine and Manen, 2007; Vigne, et al., 2012; Davis, 2015), as well as genetic studies (Pereira et al., 2005, 2006), the premodern (before 1500 CE) dispersion of livestock has also been shown to have had a maritime component. Maritime-facing cultures have historically been at the forefront of ancient trans-Mediterranean trade networks, with Phoenician traders and colonists as perhaps the most well-known progenitors of this phenomenon (Elayi, 2013; Aubet, 2014; Woolmer, 2017; Edrey, 2019; Sader, 2019). Evidence for commensal and domestic animal introductions to the western Mediterranean in the Iron Age suggests input from Phoenician maritime activities (Hernandez Carrasquilla, 1992; Morales-Muñiz et al., 1995; Oueslati et al., 2020). Domestic sheep (*Ovis aries*) were a crucial component of the animal economy in the antique Mediterranean and are therefore ubiquitous in archaeological sites in the region; however, individual stock are not known to have been historically translocated by sea until later during the Roman Period in the Western Mediterranean (Columella, 1968: Book VII, II).

2. Research background

The mobility of livestock and other domesticates has often been studied from an expansive point-of-view. Previous research has focused on the westward movements of livestock out and away from points of domestication in the Fertile Crescent (Özdoğan, 2011; Arbuckle et al.,

Abbreviations: LSI, log size index; ADI, astragalar dimension index.

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2014; Orton et al., 2016; Atici et al., 2017) and the western Mediterranean (Vigne, 2007). Other studies have investigated animal mobility associated with colonizations, such as from the Levant to Phoenician Iberia (Hernandez Carrasquilla, 1992; Morales-Muñiz et al., 1995; Valenzuela-Lamas et al., 2018) and Punic North Africa (Oueslati et al., 2020, with references). Fewer zooarchaeological studies have considered the continuous, lateral, multi-directional terrestrial and maritime mobility of domesticates around the Mediterranean basin after the Neolithic period (MacKinnon, 2010; Henton, 2012; Meiri et al., 2013, 2019; Gaastra, 2014; Colominas Barberà, 2015; Valenzuela-Lamas et al., 2016, 2018; Knockaert et al., 2018; Isaakidou et al., 2019; Nieto-Espinet et al., 2020; Valenzuela-Lamas, 2020; Wordsworth et al., 2021). This is partly because of the difficulty in detecting geographically distinct populations from the osteological materials of common domesticates in archaeological contexts. The morphological differences between wild and domesticated taxa can sometimes be more easily deduced osteologically. Variations between populations of the same domesticate are often invisible to the naked eye or difficult to detect due to sample size issues imposed by zooarchaeological materials (Noddle, 1983; Ryder, 1983; Davis, 2000). Although genetic and stable isotope studies can be used for these purposes, they are often cost-prohibitive and destructive, and therefore less attainable for the majority of zooarchaeology projects.

Fortunately, recent osteometric and geometric morphometric studies have shown important results in terms of mobility, non-local introductions, and improvements of domesticates at nodes along ancient trade routes such as the prehistoric Silk Road in Central Asia (Haruda et al., 2019), post-Neolithic (Ottoni et al., 2013) and Chalcolithic Anatolia (Pöllath et al., 2019), Bronze and Early Iron Age Eastern Mediterranean (Meiri et al., 2017), Magna Graecia (Gaastra, 2014), pre-Roman northern Italy (Trentacoste et al., 2018), early-Roman Catalonia (Colominas et al., 2019), Roman Italy (MacKinnon, 2010), and Moslem Portugal (Davis, 2017b). The present study aims to shed light on the potential for long distance translocation of livestock in the post-Neolithic Eastern Mediterranean through a study on the biometric variability of domestic sheep during the Iron Age in the southern Levant. Sheep are the ideal domesticate for this study since they were highly valuable animals in the ancient Near East, utilized for their meat, fat, milk, and wool (Ryder, 1983; Sherratt, 1983; Vila and Helmer, 2014).

The selective breeding of sheep to encourage wool production began in Mesopotamia as early as 6500 BCE; this practice was well-established in the Near East by the 3rd millennium BCE (Breniquet, 2014; Vila and Helmer, 2014). Mouflon, the wild progenitor of domestic sheep, has a brown coat of coarse kemps (hair-like fibers) interspersed with fine underwool (Ryder, 1987a). The selective breeding process encouraged the continuous growth of underwool, with an increase in the proportion of finer underwool fibers and a decrease of the hairy kemps (Ryder, 1958, 1964; 1969; 1987a). Ongoing improvement of wooly breeds to produce finer fleeces continued in the Iron Age, along with the appearance of a greater range of colors including black, white, and gray (Ryder, 1987b). The specialization of this practice was postulated to have had a northward movement out of Mesopotamia towards Anatolia and the Black Sea (Ryder, 1987a), though a purely linear trajectory of wooly breed improvement has been challenged in more recent literature (Breniquet, 2014). In the Near East, the hairy medium and generalized medium fleeces of the Bronze Age persisted as the norm until the Iron Age (Ryder, 1987b).

The development of the first truly fine-wooled sheep is attributed to the Greeks circa the 5th century BCE based on yarn remains (mean fiber diameter = 15μ) from the Greek colony of Nymphaeum in the Crimea; the Greeks are also credited with dispensing these improved stocks around the Mediterranean (Ryder, 1987a, 1987b). Research carried out on yarns found in Murrabaat (near the Dead Sea), and the Dead Sea Scrolls parchments indicated that truly fine-wooled sheep existed in the southern Levant at least ca. 2000 years ago (Ryder, 1969, 1987a). Fine-fibered yarns analyzed by Ryder from Daliyeh (near Jericho), predate the Dead Sea finds by several centuries, suggesting that fine-wooled sheep began to appear in the region as early as the 4th century BCE (Ryder, 1969).

The Iron Age southern Levant was a spatiotemporal setting known for dynamic and fluctuating shifts of political power in an increasingly important nexus of international trade (Sherratt and Sherratt, 1993; Gambash, 2014; Eshel et al., 2019; Yasur-Landau et al., 2019). Historical and archaeological sources agree that inter-regional maritime trade was spearheaded by the Iron Age Phoenician city-states of Tyre (modern Ṣūr, Sour) and Sidon (modern Ṣaydā) (Lehmann, 2001, 2021; Broodbank, 2013; Aubet, 2014; Gilboa and Sharon, 2017; Woolmer, 2017; Sader, 2019). Sheep would have been heavily utilized for their wool in what is commonly known as the 'Tyrian purple' textile industry, since this was the only raw material suitable for fine garments that would hold fast the Murex purple dye (flax linen does not take the colorant and goat's hair was too coarse) (Schneider, 2012; Strand, 2014).

Evidence for purple dye industries and textile manufacturing exists in several sites on the southern coast of the Phoenician territories during the Iron Age and Persian period, including at Tel Kabri, Tell Keisan, Tel Shiqmona, and Tel Dor (Fig. 1) (Briend and Humbert, 1980; Koren, 1995, 2005; 2013; Nitschke et al., 2011; Sukenik et al., 2017; Sader, 2019; Shalvi, 2020; Shalvi and Gilboa, 2022; Shalvi & Gilboa, In press). For the purposes of this study, we broadly define southern Phoenicia to include Iron Age and Persian period settlements on the coastal plain of the southern Levant, extending south from the Ladder of Tyre (Rosh HaNikra/Râs en-Nakûrah) to Tel Dor, Mount Carmel, and parts of the western Galilee. This definition is not based on ethnic connotations or supposed cultural homogeneity, but rather on material culture associations, and cultural and economic processes which mirror contemporaneous coastal areas farther north near Tyre and Sidon (Lehmann, 2001, 2021; Lehmann and Peilstocker, 2012; Aubet, 2014; Gilboa et al., 2015;

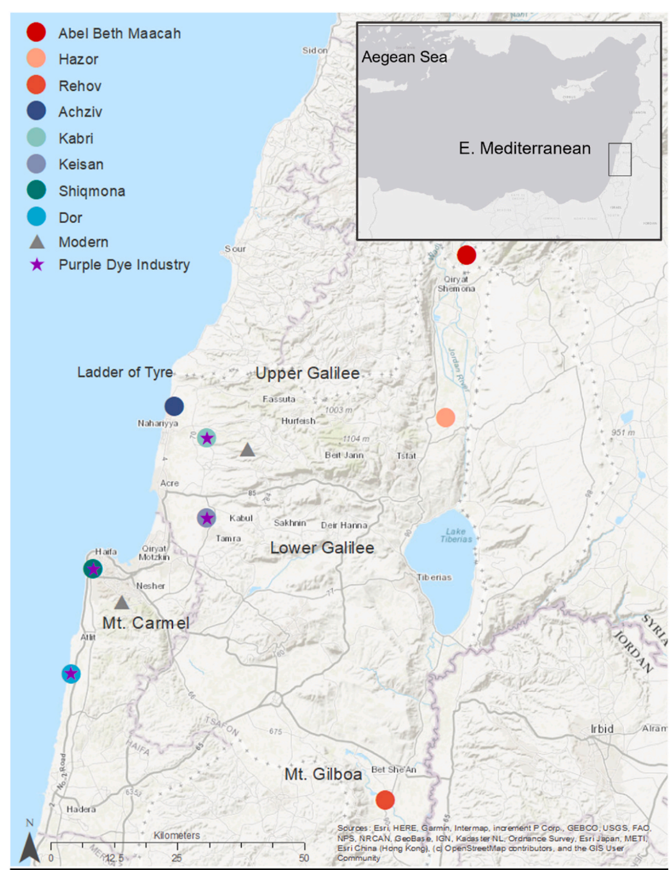

Fig. 1. Map of sites included in the biometric study of sheep in the southern Levant during the Bronze and Iron Ages. See Supplement S1 for detailed site descriptions.

Gilboa and Sharon, 2017: 288; Woolmer, 2017; Sader, 2019; Gilboa, 2022).

Since domestic sheep were in no short supply in the Iron Age southern Levant, any motivation to import nonnative types must have had a specific purpose. The introduction of non-Levantine sheep with desirable traits (e.g., finer, whiter wool) to improve local flocks could have promoted the specific economic initiatives of these settlements, such as producing high-quality wool for the Murex purple textile industry (Koren, 1995, 2013; Nitschke et al., 2011; Aubet, 2014; Graves, 2017; Sukenik et al., 2017; Sader, 2019). This may have been advantageous since the sheep traditionally raised in Southwest Asia had primitive hairy or generalized medium fleeces of black, gray, brown, and white fibers (Epstein, 1980; Ryder, 1987a, 1987b). Though importation of stock or herd improvement in pursuit of finer, whiter-woolled sheep is a likely possibility, this phenomenon has not yet been explored empirically using zooarchaeological data from the Iron Age southern Levant.

3. Research outline

Due to the dynamic influence of maritime trade and specialized industries on the coastal plain of southern Phoenicia, we speculate that these coastal Iron Age settlements may have been more likely to see the introduction of non-local sheep, or improvements of coastal flocks aimed at optimization for wool production, than their inland counterparts. In order to explore this speculation, we have organized our study to compare intra-species variability using osteometric sheep data from southern Levantine archaeological sites, from both temporal and spatial perspectives. Evidence for intra-species variability may be observed in changes in body size and proportions through time (Gaastra, 2014; Trentacoste et al., 2018, 2021; Nieto-Espinet et al., 2020). A gradual, generalized increase in body size over consecutive time periods could indicate larger animals in both sexes, and therefore improvement over time due to better feeding regimes or selective breeding. A sudden, significant increase in body size or change in anatomical proportions may be evidence of the introduction of new stock or a change in herd culling strategies aimed at the exploitation of lifetime products such as wool.

A herd optimized for wool might contain a higher proportion of adult males than a flock raised specifically for meat production (in which rams are typically culled around one year of age), as well as castrates, which are known to produce a higher quality fleece (Sherratt, 1983; Davis, 2000, 2006, 2008; Albarella et al., 2008; Trentacoste et al., 2018). This optimization may be observed in a size increase or change in proportions of sheep postcranial bones; although sheep are less sexually dimorphic than other livestock, rams (males) tend to be slightly larger than ewes (females), and wethers (castrates) tend to be taller than rams (Davis, 2000). Caprine (sheep/goat) astragalar morphology and dimensions have previously been shown to be influenced by diverse environments, viz. open (savannah, plain, steppe) or closed (forest, heavy vegetative cover, mountainous gradients) topographies (Davis, 2017a; Haruda et al., 2019). Variability in the dimensions of sheep astragalus bones (pl. astragali) may allude to geographical trends among sheep herds from distinct areas.

We applied two biometric techniques to measure intra-species variability among domestic southern Levantine sheep: log size index to measure change in body size and proportions through time, and astragalar dimension index to explore potential adaptations to open and closed environments. We chose these two techniques based on results obtained in previous studies (Gaastra, 2014; Davis, 2017a; Trentacoste et al., 2018, 2021), as well as the fact that they provide complementary data that may signal variation from both anthropogenic and environmental impetuses. The data generated in the log size index analysis may illuminate gradual or sudden changes in husbandry trends or stock introductions, but it is limited in that it cannot directly comment on the source of these transformations. To compensate for this limitation, analyses of astragalar dimensions may shed light on the topographical terrain for which a sheep's mobility was optimized. Combining these two techniques allows for the biometry of domestic sheep to be viewed through complementary lenses, which overlap to provide a well-rounded assessment of spatiotemporal osteometric variation.

From a temporal perspective, we expect to observe a significant increase in the average (mean) body size and a change in proportions of sheep from coastal settlements in southern Phoenicia between the Bronze and Iron Ages (Table 1). We chose this broad temporal boundary due to the emergence of significant seaside settlements on the coast south of Tyre and Sidon around that time (Briend and Humbert, 1980; Yasur-Landau et al., 2016; Gilboa and Sharon, 2017; Bar, 2020; Shalvi, 2020; Lehmann, 2021). Moreover, we anticipate that the recovery of maritime trade in the Iron Age (Sherratt and Sherratt, 1993; Gilboa and Sharon, 2017; Lehmann, 2021; Gilboa, 2022) after the dramatic changes in political hegemony, economic diffusion, and restructuring of settlement hierarchy which came with the fall of the Bronze Age palatial centers in the Levant (Lehmann and Peilstocker, 2012; Knapp and Manning, 2016; Lehmann, 2021) may have had an effect on the animal economy in southern Phoenicia. An additional justification for this broad temporal division is to improve statistical power by increasing sample sizes, which is often a challenge with analyzing zooarchaeological materials. However, understanding that this approach may smooth-out important sociocultural fluctuations, we also included commonly defined periods within both the Bronze and Iron Ages to observe changes at a finer temporal resolution; these include Middle Bronze Age (MBA), Late Bronze Age (LBA), Iron Age I (IA1), Iron Age II (IA2), and the Persian period (PER) (see Table 1 for period dating definitions). These periods are based on chronologies presented in Gilboa et al. (2015) and Faust and Katz (2019). Although the high and low chronologies of the Iron Age Levant are currently debated, we will not address this here (Gilboa and Sharon, 2003; Finkelstein and Piasetzky, 2011; Mazar, 2011). The Late Bronze Age definition includes the transition to the Iron Age I (LBIII: ca. 1200–1130BCE) (Lehmann, 2021). The Persian (Achaemenid) period has been delineated here due to destruction events and occupational gaps in the southern Levant between the Assyrian and Persian occupations (ca. mid-7th–late 6th centuries BCE) in several sites on the southern Phoenician coastal plain (Lehmann and Peilstocker, 2012; Gilboa and Sharon, 2016; Martin and Shalev, 2022), as well as rejuvenated interregional maritime trade beginning in the Persian period (Gilboa et al., 2017; Lehmann et al., 2019). The modern period (MOD) is also included to encompass a comparative sample used in some of the analyses. For the purposes of a biometric zooarchaeological study, we find this coarse dating scheme to be sufficiently broad to track changes in successive generations of livestock while still allowing for the appropriate sociocultural associations.

Spatially, we postulate that sheep raised in both Bronze and Iron Age inland settlements in the southern Levant (east of the central mountain ranges of the Galilee, Carmel, and Gilboa) would be more likely to be relatively stable in size and proportions in comparison to coastal flocks. This biometric stability might be due to being more insulated to introductions of non-Levantine sheep based on their distance from coastal trading depots. In addition, the distinct economic initiatives of the Iron Age inland settlements compared to those on the coastal plain—i.e., agropastoralism (Marom et al., 2009, 2014; Susnow et al., 2021) vs. specialized maritime production and trade (Gilboa and Sharon, 2017;

Table 1
Dating period definitions used in the biometric analyses.

Era	Period	Dating	Abbreviation
Bronze Age	Middle Bronze Age	ca. 1950–1550 BCE	MBA
Bronze Age	Late Bronze Age	ca. 1550–1130 BCE	LBA
Iron Age	Iron Age I	ca. 1130–950 BCE	IA1
Iron Age	Iron Age II	ca. 950-539 BCE	IA2
Iron Age	Persian Period	ca. 539–332 BCE	PER
Modern	Modern	After 1700 CE	MOD

Lehmann, 2021; Gilboa, 2022)—might influence sheep biometry. An additional variable to consider is that the coastal–inland divide could result in distinct morphologies of sheep astragali between zones due to locomotive adaptations to open vs. closed environments (Haruda et al., 2019). Although the southern Levant is a relatively small geographic area, it is topographically complex (Fig. 1); the littoral of the southern Levantine coast is an open environment comprised of sandy beaches with *Kurkar* ridges (aeolian quartz sandstone with carbonate cement), which give way to fertile alluvial plains just inland. The terrain of the Upper and Lower Galilean hill country is rough with dense vegetation, and rises quickly in elevation (Lehmann, 2001; Lehmann and Peilstocker, 2012). To the south of the Sea of Galilee (Lake Tiberias), the eastern foothills of Mt. Gilboa descend rapidly to elevations below sea level in the Beit She'an valley. Settlements in these closed, inland environments exist at altitudes 1–2 orders of magnitude higher (above sea level) or lower (below sea level) than the coastal plain. Therefore, a result showing homogeneity between the astragalar dimensions of inland and coastal flocks might signal east-west transhumance or livestock exchange across the central mountain ranges of the southern Levant. On the contrary, notable variance among inland and coastal sheep astragali would suggest distinct lifeways and mobility trajectories for these animals. Similar to the temporal boundaries defined above, we assessed variation across zones (Coastal/Inland) as well as by site (see section 2.1), to parse out patterns in the data.

Based on this combination of biometric and spatiotemporal factors, we expected sheep from Iron Age coastal settlements to show an increase in body size, more variability in proportions and differences in astragalar dimensions than contemporary Iron Age inland and previous Bronze Age coastal populations. If this expectation were to be supported by the data, we would consider it as evidence suggesting the improvement of flocks or the possibility of non-Levantine sheep having been introduced into the coastal zone which might have been influenced by the maritime trade of that period. Absence of evidence for the expected results—i.e., biometric data of sheep from Iron Age southern Phoenicia do not show an increase in body size, change in proportions, nor a significant variation in dimensions in comparison to the earlier periods and contemporaneous inland sites—would suggest that exotic sheep were not introduced to the region along the Iron Age Mediterranean maritime trade networks, or that this introduction is not detectable using the methodology employed in this study.

4. Materials

4.1. Coastal zone

We collected data from eight archaeological sites in the southern Levant, including five sites along the coastal plain of southern Phoenicia (Coastal Zone: Tel Achziv [AZV], Tel Kabri [KBR], Tell Keisan [KSN], Tel Shiqmona [SHQ], Tel Dor [DOR]), and three inland sites (Inland Zone: Tel Abel Beth Maacah [ABM], Tel Hazor [HZR], Tel Rehov [RHV]) (Fig. 1; Table 2; see Supplement S1 for detailed site descriptions [Harding, 2021a]). The coastal sites had strong material culture connections to the Phoenician sphere of influence during much of the Iron Age. Except for Tel Achziv, each of the coastal sites in our study have produced archaeological evidence for Murex dye or textile industries on site in the Iron Age (Tel Achziv Excavations, n.d; Briend and Humbert, 1980; Stern et al., 1993b, 1993a; Koren, 1995, 2013; Lehmann, 2002a, 2021; 2002b; Nitschke et al., 2011; Lehmann and Peilstocker, 2012; Aubet, 2014; Gilboa, 2015; Thareani and Jasmin, 2016; Sukenik et al., 2017; Gilboa and Sharon, 2017; Graves, 2017; Sader, 2019; Shalvi, 2020, 2021; Bar, 2020). Topographically, these sites range from 3 to 52m above sea level. Available zooarchaeological ovicaprine data from these tells suggests that domestic sheep and goats dominated the faunal assemblages in both the Bronze and Iron Ages (Deonarain, unpublished data; Harding, unpublished data; Vermeersch, unpublished data; Bartosiewicz and Lisk, 2018; Ujma, 2021). A mixed caprine exploitation strategy has been observed in zooarchaeological analyses previously conducted on remains from Tel Dor and Tel Shiqmona; this approach typically aimed to provide meat as well as secondary products such as milk and wool to settlement residents (Sapir-Hen et al., 2014; Bartosiewicz and Lisk, 2018; Ujma, 2021).

Table 2
Archaeological sites included in this study, along with zone designations, elevation, and abbreviations used throughout this study. The modern samples from Mt. Carmel and the Upper Galilee are also noted. See also Fig. 1.

Zone	Site	Elevation (meters)	Abbreviation
Coastal	Tel Achziv	11	AZV
Coastal	Tel Kabri	52	KBR
Coastal	Tell Keisan	31	KSN
Coastal	Tel Shiqmona	6	SHQ
Coastal	Tel Dor	3	DOR
Inland	Tel Abel Beth Maacah	414	ABM
Inland	Tel Hazor	219	HZR
Inland	Tel Rehov	−135	RHV
–	Mt. Carmel (MOD)	534	ISL
–	Upper Galilee (MOD)	546	ISL

4.2. Inland zone

The inland sites included in our study are separated from the Mediterranean coastline by the Galilee, Carmel, and Gilboa mountain ranges (Fig. 1). Their elevations are over 100m above or below sea level (Table 2). The material culture associations of these settlements are distinct from those on the coast in the Bronze and Iron Ages, reflecting the geopolitical realities of regional powers and ethnocultural centers in the inland southern Levant during these eras (see Supplement S1 for further details) (Mazar et al., 2005; Panitz-Cohen et al., 2013; Ben-Tor, 2016; Ben-Tor et al., 2017; Yahalom-Mack et al., 2018). Previous zooarchaeological analyses from these tells suggest animal economies based on ovicaprids that range from traditional agropastoralism to proximate producer/consumer scenarios (Marom et al., 2009, 2014, 2020; Marom and Zuckerman, 2012). Near-by vertical transhumance in non-agricultural landscapes around these settlements may have occurred historically, but this phenomenon is extremely difficult to detect archaeologically (Marom et al., 2009, 2014, 2020, with refs.).

4.3. Modern sample

In addition, a modern sample of known provenience from northern Israel was included as a comparative baseline for astragali analyses (MOD ISL, N = 10); this sample was comprised of wild sheep (*Ovis orientalis*, N = 2) and domesticated sheep (*Ovis aries*, N = 8), housed in the comparative collection of the Laboratory of Archaeozoology at the University of Haifa (Table 3). The wild sheep were collected from the Hai-Bar Carmel Nature Reserve near the University of Haifa. The domesticated Awassi-type sheep were raised by small herd owners and processed by a traditional butcher (Ali Saif) in the Druze village of Januh

Table 3
Proveniences of the modern sample (ISL) included in the ADI analysis.

Catalogue #	Taxon	Provenience
819	*Ovis aries*	Januh Village, Upper Galilee
797	*Ovis aries*	Januh Village, Upper Galilee
498	*Ovis aries*	Januh Village, Upper Galilee
704	*Ovis aries*	Januh Village, Upper Galilee
670	*Ovis aries*	Januh Village, Upper Galilee
697	*Ovis aries*	Januh Village, Upper Galilee
596	*Ovis aries*	Januh Village, Upper Galilee
508	*Ovis aries*	Januh Village, Upper Galilee
521	*Ovis orientalis*	Hai-Bar Nature Reserve, Mt. Carmel
538	*Ovis orientalis*	Hai-Bar Nature Reserve, Mt. Carmel

in the Upper Galilee.

The zooarchaeological data attained for the following analyses came from studies conducted by the authors, and published datasets from previous works in the case of Tel Dor Area G (N = 88) (Bartosiewicz and Lisk, 2018) and Tel Rehov (N = 844) (Tamar et al., 2021) (Table 4; see Supplement S2 for raw datasheet [Harding et al., 2021]). Demographic analyses were lacking for many of these datasets, so we cautiously infer changes associated with herd sex profiles based on size variations (Davis, 2000), understanding the limitations of these interpretations. We conservatively refrain from using the terms 'breed' or 'landrace' to refer to premodern livestock populations (Haruda et al., 2019; Pöllath et al., 2019). Archaeologically, the term 'context' refers to material culture from a discrete position in time and space. We utilized this concept here, specifically in the description of astragali samples we analyzed to observe spatiotemporal variation in their dimensions; these include: Iron Age II Abel Beth Maacah (IA2 ABM, N = 87); Iron Age II Tel Dor (IA2 DOR, N = 14); Iron Age II Keisan (IA2 KSN, N = 8) and Persian period Keisan (PER KSN, N = 11) (Table 5; Supplement S3 [Harding, 2022]). Although every effort was made to achieve a spatiotemporally balanced dataset for each method, the diverse zooarchaeological assemblages included in this study are not homogenous with respect to the sample size from each site and time period, or context.

5. Methods

The zooarchaeological post-cranial sheep bones utilized in the following analyses were fused and osteologically mature at time of death, as well as free from surface damage, modifications, burning, pathology, or other anomalies that would inhibit comparison using linear measurements. Linear measurements were taken using vernier calipers accurate to 0.1 mm. Skeletal elements were visually identified as *Ovis* sp. using morphological criteria (Boessneck, 1971; Zeder and Lapham, 2010) and the comparative collection at the Laboratory for Archaeozoology at the University of Haifa.

6. Size change analysis

Log size index (LSI), sometimes called 'log-ratio technique', is a method by which variability in animal size can be compared by units of scale rather than direct measurements (Simpson, 1960; Boessneck et al., 1978; Meadow, 1999; Albarella, 2002; Wolfhagen, 2020). Linear measurements used in the LSI analysis followed von den Driesch (1976) and Davis (1992) (Table 6). Aside from the greatest length measurements of complete long bones, the skeletal elements included in this analysis are less sensitive to differences between rams, ewes, and wethers, as well as growth after epiphyseal fusion in sheep (Davis, 2000). In previous research, LSI width values have been considered to be a more robust indicator of sheep body size variation since they are less influenced by sexual size dimorphism (Gaastra, 2014).

Length and width measurements were assessed separately in the LSI analysis in order to track two-dimensional variability (changes in height vs. robustness); depth measurements were less frequent and not considered. Summary statistics were tabulated for each period per site. Nonparametric tests were chosen to test our hypotheses as the LSI values were not normally distributed in many cases. The effects of period, site, and the interaction between them were inferred from the results of a Kruskal-Wallis test, followed by a Dunn's post hoc test (P-values adjusted by the Holm method). Effect size is reported as epsilon squared (ε^2) for the Kruskal-Wallis tests (Tomczak and Tomczak, 2014), and magnitude of the effect is interpreted on a scale from 0.00 (negligible) – 1.00 (very strong) (Rea and Parker, 2014: exhibit 10.2, 219, 250; Tomczak and Tomczak, 2014: 24).

Linear measurements were analyzed for LSI using the 'zoolog' package (Pozo et al., 2022) in the R software environment (v. 4.1.2) (R Core Team, 2022), using the 'Clutton' standard for sheep reference measurements (Clutton-Brock et al., 1990). Only one measurement per specimen was used following the 'priority' method in the 'zoolog' package, as detailed in Trentacoste et al. (2018).The following packages were used to manipulate and summarize the data: 'effsize' (Torchiano, 2020), 'rstatix' (Kassambara, 2021), 'rcompanion' (Mangiafico, 2021), 'FSA' (Ogle et al., 2021), 'EnvStats' (Millard, 2013), 'car' (Fox and Weisberg, 2019), 'tidyverse' (Wickham et al., 2019), and 'dplyr' (Wickham et al., 2021). Graphics were created in R using the 'ggplot2' (Wickham, 2016) and 'ggsci' (Nan and Miaozhu, 2018) packages.

Table 4
Number of specimens included in the size change analysis, per site and time period. Abbreviations as in Tables 1 and 2.

Post-cranial Bone Sample	Bronze Age		Iron Age			Total
	MBA	LBA	IA1	IA2	PER	
ABM	11	18	56	178	–	263
HZR	22	42	12	53	–	129
RHV	–	12	33	738	–	783
AZV	1	–	–	10	–	11
KBR	40	–	6	–	–	46
KSN	–	–	–	121	57	178
SHQ	–	4	8	3	–	15
DOR	–	76	17	77	17	187
Total	**74**	**152**	**142**	**1170**	**74**	**1612**

Table 5
Number of specimens included in the astragalar dimension analysis, per site and time period. Abbreviations as in Tables 1 and 2.

Astragali Sample	IA2	PER	MOD	Total
ABM	87	–	–	87
KSN	8	11	–	19
DOR	14	–	–	14
ISL	–	–	10	10
Total	**109**	**11**	**10**	**130**

Table 6
Post-cranial bone measurements used in the LSI study after von den Driesch (1976) and *Davis (1992).

Element	Length Measurement	Width Measurement
Humerus	GL, HTC	BT, Bd
Radius	GL	Bp, Bd
Metapodials	GL	Bp, Bd, *WCM, *WCL
Femur	GL	Bp, Bd
Tibia	GL	Bp, Bd,
Astragalus	GLl	Bd
Calcaneum	GL	–
First phalange	GLpe	Bp, Bd, BFd
Second phalange	GL	Bp, Bd

7. Astragalar proportion analysis

Astragalar dimension index (ADI) was utilized to detect variability in astragalar proportions, a method originally devised by Davis (2017a) to metrically distinguish between breeds of sheep and goats from diverse geographical locations. These indexes mathematically express differences in relative proportions via ratios calculated from linear measurements. The ADI analysis was conducted on a sample of fully ossified sheep astragali (N = 130) from selected contexts within the study sites (Table 5). This method utilized common linear measurements taken for artiodactyl astragali (greatest lateral length [GLl], distal width [Bd], and lateral depth [Dl], after von den Driesch [1976]) following the method outlined by Davis (2017a). Indexes were formulated based on these measurements' ratios (Bd/Dl, Dl/GLl) and points for each specimen were plotted in a scatter diagram, after Davis (2017a: Fig 9.3). Raw measurements and index values for the sample are available in Supplement S3 (Harding, 2022).

8. Biometry results

8.1. Size change results

Analysis of sheep biometry using LSI produced 1059 length and 1478 width measurements from sheep post-cranial skeletal elements. Summary statistics per site and time period are presented in Table 7 (summary statistics per skeletal element are available in the Supplement S5 [Harding, 2021b]). When viewed through the broader categories of zone (Coastal/Inland) and era (Bronze Age/Iron Age), there was a very slight increase in lengths and a more appreciable increase in widths on the coast between the Bronze and Iron Ages (Fig. 2). In the inland sites, lengths do not change between eras, while widths decrease slightly. In the Bronze Age, inland sheep were slightly more robust than coastal sheep. However, an increase in the width values of coastal sheep in the Iron Age brings them on par with the inland flocks. The results of a Kruskal-Wallis test on changes in size values between eras suggest that differences in lengths between the Bronze and Iron Ages were weakly significant, while widths were highly significantly different; size value differences between zones were not significant (Table 8).

To explore the significant differences in LSI size values at a finer spatiotemporal resolution, summary statistics for both lengths and widths for each site and time period were visualized (Lengths: Fig. 3; Widths: Fig. 4). A Kruskal-Wallis test on the variables ‘Site’ and ‘Period’ for both lengths and widths suggest that size variation between the study sites and periods is significant (Table 9). Pair-wise comparisons performed separately for sites and periods on the length values using the Dunn’s post-hoc test revealed few significant differences (Sites: ABM - Kabri [P.adj = 0.004], Rehov - Kabri [P.adj = 0.030 and Dor - Kabri [P.adj = 0.004]; Periods: IA 2 - MBA [P.adj = 0.008], MBA - PER [P.adj = 0.003]). A Dunn’s pair-wise comparison on width values, however, showed significant differences among many sites (Table 10) and periods (Table 11). Size differences among southern Levantine sheep were not significant between the coastal and inland *zones* between the Bronze and Iron Ages; however, the Dunn’s test results suggest that the robusticity of sheep was significantly different between individual sites through the different time periods included in the study; this phenomenon was most notable in Keisan and Dor during the Persian period.

The mean LSI width values per site and time period show that sheep in Tel Dor saw continuity in size from the LBA through IA2, then experienced a 43.6% increase in robusticity in the Persian period. Keisan saw a similarly dramatic 32.2% increase between the IA2 and Persian periods. The differences in sheep robusticity in Achziv, Kabri, and Shiqmona are unfortunately hampered by small sample sizes and temporal gaps in the dataset. ABM and Hazor demonstrate little change between the MBA and IA2. This is matched by Rehov in the IA1 and IA2. It appears that individual sites with sufficiently representative sample sizes (ABM, Hazor, Dor) show continuity in overall body size between the Bronze Age and Iron Age 2. The coastal sites of Dor and Keisan both show marked increases in sheep robusticity in the Persian period.

8.2. Astragalar proportion results

The ADI results demonstrated the range of astragalar proportions present in the study sample (Fig. 5). The inland group (IA2 ABM) tended have higher Bd/Dl index values, and be wider-bodied (lateral-medial axis). The coastal group (IA2 DOR, IA2 KSN, PER KSN) tended to have higher Dl/GLl index values, and appear to be squatter and deeper-bodied (anterior-posterior axis). There was some overlap between the zones at the center of the distribution, where the modern sample (MOD ISL) clustered at the coastal/inland intersection. This result seems to indicate that the proportions of the sheep astragali in this study tend to reflect the specific terrain conditions of the coastal (open environment) and inland (closed environment) zones.

9. Discussion

9.1. Size change observations: herd improvement or stock introduction

The LSI results demonstrated a significant and sudden increase in the robusticity of sheep between the Iron Age II and Persian period in Tel Dor and Tell Keisan. This width-focused increase suggests a relatively rapid enlargement of body size at the population level in these sites. This is less likely to be due to feeding or husbandry improvements, which would appear as a gradual increase over sequential time periods. This size increase could indicate more mature males being kept in a sheep population to exploit their only secondary or ‘lifetime’ product – wool (Sherratt, 1983; Vigne and Helmer, 2007; Trentacoste et al., 2021).

Table 7
Summary statistics per site and time period for length and width LSI values.

LSI			Length						Width					
Zone	Site	Period	N	mean	median	min	max	sd	N	mean	median	min	max	sd
Inland	ABM	MBA	7	0.040	0.041	0.008	0.071	0.025	9	0.058	0.065	0.015	0.100	0.036
	ABM	LBA	12	0.033	0.036	−0.067	0.092	0.046	17	0.048	0.041	−0.006	0.115	0.028
	ABM	IA 1	45	0.036	0.036	−0.067	0.120	0.038	50	0.052	0.056	−0.026	0.108	0.028
	ABM	IA 2	178	0.051	0.051	−0.023	0.114	0.021	178	0.042	0.043	−0.018	0.099	0.022
	HZR	MBA	9	0.040	0.037	0.009	0.075	0.024	18	0.054	0.067	−0.007	0.096	0.034
	HZR	LBA	21	0.052	0.054	−0.017	0.102	0.034	36	0.052	0.047	−0.012	0.118	0.035
	HZR	IA 1	6	0.059	0.060	0.033	0.077	0.017	11	0.055	0.052	0.024	0.091	0.022
	HZR	IA 2	40	0.034	0.037	−0.051	0.144	0.046	47	0.050	0.045	−0.078	0.169	0.041
	RHV	LBA	4	0.026	0.018	−0.007	0.076	0.035	10	0.072	0.073	−0.023	0.179	0.060
	RHV	IA 1	10	0.046	0.043	−0.008	0.093	0.032	31	0.049	0.047	−0.010	0.116	0.028
	RHV	IA 2	473	0.044	0.045	−0.104	0.226	0.035	666	0.049	0.049	−0.098	0.155	0.033
Coastal	AZV	MBA	1	−0.017	−0.017	−0.017	−0.017	–	1	0.050	0.050	0.050	0.050	–
	AZV	IA 2	5	0.025	0.019	−0.058	0.116	0.062	10	0.047	0.046	−0.001	0.112	0.038
	KBR	MBA	33	0.014	0.017	−0.193	0.089	0.055	34	0.014	0.018	−0.100	0.093	0.044
	KBR	IA 1	5	0.029	0.021	−0.026	0.091	0.044	3	0.003	−0.004	−0.052	0.064	0.058
	KSN	IA 2	79	0.033	0.038	−0.064	0.105	0.039	111	0.059	0.057	−0.057	0.150	0.038
	KSN	PER	35	0.055	0.047	−0.026	0.126	0.035	55	0.078	0.080	−0.006	0.142	0.035
	SHQ	LBA	3	0.023	0.018	0.006	0.046	0.021	4	0.014	0.002	−0.010	0.061	0.032
	SHQ	IA 1	6	0.035	0.021	−0.022	0.157	0.063	8	−0.035	−0.023	−0.141	0.029	0.064
	SHQ	IA 2	3	0.046	0.043	0.041	0.055	0.008	3	0.067	0.065	0.063	0.074	0.006
	DOR	LBA	15	0.054	0.045	0.006	0.117	0.029	70	0.038	0.037	−0.033	0.115	0.031
	DOR	IA 1	9	0.061	0.056	0.025	0.122	0.035	14	0.033	0.039	−0.173	0.112	0.069
	DOR	IA 2	54	0.038	0.049	−0.150	0.135	0.048	76	0.039	0.035	−0.094	0.158	0.043
	DOR	PER	6	0.058	0.069	0.021	0.087	0.028	16	0.056	0.045	0.017	0.118	0.033
	Total		**1059**						**1478**					

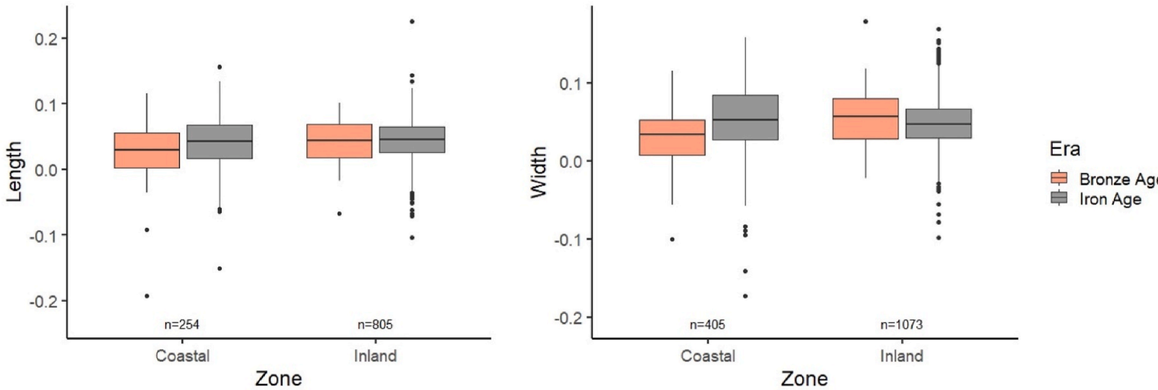

Fig. 2. LSI values for length (left) and width (right) grouped by zone (Coastal/Inland) and subset into era (Bronze Age/Iron Age).

Table 8
Results of the Kruskal-Wallis test for the LSI length and width values by era and zone. Significant results are italicized.

Data	Chi-squared	Df	P-value	Effect size ε^2
Length ~ Era	4.4615	1	*0.035*	0.003
Width ~ Era	9.0086	1	*0.003*	0.005
Length ~ Zone	2.9441	1	0.086	0.002
Width ~ Zone	0.028719	1	0.8654	<0.001

Although a larger proportion of male animals in a herd would be expected to manifest in an increase in both lengths and widths, the difference in sample sizes for length and width LSI values in this study may account for the less significant increase in lengths. The introduction of non-local sheep is another possible explanation for this result; similar jumps in size in a relatively short time period have previously been linked to the introduction of foreign stock (Davis, 2006, 2008; Trentacoste et al., 2018).

9.2. Astragalar proportion variation: functional adaptation to Open–Closed environments

The visualization of the ADI analysis alludes to geographical variation of astragalar proportions, perhaps based on inherited locomotive functionality adapted to the differing topographies of open and closed environments (Haruda et al., 2019). Sheep astragali from open environments (savannah, steppe, plain) are optimized for speed and stability, whereas those inhabiting closed environments (forests, heavy vegetative cover, mountainous gradients) are optimized for mobility and powerful bursts of movement (Haruda et al., 2019). The astragalar proportions of the coastal sheep (IA2 DOR, IA2 KSN, PER KSN) in our study seem to align with those from more open environments (c.f. Neolithic sheep from Khirokitia, Cyprus, situated on a hill 6 km from the coastline [Davis 2017a: 65, Fig 9.3], while the inland group (IA2 ABM) seems to reflect that of more isolated, closed environments (c.f. unimproved Shetland sheep from Hoy, Orkney, Scotland [Davis 2017a: 63, Fig. 9.2]). An east-west gradient of astragalar proportions appears to encompass the spectrum of coastal and inland sheep ecomorphotypes. We interpret this pattern as a manifestation of an aspect of the variability among astragalar morphologies of the region's sheep in the Iron Age and Persian period southern Levant.

9.3. Possible influences on sheep biometry in Southern Phoenicia

The sites in which we found evidence for size changes in sheep flocks between the late Iron Age and Persian Period, Tel Dor and Tell Keisan, were within the southern periphery of the territory controlled by the Phoenician city-states of Tyre and Sidon during this time (Briend and Humbert, 1980; Lehmann, 2001, 2021; Aubet, 2014; Gilboa, 2015; Gilboa et al., 2015; Yasur-Landau et al., 2016; Gilboa and Sharon, 2017;

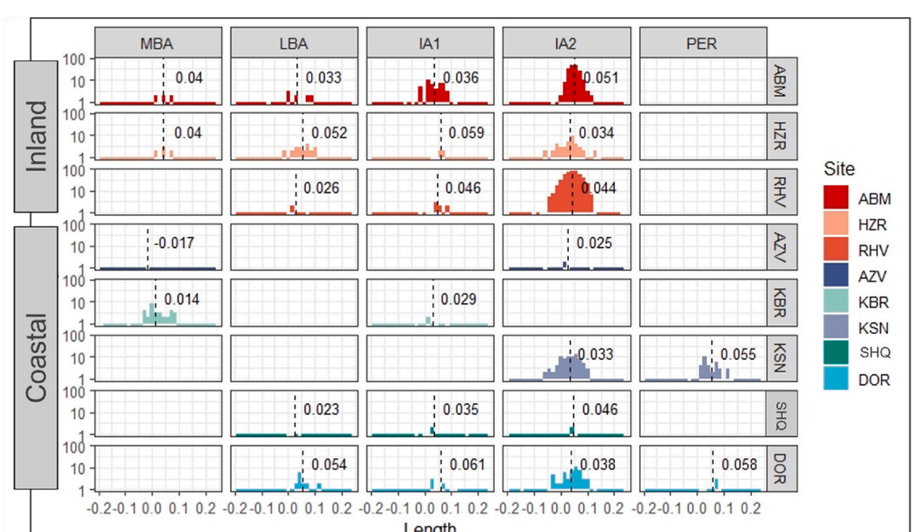

Fig. 3. Distributions of LSI length values per site and period. Sample size is represented on the y-axis, and LSI values are represented on the x-axis. Vertical black dashed line and text within the facets represent mean values.

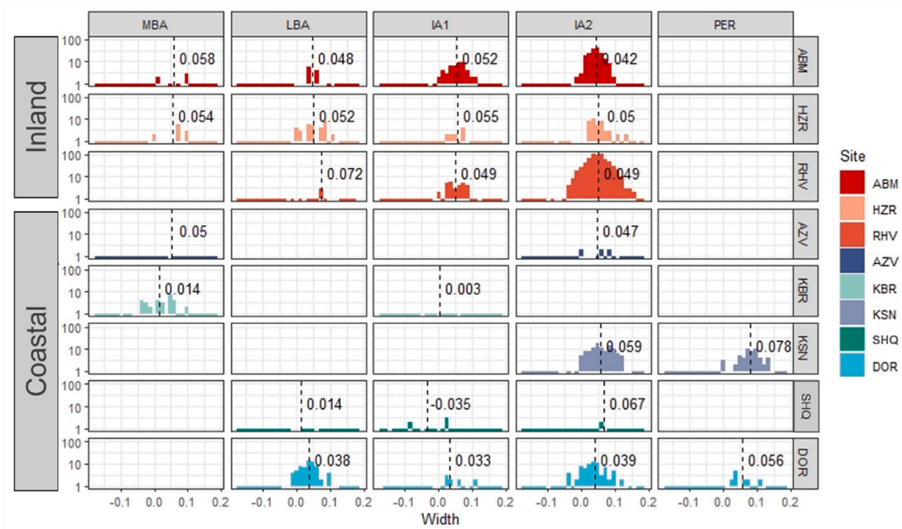

Fig. 4. Distributions of LSI width values per site and period. Sample size is represented on the y-axis, and LSI values are represented on the x-axis. Vertical black dashed line and text within the facets represent mean values.

Table 9
Results of the Kruskal-Wallis test for the LSI length and width values by site and period. Significant results are italicized.

Data	Chi-squared	Df	P-value	Effect size ε^2
Length ~ Site	23.013	7	*0.002*	0.014
Width ~ Site	80.375	7	*<0.001*	0.048
Length ~ Period	15.171	4	*0.004*	0.009
Width ~ Period	42.18	4	*<0.001*	0.025

Table 10
Results of the Dunn's test on the pair-wise comparisons between the width values of the study sites. Significant results are italicized.

Comparison	Z	P.adj
ABM - AZV	−1.4613202	0.864
ABM - DOR	0.9873224	1.000
AZV - DOR	1.9519939	0.509
ABM - HZR	1.7010617	0.712
AZV – HZR	0.3550061	0.723
DOR - HZR	−2.4181552	0.187
ABM - KBR	3.5674285	*0.007*
AZV - KBR	3.7858517	*0.003*
DOR - KBR	2.9645791	*0.0455*
HZR - KBR	4.3331583	*<0.001*
ABM - KSN	−5.7640019	*<0.001*
AZV - KSN	−1.6926384	0.634
DOR - KSN	−6.3214945	*<0.001*
HZR - KSN	−3.1183110	*0.029*
KBR - KSN	−6.6376956	*<0.001*
ABM - RHV	−1.8458617	0.584
AZV - RHV	0.7336045	1.000
DOR - RHV	−2.8201408	0.067
HZR – RHV	0.5665669	1.000
KBR – RHV	−4.5349198	*<0.001*
KSN - RHV	5.1027724	*<0.001*
ABM - SHQ	2.7916177	0.068
AZV - SHQ	3.2600335	*0.020*
DOR - SHQ	2.4156030	0.173
HZR - SHQ	3.3985375	*0.013*
KBR - SHQ	0.3979702	1.000
KSN - SHQ	4.8725240	*<0.001*
RHV - SHQ	3.3593205	*0.014*

Table 11
Results of the Dunn's test on the pair-wise comparisons between the width values of the study periods. Significant results are italicized.

Comparison	Z	P.adj
IA1 - IA2	−0.4353700	0.663
IA1 - LBA	0.8075775	0.839
IA2 – LBA	1.5888186	0.448
IA1 - MBA	1.6799531	*0.047*
IA2 - MBA	2.3456889	0.114
LBA - MBA	1.0599409	0.868
IA1 - PER	−4.8359819	*<0.001*
IA2 - PER	−5.5941113	*<0.001*
LBA - PER	−5.6702643	*<0.001*
MBA - PER	−5.7036537	*<0.001*

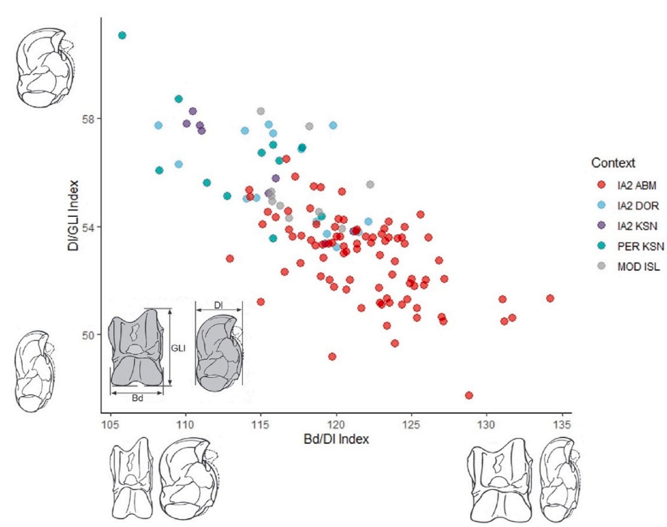

Fig. 5. A scatter diagram of the two ADI indexes, Bd/Dl and Dl/GLl, formulated from linear measurements taken on the N = 130 astragali included in the GMM analysis, modified after Davis (2017a: 65, Fig 9.3) (used with permission).

Woolmer, 2017; Sader, 2019). Both of these coastal settlements were well connected to Eastern Mediterranean maritime trade networks; Keisan was serviced by the harbor at Akko, and Dor was itself a port town on the Carmel coast (Briend and Humbert, 1980; Nitschke et al., 2011; Gilboa, 2015; Gilboa et al., 2015; Gilboa and Sharon, 2017; Sader, 2019; Tell Keisan Excavations, 2020). The ceramic assemblages of these two extremely well-stratified tells suggest deep and long-lasting trade relationships with Cyprus and the Aegean, among other far-flung Eastern Mediterranean locales, during the Iron Age and Persian period (Aubet, 2014; Gilboa and Sharon, 2017; Gilboa et al., 2017; Lehmann et al., 2019; Sader, 2019). These settlements were directly involved in the economic initiatives of Tyre and Sidon, including the manufacture of Murex purple dyes and fine wool tinted with these pigments (Aubet, 2014; Woolmer, 2017; Sader, 2019). Therefore, wooly sheep would likely have been in high demand to supply the local textile industry.

The combined biometric results of this study suggest that data from sheep herds in Persian period southern Phoenicia do appear to show a sudden and significant increase in body size when compared to earlier coastal and contemporaneous inland flocks. This phenomenon suggests herd improvements and does not rule out the possibility of non-local introductions to coastal sheep flocks, specifically at Tel Dor and Tel Keisan. Based on the data at hand, we find the most parsimonious explanation for this size increase to be a change in herd culling strategies which retained more mature males—possibly in support of the textile industries in southern Phoenicia. Stock introductions may also have taken place on the coast, as variation in astragalar proportions tended to reflect geographical trends in the data. Considering the slight overlap of coastal and inland sheep in the ADI analysis, some east-west exchange of sheep may have taken place. Based on this metric alone, however, it is not possible to say in which direction the sheep were being moved, nor from where any introduced sheep arrived.

A possible source for any introductions into the coastal flocks could be from the inland settlements, though ostensibly these sheep would have been of a similar regional fleece type. An alternative origin could be non-Levantine sheep introduced by sea trade along the Phoenician maritime trade networks, i.e., fine-woolled sheep imported by ship from the Aegean region. This latter speculation is especially supported by various ceramic studies which indicate a rejuvenation and expansion of maritime trade in the eastern Mediterranean during the Persian period. The ceramic assemblages on the littoral of southern Phoenicia suggest intensive trade with Athens and the Greek isles (Chios, Samos, Miletos, Mende, Thasos, and Clazomenia), Crete, Cyprus, and Cilicia, probably facilitated by Greek mariners, beginning in c. the 5th century BCE (Steward and Martin, 2005; Nitschke et al., 2011; Gilboa et al., 2017; Lehmann et al., 2019). It was noted that the ships carrying these ceramic cargoes from the Aegean to southern Phoenicia also transported other high-value commodities, including wool (Lehmann et al., 2019); perhaps livestock were also carried onboard.

10. Conclusions

The present study utilized log size index and astragalar dimension index analyses to detect changes in body size and demonstrate the spectrum of astragalar proportions of domestic sheep in the Bronze and Iron Ages in the southern Levant. The significant increase in robusticity seen in the Persian period in Tel Dor and Tell Keisan may be attributed to a herd profile optimized for wool production or the introduction of new breeding stock in pursuit of a specific, highly desired trait such as finer fleece—which native flocks ostensibly did not possess. If sheep were indeed being imported into Persian period southern Phoenicia, we suggest that possible sources of these imports could be from inland southern Levant settlements or from elsewhere along the Phoenician eastern Mediterranean trade networks. The established connections between the Aegean and the Carmel coast in the Persian period could hint at an alternative origin, however further research is needed to confirm the provenance of any potentially imported stock. A geometric morphometric study on the astragali used in the ADI analysis may reveal more information regarding the geographic origins of this phenomenon.

Increasing knowledge of the human-mediated translocation of domesticated animals in the Persian period southern Levant has implications not only for the study at hand, but broadens our understanding of the types and modes of exchange of diverse goods and commodities in the premodern Eastern Mediterranean. The movement of livestock through ancient Mediterranean trade networks, especially maritime, has been postulated to have occurred in southern Phoenicia but without specific comprehension of where, how, why, and by whom because of the previous difficulty in detecting this phenomenon archaeologically (Gilboa et al., 2015: 70). Answers to these questions shed light on trans-regional trading partners, the *chaîne opératoire* of ancient wool textile production, as well as complement current studies aimed at increasing understanding of the prototypes of modern sheep breeds in the ancient Near East (Vila et al., 2021). Additionally, the combination of methodologies used herein may be applied in other spatiotemporal settings to inform upon the dispersal trajectories of domestic sheep, one of the most important livestock species in the ancient world.

Author contributions

Conceptualizing Methodology: Nimrod Marom, Sierra Harding; **Software:** Sierra Harding, Nimrod Marom; **Validation:** Nimrod Marom, Sierra Harding; **Formal analysis:** Sierra Harding, Nimrod Marom; **Investigation:** Sierra Harding, Shyama Vermeersch, Catherine Ujma, Ghavin Deonarain, Matthew Susnow, Ayelet Gilboa, Gunnar Lehmann, Nimrod Marom; **Resources:** Roee Shaffir; **Writing – Original Draft:** Sierra Harding; **Writing – Review & Editing:** Sierra Harding, Shyama Vermeersch, Catherine Ujma, Ghavin Deonarain, Matthew Susnow, Ayelet Gilboa, Gunnar Lehmann, Nimrod Marom; **Visualization:** Sierra Harding; **Supervision:** Nimrod Marom; **Project Administration:** Sierra Harding; Funding **Acquisition:** Nimrod Marom, Gunnar Lehmann.

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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.quaint.2023.02.014.

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