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Ecology of the Past - Late Bronze and Iron Age Landscapes, People and Climate Change in Philistia (the Southern Coastal Plain and Shephelah), Israel

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Abstract

Here we present a case study using modern ecological data (collected over the period 1948-2014) to assess changes that took place in plant and animal occurrences in the 12th century BCE in Philistia – the southern coastal plain of Israel and the Judean foothills in its immediate hinterland, as a result of either shifts in anthropogenic behavior or climate. Using published archaeobotanical and archaeozoological data from several archaeological sites in this region (e.g. Tel Aphek, Tell es-Safi/Gath, Tel Miqne/Ekron, Ashkelon), we compared habitat associations of these palaeo-assemblages to observations on modern plants and animals from the same geographic region. Multivariate analytical methods, DCA and CCA ordination, showed mesic to xeric gradients in both the modern and the archaeological data. The clearest pattern in the archaeological data was a separation of Late Bronze Age (mesic) from Iron Age I and Iron Age II sites (xeric). We interpret this shift as reflecting the decrease in rainfall between the Late Bronze Age (ca.1550-1180 BCE) and Iron Age (ca. 1180-586 BCE) periods, a phenomenon that has been documented in the Eastern Mediterranean in general by other palaeoclimatic proxies (e.g. pollen, cave speleothems and the Dead Sea level).

Introduction

For archaeologists and anthropologists today, the meaning of the word “landscape” is perceived as “part of a world of movement, relationships, memories and histories” (Bender 2001). In this sense, landscapes are first and foremost cultural products (Tilley 1994:25). This perception conforms to one of the central topics of landscape ecology, namely the role played by humans in creating and influencing patterns and process in landscapes (e.g. Forman and Godron 1986; Hirsch and O’Hanlon 1995; Naveh and Lieberman 1994; Turner et al. 2001).

It is clear that as humans inhabit and exploit a natural landscape they modify it, resulting in human-induced habitat changes (e.g. Mercuri 2014). As Blondel (2006:713) noted with respect to the Mediterranean Basin, “A complex ‘coevolution’ has been claimed to shape the interactions between ecosystem components and human societies”. Though we can detect some signals indicative of changing landscapes in the archaeological record, it is often difficult to determine whether these are anthropogenically engendered or a response to a change in the natural environment or climate, since the pattern of response may be similar (for example overgrazing versus drought - Olsvig-

Whittaker et al. 2006). In many instances this misperception may be clarified when adequate information on ancient physical environmental conditions as well as palaeo-biological information is available, as with the present study.

In this paper we have used multivariate analytical methods - DCA (detrended correspondence analysis) and CCA (canonical correspondence, see Jongman and van Tongeren 1995 for methods) - to compare diachronic patterns in palaeobotanical and archaeozoological assemblage data across three periods - the Late Bronze (ca.1550-1180 BCE), Iron Age I (ca. 1180-950 BCE) and Iron Age II (ca. 950-586 BCE), from two contiguous geographic regions in Israel that make up Philistia (Fig. 1) - the southern coastal plain and the Judean foothills lying in its immediate hinterland (the Shephelah in Hebrew). These regions comprise the area occupied at the Late Bronze/early Iron Age transition by the Philistines, one of the so-called “Sea Peoples” and have been the focus of research by the authors (e.g., papers in Maeir 2012).

To document the sequence of palaeoenvironmental and palaeoclimatic changes that may have taken place in this region, we compared species lists of ancient floral and faunal assemblages from several archaeological sites (Fig. 1), to a modern proxy dataset, all from the same region. In particular, we wished to determine whether we could detect effects of the Levantine Late Bronze Age (LBA) climate collapse, characterized by a shift from cool and moist conditions to more arid, drier ones towards the end of the Late Bronze Age through the Iron Age (IA) ca. 1100 BCE, as documented in numerous studies based on different palaeoclimatic proxies (e.g., Bar-Matthews et al. 1998; Bar-Matthews and Ayalon 2004; Bookman et al. 2004; Kaniewski et al. 2013; Langgut et al. 2013, 2015; Neumann et al. 2007; Rosen 2007). It should however, be noted, that, many of these palaeoclimate proxies (e.g. palynology, isotope analyses, Dead Sea Levels) that cover this timespan, do not derive from the immediate study region, but rather from the Jordan Valley and its proximity, which lies ca. 150 km to the east of the study area (e.g. Baruch 1986; Bookman et al. 2004; Migowski et al. 2006; Litt et al. 2010; Neumann et al. 2010). As such, the current study may assist in filling this geographic hiatus in the palaeoenvironmental/palaeoclimatic record of the southern coastal plain and the Shephelah in Israel.

The Southern Coastal Plain and its Hinterland (the Shephelah)

Geography

The study area stretches from the southern coastal plain (The Philistine Plain) that abuts the Mediterranean Sea in the west, up to and including the Judean foothills (Shephelah) in the east (Fig. 1).

The coastal plain comprises sand fields, dunes and a series of elongated sub-parallel aeolianite ridges that

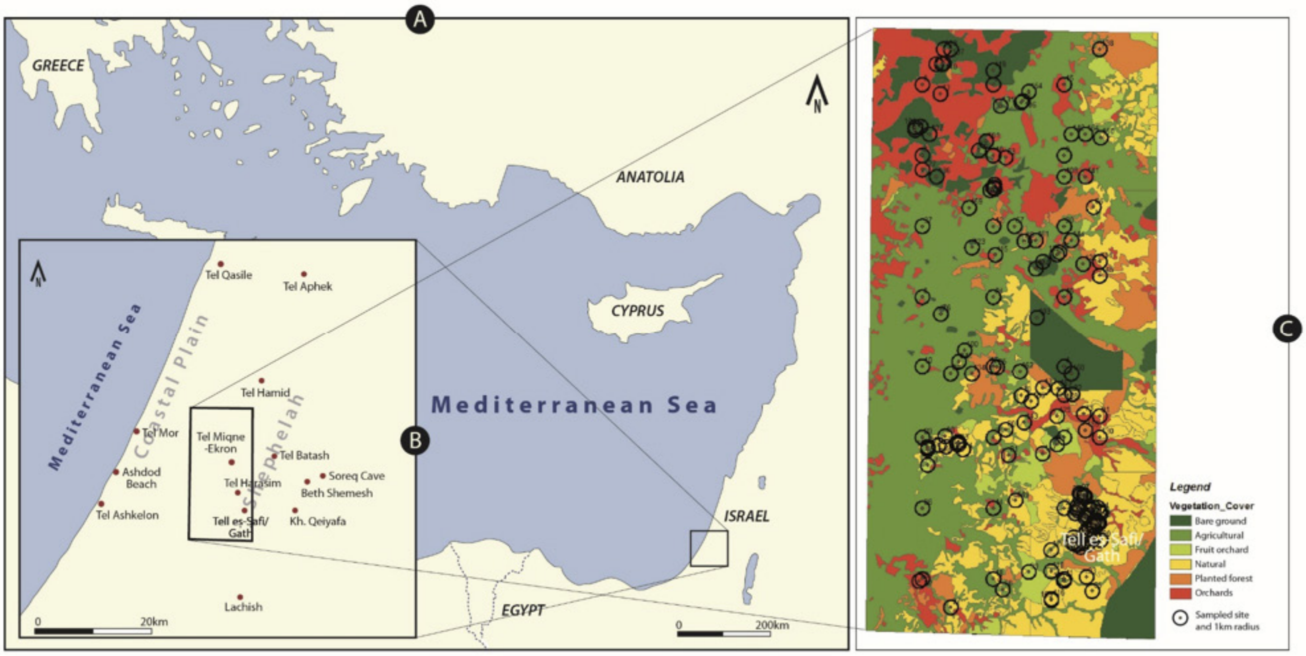


Fig. 1. Left: Map showing archaeological sites for which published archaeobotanical and archaeozoological data were used in this study. Also shown is Soreq Cave - a source of palaeoclimatic data for the research region and the boundaries of the coastal plain and Shephelah Right: Modern plant observations superimposed on GIS vegetation cover layer (where: 0=Bare ground; 608= Agricultural; 609=Bustan (fruit orchard); 617=Natural; 626= Planted forest; 660-Orchards-see Appendix 2) Circles around the points represent a 1 km radius within which the different environmental factors (soil type, land use type and vegetation cover, see Appendix 2), were quantified for each sampled modern locality.

reach a height of ~20m (Tsoar 2000). In between the ridges are low depressions known as troughs (slack; Almagor 2005; Gvirtzman et al. 1998; Zilberman et al. 2006). These ridges and troughs contain aeolianite sandstone (*kurkar)*, intercalated with layers of Hamra, red sandy clay loam (*Luvisols)*, and clayey soil Grumusols and dark brown soils (*Vertisols).* In the southern coastal plains sandy to loamy Pararendzinas occur on the aeolianite ridges (Dan et al. 1972; 1976; 2007; Singer 2007).

The geomorphological structure of alternating ridges and troughs as well as the small number of natural channels that cut the ridges and drain water from the Judean hills and Judean Mountains, has resulted in poor drainage conditions on the coastal plain, creating a swamp-like environment. Such conditions would have prevailed primarily during periods of increased rainfall (Cohen-Seffer et al. 2005; Faust and Ashkenazi 2007, 2009). For the same reasons there are also seasonal wetlands (vernal pools) on the coastal plain that have persisted until today, but are currently threatened by drainage and development (Levin et al. 2009).

The Judean foothills to the east of the coastal plain, range in height from 200 to 400 m.a.s.l. The bedrock of the hills is primarily composed of white Eocene chalk of the "Maresha" and "Adulam" formations (Buchbinder 1969; Sneh et al., 1988) which is overlain by calcrete, known locally as *Nari* (Wieder et al. 1994; Itkin et al. 2012). The slopes and the footslopes are covered by Brown Rendzina soil (*Rendzinas*) which is found in soil pockets on slopes with calcrete, while Pale Rendzina soil (*Rendzinas*)) is found on the soft chalk where the calcrete is absent. In the large valleys beteween the foothills, there are dark brown soils or Grumusols (*Vertisols*) (Dan et al. 1972, 1976, 2007; Singer 2007).

Rainfall and Vegetation

The research region is characterized as semi-arid Mediterranean (Kafle and Bruins 2009). Summers are hot and dry while winters are cool and rainy. Mean temperatures in January and August are 12°C and 26°C, respectively, with a mean annual temperature of 20°C. The rainy season generally lasts from October to May, and rainfall ranges from 401-600 mm per year, with a mean annual rainfall of 450 mm (Israel Meteorological Service 2011).

In his classic study of the phytogeography of the region of Israel, Palestine and Jordan, Zohary (1962) placed the Philistine Plain solidly within the Mediterranean phytogeographic zone, with a narrow coastal strip having Saharo-Arabian elements. The coastal strip has moving and stable dunes, with kurkar ridges, each with distinctive azonal plant assemblages, particularly dominated by *Artemisia monosperma*, *Ammophila arenaria*, *Cyperus mucronatus* and *C. conglomeratus*, with a fairly rich assortment of annuals inland beyond the salt spray.

Although the coastal plain and its hinterland (the Shephelah) are now highly developed for both urban and agriculture areas, what remains of the natural vegetation is varied. The most distinctive alliance of th coastal plain is what Zohary (1962, p. 102) terms the "Carob-Lentisk after Maquis, dominated by *Ceratonia siliqua*, *Pistacia palaestina*, and *P. lentiscus*, with *Sarcopoterium spinosum* common in the dwarf shrub layer in the zone between maquis and steppe (Danin 1988a). Zohary describes this zone as "steppe-maquis" with invasive Irano-Turanian elements, which is distinctive for the southern part of the Philistine Plain, with scattered *Amygdalus communis* and *Crataegus azarolus*. The herbaceous vegetation in this transitional area is very rich in annual species and geophytes. The natural vegetation of the Shephelah also has the Carob-Lentisk Maquis but with a denser understory of Mediterranean chamaephytes such as *Cistus villosus*, *C. salviifolius, Calycotome villosa, Salvia fruticosa* and other shrub species (Zohary 1962; plant nomenclature used here follows Danin 1998). It sometimes includes *Olea europaea*, the wild olive. However, this zone has been widely disturbed by agriculture, viticulture and forest plantations (cypress, pine, eucalyptus and other introduced species) which have greatly altered the vegetation. Similarly, most fauna found today in the research area are managed herds of caprines or cattle, while in terms of game animals, this region has suffered severe denudation due to hunting, human settlement and habitat destruction (Yom-Tov and Mendelssohn 1988).

Ecologically the area is interesting as a transition zone from Mediterranean to semi-desert steppe, which is sensitive to climate change, as Irano-Turanian elements infiltrate from the northern Negev under drier conditions, or due to the invasion of xeric plants into Mediterranean communities following anthropogenic disturbance to the soil (Yom-Tov 1988; Mendelssohn and Yom-Tov 1988; Zohary 1962: 109).

The Alluvial and Climatic Records

Few high-resolution palaeoclimatic records exist for the study region.

The Holocene alluvial sedimentological history of the Shephelah region was studied by Rosen (1986a; 1986b; 1995; 2007) based on Nahal Lachish near Tel Lachish and Tel Erani (Fig. 1) and by Ackermann et al. (2014a) based on Nahal Ha'-Ela, near tell es Safi/Gath (fig Fig. 1. Four main alluvial phases were defined: (1) Aggradation (fill of sediment) of fine-grained sediments during the Chalcolithic period and the Early Bronze Age (5500–2000 BCE) on the floodplains. probably indicating more frequent flows (Rosen 1995); (2) Overbank flows ceased, almost completely, degradation (cut and sediment evacuation) with short depositional episodes in the valleys during the Middle Bronze Age (ca. 2000 BCE, see Bietak 2002) to the Roman period to (ca.300 CE), (3) Regional aggradation during the Roman and Byzantine periods or shortly thereafter (post-2nd century CE); (4) Incision and degradation during post-Byzantine period (post-7th century CE).

Rainfall records from speleothems dated by U-series in the nearby Soreq Cave (at a distance of ca. 20-40 km from the research area) , show a drop in annual rainfall towards the end of the Late Bronze Age (ca. 1200 BCE), a trend that persisted until the mid-Roman era (circa 100 CE) though punctuated by fluctuations (Bar-Matthews et al. 1998, 2004). The isotopic composition of plankton from Mediterranean Sea marine cores near Ashdod on the coastal plain, provides a further proxy dataset and demonstrates that by the terminal Late Bronze Age (ca. 1050 BCE), arid conditions prevailed in the region (Schilman et al. 2002).

A recent, multi-proxy study was undertaken by Ackermann et al. (2014a; 2014b) including geomorphology and analyses of phytolith, pollen and isotope records from sediment sections adjacent to Tell es-Safi/Gath. Results show that during the middle Holocene stable and relatively wet climatic conditions prevailed in the sites environs. However, during the subsequent Late Bronze and early Iron Ages there are some indicators for arid conditions prevailing in the region.

The Archaeological Record

In the Late Bronze Age, this part of the coastal plain of Israel and its hinterland was occupied primarily by the Canaanites, a local Levantine community who lived in city-states, although the region was under the rule of the Egyptian New Kingdom (Mazar 1992: 232 ff; papers in Bar et al. 2011). However, at the Late Bronze Age/Iron Age I transition, the Philistine culture appeared in this region (e.g., Yasur-Landau 2010). This culture, which is comprised of an amalgamation of newly arrived foreign migrants – many of whom derived from the Aegean and other central and eastern Mediterranean regions – and intermingled with local populations, was centered in five major cities (Gaza, Ashkelon, Ashdod, Tell es-Safi/Gath, Tel Miqne/Ekron). From this time on, until the late Iron Age II, there is material evidence in this region for the presence of a distinctive Philistine culture that combined various local (Canaanite) and non-local cultural traditions and communities (e.g. Maeir et al. 2012; Hitchcock and Maeir 2013).

Excavations of Late Bronze and Iron Age levels at sites in this region have provided a rich corpus of material artefacts (e.g. architecture, ceramics, lithics), as well as large assemblages of ecofacts (macro-/micro-fauna and plant remains). Studying these ecofacts (including identification of floral and faunal species represented) can supplement our understanding of the changes and processes that took place in the region. Specifically, we can learn about the diet of past peoples, their subsistence activities (i.e. hunting, gathering, fishing, herding, cultivation), management strategies and technologies used in plant and animal husbandry, habitats exploited as well as the climatic conditions prevailing in the region (e.g. Davis 1987; Hastorf and Popper 1989; Reitz and Wing 2008; Cappers and Neef 2012; Ackermann et al. 2014a).

Materials

Archaeobotany

An archaeobotanical data base was created from published species lists from seven sites in the research area (Lachish; Tel Aphek; Tell es-Safi/Gath; Tel Miqne/Ekron; Timna/Tel Qasile, Ashdod, for references see

Table 1. Sites used in the archaeobotanical analysis, their period attribution and publication reference.

Period	Site	Reference
Late Bronze	Tel Aphek	Kislev & Mahler-Slasky, 2009
	Tel Miqne/Ekron	Mahler-Slasky, 2004
	Tell es-Safi	Mahler-Slasky, 2004; Mahler-Slasky & Kislev, 2012
	Tel Batash (Timna)	Kislev et al., 2006
	Ashdod	Melamed, 2013
Iron Age II	Tel Aphek	Kislev & Mahler-Slasky, 2009
	Tel Miqne/Ekron	Mahler-Slasky, 2004
	Tell es-Safi/Gath	Mahler-Slasky & Kislev, 2012
	Tel Qasile	Kislev & Hopf, 1985
Iron Age IIII	Tel Aphek	Kislev & Mahler-Slasky, 2009
	Tell Miqne/Ekron	Mahler-Slasky, 2004
	Tell es-Safi/Gath	Kislev & Mahler-Slasky, 2012
	Lachish	Helbaek, 1958

Table 1), spanning the time periods examined here.

The plant remains that comprise this archaeobotanical dataset primarily represent seeds and fruit stones (see Appendix 1 for species list) that were either hand collected during excavation, collected after dry sieving of sediments, or, most commonly, following flotation. Most of plant remains are charred, the result of conflagrations that occurred at some of the sites (e.g., Tell es-Safi/Gath – Namdar et al. 2011), or else derive from hearths, a factor that has contributed to their preservation (for more details see Mahler-Slasky 2004; Mahler-Slasky & Kislev 2012).

Based on these published archaeobotanical reports, it is evident that during the Late Bronze and Iron Ages, both Canaanite, Philistine and other communities inhabiting or bordering on the research area had a common agrarian subsistence base focused on the cultivation of cereals (wheat, *Triticum turgidum* subsp. *parvicoccum*, barley, *Hordeum vulgare*), legumes (especially lentils, *Lens culinaris*), and grape (*Vitis vinifera*), fig (*Ficus carica*) and olives (*Olea europaea*). In addition to cultivars, a wide range of wild species were exploited (see Appendix 1 for species list). Notably though, the quantity and range of plant species exploited in the region increased following the Philistine migration due to the inclusion (as well introduction) of new local species (e.g. coriander *Coriandrum sativum*) as well as exotic species (e.g. cumin *Cuminum cyminum*) into the diet (Frumin 2014; Frumin et al. 2015).

Archaeozoology

Remains of animals that had been kept or consumed by past peoples comprise a large proportion of archaeological remains recovered during excavations. The remains include both post-cranial and cranial bones and teeth, the latter usually better represented given the robusticity of enamel (e.g. Reitz and Wing 2008). For most assemblages studied here, the faunal remains had been hand collected during excavation. Consequently, small sized species such as rodents, reptiles, fish and birds are under-represented in the sites due to biased recovery methods in the field (i.e. no sieving of sediments), and as such were excluded from this study.

A list of faunal species that had been identified from 12 archaeological sites in the Philistine plain (Lachish; Tel Aphek; Tel Qasile; Tell es-Safi/Gath; Tel Miqne/Ekron; Tel Harasim; Khirbet Qeiyafa; Tel Bet Shemesh; Tel Mor; Ashdod South; Ashkelon; Tel Hamid), spanning the same time periods as the archaeobotanical remains, was compiled on a site-by-site basis from published archaeozoological reports (for references in Table 2). Some sites have more than one time period and as such yielded multiple data sets. Based on these published reports it is evident that domestic herd animals - sheep (*Ovis aries*), goat (*Capra hircus*), cattle (*Bos taurus*) and pigs (*Sus scrofa*) - were the most common fauna exploited in all assemblages (Philistine and non-Philistine alike) and in all periods studied. Since these animals are raised and tended by people (including watering and foddering), they do not necessarily provide a reliable picture of the natural environment, and so were excluded from this analysis. It should be noted that translocation of European-bred domestic pigs to Philstia took place in the region during the Late Bronze-early Iron Age, and probably represent food animals introduced by the Philistines (Meiri et al. 2013).

Only wild mammals were included in the current study and represented 18 species (see list in Appendix

Table 2. Sites used in the archaeozoological analysis, their period attribution and publication reference.

Note: A few of the sites have yielded data from more than one period. We consider each period at a site to represent an independent archaeological entity.

Period	Site & Stratum	Reference
Late Bronze II-III	Tel Aphek XII-XI	Horwitz, 2009
	Tel Miqne/Ekron IX–VIII	Lev-Tov, 2000
	Tell es-Safi/Gath	Lev-Tov, 2012
	Tel Harasim V	Horwitz & Sade, 1993
	Tel Beth Shemesh 7	Tamar et al., 2013
	Tel Lachish S/3-2-1 & VI	Croft, 2004
	Tel Mor XI–VII (Ashdod)	Maher, 2007
	Ashdod S. Beach site	Hakker-Orion in Nahshoni 2013
Iron Age II	Tel Miqne/Ekron VI –IV	Lev-Tov, 2000
	Tell es-Safi/Gath	Lev-Tov, 2012
	Tel Beth Shemesh 6–5	Tamar et al., 2013
	Tel Aphek X10-9	Horwitz, 2009
	Tel Qasile	Davis, 1985
	Khirbet Qeiyafa	Kehati, 2009
Iron Age IIIIA	Tel Aphek X8	Horwitz, 2009
	Tel Hamid	Hesse & Griffith, in press
	Tell es-Safi /Gath	Lev-Tov, 2012
	Tel Lachish V-IV	Croft, 2004
Iron Age IIIIB	Tell es-Safi/Gath	Lev-Tov, 2012
	Tel Miqne/Ekron Ic /Ib	Lev-Tov, 2000
	Tel Lachish III-II	Croft, 2004
	Tel Ashkelon Grid 38,50	Hesse, Fulton & Wapnish, 2011

1). We note that many of the larger mammals identified in the sites (e.g., hippopotamus, *Hippopotamus amphibius*; hartebeest, *Alcelaphus bucelaphus*; lion, *Felis leo*; leopard, *Panthera pardus*) have since become extinct in the area as a result of multiple factors including hunting, disappearance of natural habitats and competition for prey species (Yom-Tov and Mendelssohn 1988; Tsahar et al. 2009; Yom-Tov 2013, Bar-Oz et al. 2015). They were included in the analysis since they represent the natural environment of that time.

Modern assemblages

For the modern data sets used in this paper we defined the core research area (using WGS84 coordinates as latitude v=370900 to 373800, longitude 387400 to 388700; or in New Israel National Grid as latitude 610 to 650, longitude 182 to 195), as roughly bounded by the modern settlements of Yad Binyamin in the north, Beit Guvrin in the south, Kiryat Gat in the west, and Kfar Zechariah in the east (Fig. 2).

In order to examine present-day habitats available in this region, we compiled two modern databases for the entire area, one for plants and a second for mammals that included all observations from the modern era (since ca. 1948 to 2014 CE). All available Israeli biological databases were queried: the observational records of the Israel Nature and Parks Authority (INPA), the BioGIS observational and collections database, and those of the Tel Aviv University (TAU) and The Hebrew University Natural History collections (HUJ). Only records with coordinates were used; WGS84 coordinates were converted to the New Israel National Grid for this study.

Sampling Problems

(1) Different species assemblages: Most of the modern observations were collected as individual observations following which assemblages were created by us, so that the correct association of species is unknown. The palaeobiological assemblages represent random collections that suffer from differential preservation and moreover, represent species that have been through an anthropogenic filter (selected- see point 5 below.

(2) Different time scales: The modern observations were pooled over time, though at most this was a 50 year time span. In contrast, the archaeobiological assemblages represent time averaging of far longer periods that also vary in the extent of the time spans represented.

(3) The location data in the modern databases may be inaccurate, while the archaeobiological assemblages integrate environmental conditions over a wide area that was exploited, not necessarily at the same time in each period.

(4) For both the modern and archaeobiological assemblages, no attempt was made to undertake statistically valid sampling.

(5) The archaeobotanical and archaeozoological remains are strongly influenced by human selection

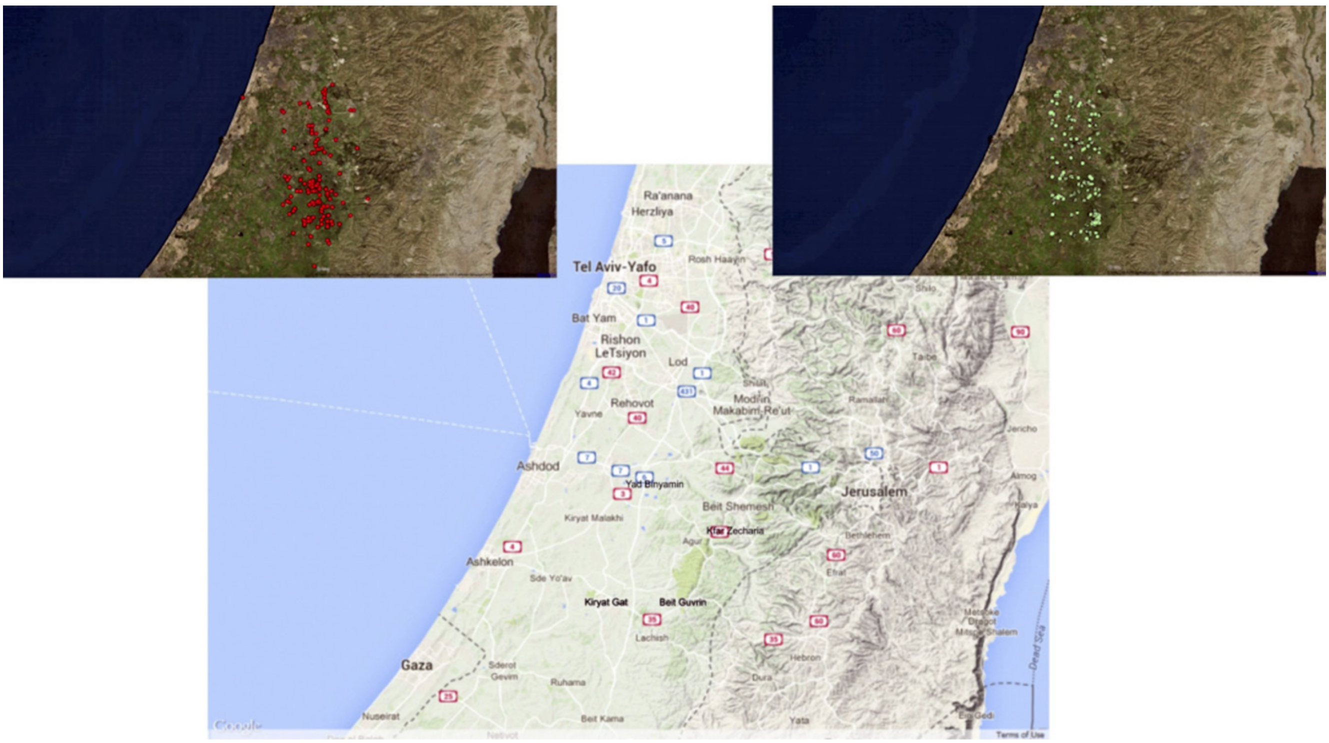


Fig. 2: Spatial distribution of modern plant and animal observations on the Coastal Plain and Shephelah. The area of observations (center) is roughly bounded by the modern settlements of Yad Binyamin in the north, Beit Guvrin in the south, Kiryat Gat in the west, and Kfar Zechariah in the east and correspond to the boxed area shown in Fig. 1b. (Upper right) Plant observations. (Upper left) Animal observations.

and preferences. Even though the archaeobotanical remains may come from burned dung (thus from natural rangeland species), the composition of rangelands may be heavily influenced by human activity as well. Likewise, the fauna may reflect cultural and dietary preferences rather than the full spectrum of species available in the landscape in a given time period.As such, the results obtained from the analyses of these data sets must be seen as purely heuristic.

Methods

Data management

Floral and faunal assemblages were analyzed separately. Most modern records of animals or plants were individual observations, so for use in multivariate analysis, artificial assemblage sites were created. This was undertaken by pooling (for fauna and plants separately), all records occurring at the same spot (i.e. same georeferenced coordinates) into what we term a "locality", regardless of observation date. The geographic distribution of the localities for modern vascular plants is shown in Figure 2, upper right. For modern plants the pooling produced 164 localities and 1166 species. A query for modern mammal data from the same sources provided 141 localities and 35 species (Fig. 2 upper left).

Analysis of archaeobotanical data was based on species lists from the five sites over three time periods (Late Bronze Age, Early Iron I and Early Iron II, see Table 1). Altogether, 167 taxa were identified. The lists were converted to a site by taxon matrix of presence-only data (1 for presence, 0 for absence) and this matrix was used in the analyses.

Analysis of archaeozoological data was based on species lists (wild species only) from 14 sites over four time periods (Late Bronze II-III, Iron Age I, Iron Age I and two phases of Iron Age II A and B; see Table 2). Altogether we used 22 wild animal taxa identified to the species level. As with the archaeobotanical data, the lists were converted to a matrix of presence-only data.

Analysis of assemblage patterns

For this research we have assumed that association between a given species and habitat (very generally defined) has not substantially changed over the period of time studied here. Thus, for example, species associated with open or closed vegetation in the present, were also associated with open or closed vegetation in the past (Zohary 1962).

Our best data for determining this association were the modern plant species assemblages. To obtain habitat information, we used the geographic layers available in the GIS lab of the INPA, including vegetation type, land use and soil type (see Appendix 2 for categories used). A radius of 1 km around the locality where plants were observed was used as the basis for compiling environmental data (Fig. 1c). For this map, vegetation type was based on the Open Areas survey, a national survey undertaken by Amos Sabach in 1995 for the INPA and mapped to GIS in the same year. This was a very coarse classification based on the dominant species, and would be equivalent to Land Use Type in today's practice. It was intended strictly for conservation management, not phytosociological studies. Soil type was taken from the national soil survey (Israel Geological Survey, updated 2014). Land use layers were from MAPI the Israel Land Survey, updated 2014. See Table 3 for categories used.

Multivariate analysis - indirect ordination and direct ordination - using Canoco 5 (Šmilauer and Lepš 2014) was selected as the tool for assessing patterns in both modern and archaeological mammal and plant data. While ordination has long been in use in community ecology, its application to archaeological data is somewhat more recent. There is a vast literature on the subject of ordination and many algorithms to do it (see Jongman et al 1995 for a review). In general, ordination methods help to find structure in complex community data sets, i.e. the predominant patterns in the species matrix. In the case of direct ordination, this is basically a regression of the species data versus the environmental data, conceptually similar to a stepwise multiple regression. Direct ordination can be used either heuristically or as a statistical test of correlation with measured driving factors, using Monte Carlo simulations. When environmental data are unavailable, indirect ordination is used. Most algorithms for indirect ordination calculate similarity/dissimilarity between species and sites. Results are projected onto two dimensions in such a way that similar species and sites are plotted close together, and dissimilar species and sites are placed far apart (Peet 1980). In the case of indirect ordination, interpretation depends on expert knowledge of species distribution by the botanists and zoologists participating in the project. In this study, interpretations of the botanical analyses were based on field experience and on floral distribution information given in the Flora of Israel Online website (http://flora.org.il/en/plants/), which is derived from Feinbrun-Dothan et al. (1991) and later work by A. Danin. For fauna, interpretations of the analyses were based on ecological information for each species given in Mendelssohn and Yom-Tov (1988).

Most importantly, in both direct and indirect ordinations, the species scatter (first and second ordination axes) and the site scatter plot can be superimposed. In this way we can see which species are driving the patterns in sites, and vice versa. This type of multivariate analysis of assemblage data has two advantages over single species analysis:

(1) When individual species data are too sparse to detect patterns, the correlation of less common species with more common species may reveal such patterns, and (2) A multivariate analysis can identify which species show the strongest correlation with driving variables; then these key species can be studied separately (Jongman et al. 1995).

Detrended Correspondence Analysis (DCA)

Detrended correspondence analysis (DCA) was used on the species matrices (both modern and archaeological) to determine major trends in variation of species distribution. Detrended correspondence analysis, is an indirect ordination method using only species data. DCA is an analytical approach in its own right, and is also is a necessary first step in every CANOCO analysis, regardless of algorithm. The first information obtained in DCA is the species turnover along the first gradient (Axis 1, horizontal), which is either short (less than 4 standard deviation units in species composition), in which case a linear model such as PCA or RDA can be used in in subsequent steps. If the gradient is longer than four standard deviation units, a unimodal model such as DCA, or Canonical Correspondence Analysis (CCA) is used in subsequent steps.

Canonical Correspondence Analysis (CCA)

In the case of the modern vegetation data, this particular dataset produced a long gradient (7 standard deviation units), hence analysis continued with the unimodal model in Canonical Correspondence Analysis. CCA was used to correlate the environmental data matrix only with the modern plant species. The strength of correlation was tested using Monte Carlo simulations, an option included in the CANOCO software.

Findings

The results of the multivariate analyses carried in this study are generated by information obtained from 'expert knowledge' and as are interpretations of the graphs rather than clinical observations. Without such interpretations there are in fact, no results.

Flora

Modern Plants

DCA: After an initial DCA ordination identified outlier localities (e.g. localities with composition so different that they dominated the ordination), three (aquatic) localities were removed, leaving 162 localities.

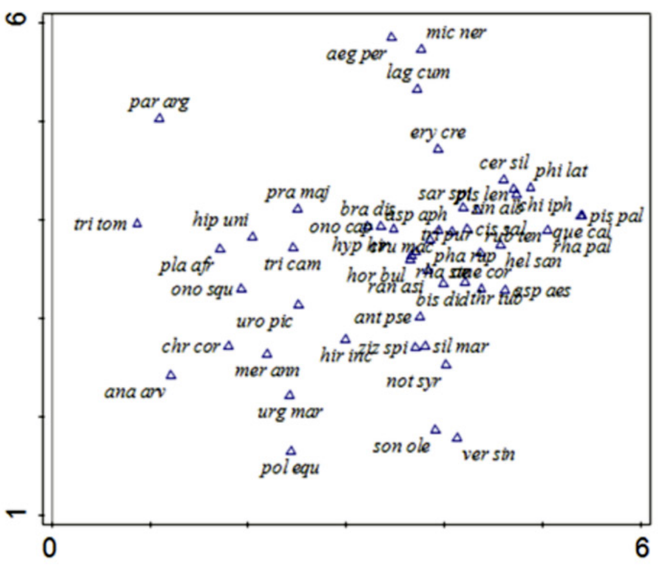
On the basis of our ecological knowledge of the species, the first (horizontal) axis of the DCA ordination (Fig. 3) was interpreted as a gradient from open vegetation species on the left, to dense maquis/forest species on the right on the first axis. The second (vertical) axis was less clear, but species that increase with grazing (like *Notobasis syriaca*) below the axis center, and species that decrease with grazing (like *Aegilops peregrina*) above it, indicate that this may be a grazing gradient, which is a common pattern in the mixed steppe and maquis vegetation of this area (Olsvig-Whittaker et al. 2006).

CCA: When all environmental factors were included in the analysis, two main groups of species and environmental factors appeared. One group included "agriculture" and "grumusol soil" (Appendix 2) as the driving factors; the second cluster included "woodland" and "orchards" and included the majority of the plant species. However, only the factors "orchards" and "agriculture" were significant. Therefore, to clarify this pattern, a second CCA test was run using only the two most significant environmental factors, "orchards" and "agriculture" (Fig. 4). This ordination was statistically significant ($p = 0.058$ on the first axis, and $p = 0.04$ on all axes).

The main gradient in the localities data set is from open to closed vegetation, or from "agricultural fields" to "orchards" (the latter probably include forest and maquis). Most species (top right of plot) are associated with the more 'natural' vegetation, (forest and maquis) and orchards (perhaps terraces), but several species such as *Dittrichia viscosa, Bituminaria bituminosa, Amaranthus retroflexus* and others cluster together (bottom left of plot) and are correlated with open areas or agricultural fields (Fig. 4). These may be noteworthy when looking at the archaeobotanical record. Their presence should indicate clearing and field development.

Archaeobotanical Data

DCA ordination of archaeobotanical data was run both with and then without *Olea europaea* (olives) since this is a dominant species in all assemblages and tended to swamp the more subtle patterning. When olives were removed from the data base, the first axis (horizontal) of the DCA (Fig. 5) showed a separation between relatively "xeric" species such as *Echium judaeum* in the upper right hand corner of the DCA biplot and relatively "mesic" taxa such as *Galium* sp. in the lower left corner. However, the patterns differ from the modern plant species and along the second axis they do not separate out as clearly as



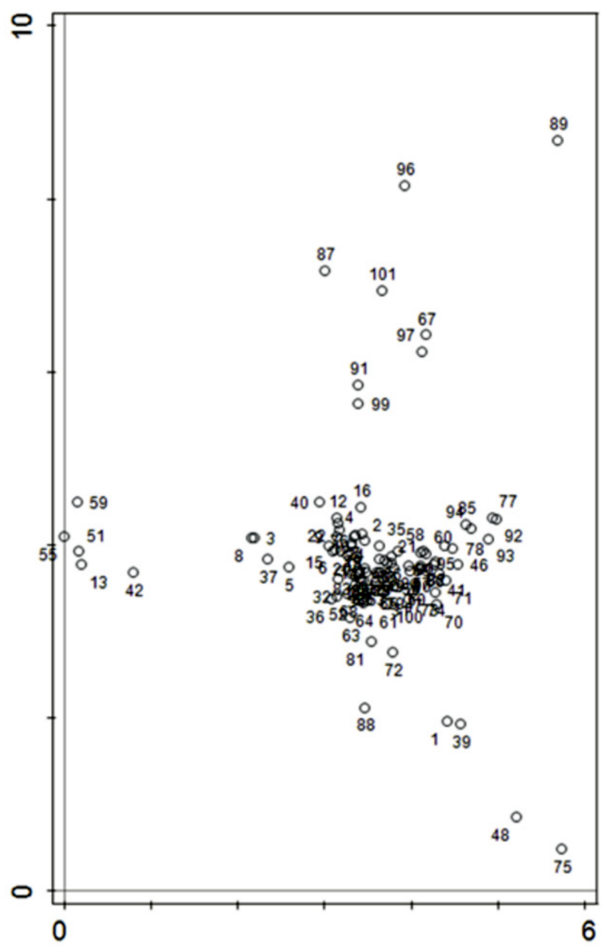


Fig. 3: DCA ordination of modern vascular plant observations, showing 50 species with best fit to the axes, and corresponding sample sites. (As with all CANOCO ordinations, the samples can be superimposed on the species to determine which species correlate best with which samples.) Left: species biplot on DCA axes 1 and 2; Right: site biplot on DCA axes 1 and 2. See Appendix 1 for species abbreviations.

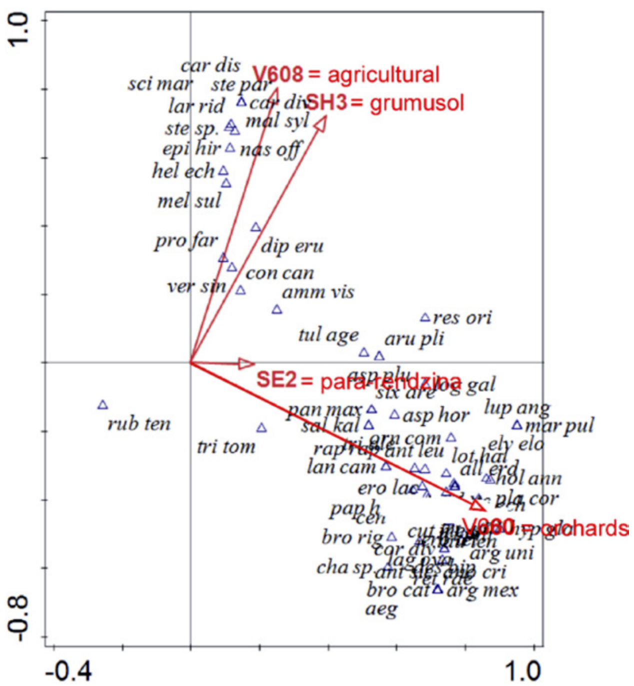


Fig. 4: CCA ordination of modern vascular plant observations versus the two most significant environmental factors - V660 = orchard; V608 = agricultural fields. See Appendix 1 for species abbreviations.

the modern plant data, illustrated in Figure 3 and 4, which followed "open" to "closed" or "natural" to "agricultural" gradients. This difference may be attributed to the fact that most archaeobotanical species are cultivars or weeds while most the observations of modern plants are of wild taxa.

The archaeological sites tend to follow the mesic to xeric gradient. Along this gradient, the sites cluster by period into reasonably distinct groupings: Late Bronze Age sites are mostly in the lower portion of the plot (which correlates with more mesic conditions), while Iron Age I and II sites fall in the upper right portion (xeric conditions). Notable exceptions are Tel Aphek (a site located in northern Philistia, in a wet environment on the Yarkon River) that is consistently in the "mesic" corner while Tell es-Safi/Gath, an inland, more southern and drier site, is consistently in the "xeric" corner even in the Late Bronze Age. This suggests that "mesic" and "xeric" site clusters are influenced by a combination of factors – changing environmental conditions, especially rainfall, but also site location.

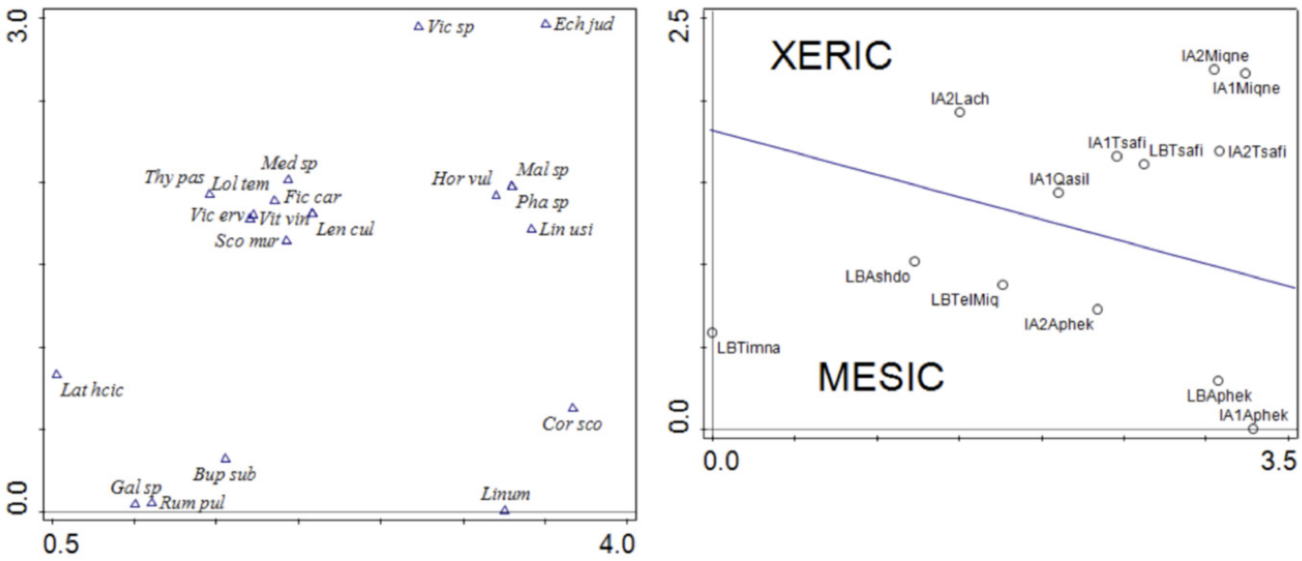


Fig. 5: DCA ordination of sites with archaeobotanical data in the Philistine Plain. Left: species biplot on DCA axes 1 and 2; Right: site biplot on DCA axes 1 and 2. Species distributions suggest that the sites above the line are relatively dry; those below the line are relatively. mesic The lines dividing xeric from mesic are drawn based on expert judgement. See Appendix 1 for species abbreviations.

Fauna

Modern Mammals

The DCA of modern mammals (Fig. 6), with habitat information carried passively (which means the environmental factors are mapped in the biplot without actually driving the ordination - see Jongman et al. 1995 for technical details), shows the first axis gradient from arid to mesic (forest) and the second axis gradient from natural (maquis) to anthropogenic habitats (i.e. disturbed habitats – fields, urban areas and orchards).

There are very few modern species associated with mesic, forest habitats (all three are from the Order Chiroptera - bats) with the majority of species trending towards arid environments. There are almost equal proportions of species in the maquis and orchard/field habitat categories. Interestingly, most of the modern carnivores (i.e. red fox, wolf, and small cats) are associated with anthropogenic habitats. This is not surprising since researchers have noted that many carnivore species have increased in abundance as well as body size and also expanded their geographic distributions as a result of access to anthropogenic food sources (Yom-Tov and Mendelssohn 1988; Yom-Tov 2003).

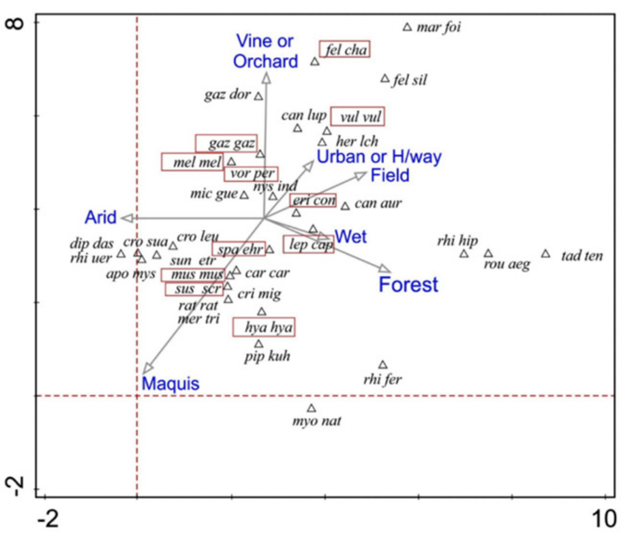


Fig. 6: DCA ordination of modern mammal observations. Species in the red boxes also occur in the archaeozoological data. See Appendix 1 for species abbreviations.

Archaeozoological Data

The results of the DCA ordination of archaeozoological data is given in Figure 7. The resultant graph shows a gradient from wet to dry with a clear clustering of moist-adapted species (such as *Sus scrofa, Meles meles, Hippopotamus amphibius, Dama mesopotamica, Cervus elaphus*) on the bottom of the graph. Many of the archaeological sites cluster by period and habitat, with several of the Late Bronze Age sites falling in the mesic range (lower part of graph). Late Bronze Age Tel Mor (located on the coast at Ashdod) lies below the line indicative of a mesic environment, while Iron Age II Ashdod falls above the line indicative of more xeric conditions. The same picture is found for Late Bronze and Iron Age II Tell es-Safi/Gath, and Late Bronze and Iron Age I Tel Miqne/Ekron. Little difference is discernible over time at Tel Lachish with all three time periods at this site consistently associated with a relatively dry environment in contrast to Tel Aphek, where all three periods are characterized by moist environmen-

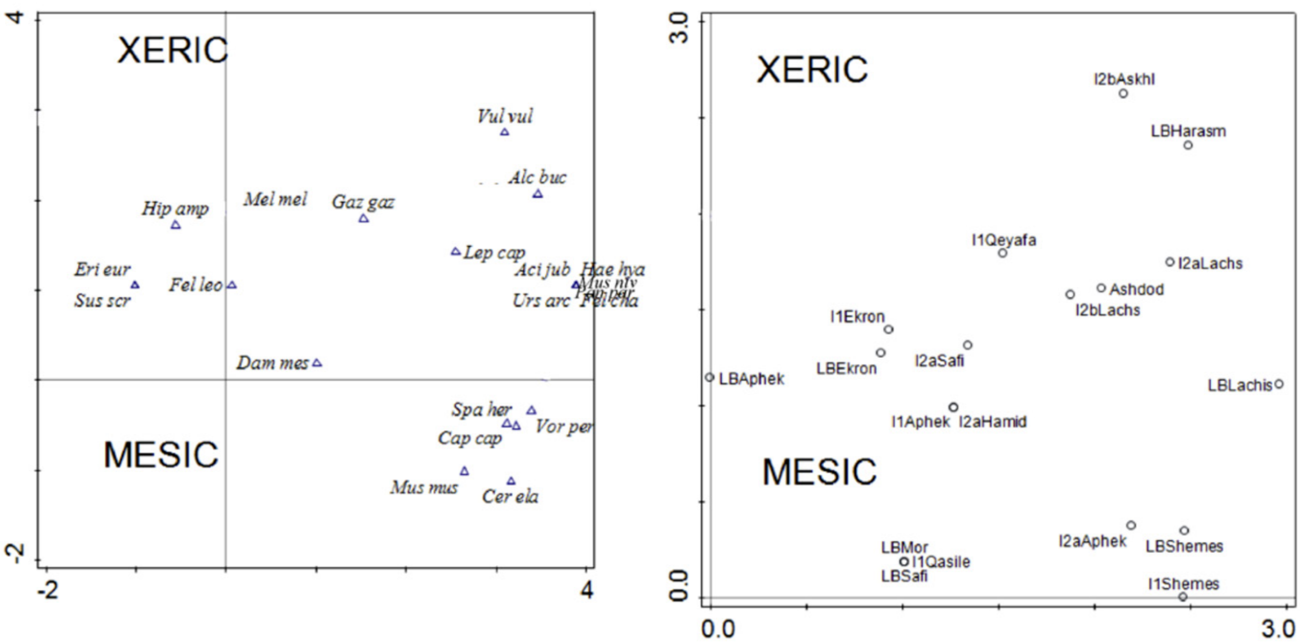


Fig. 7: DCA ordination of archaeozoological data for mammals. The lines dividing xeric from mesic are drawn based on expert judgement. See Appendix 1 for species abbreviations.

tal conditions, undoubtedly reflecting the proximity of the Yarkon River to the site. These results suggest that in many, but not all sites, a shift took place in environmental conditions between the Late Bronze and Iron Age.

Discussion

Despite the drawbacks of the data bases, some interesting and fairly consistent patterns can be discerned. The modern vegetation and faunal gradients range along the first axis, from mesic to xeric and along the second axis from natural to anthropogenic. The archaeobotanical, and to a lesser extent the archaeozoological datasets, follow these gradients reflecting a trend - from more mesic conditions in the Late Bronze Age to a more xeric environment by the Iron Age II. The question then is to what can we attribute this shift – climate change, shifts in landscape use (more agriculture, more grazing, use of different habitats etc.) or a combination of factors?

If the shift in mesic to xeric conditions indicated by floristic assemblages is solely due to a change in anthropogenic land use and/or habitat exploitation, it is unlikely to have affected wild fauna to the same extent, and in the same manner as cultivated plants. Consequently, unless a larger driving factor such as climate change was involved, unidirectional change would probably not have occurred contemporaneously for both animals and plants and for groups of different species. Finally, though the Philistine migration was associated with the translocation of a range of plants and one species of domestic animal, the pig (Meiri et al. 2013, Frumin 2014, Frumin et al.2015), this is unlikely to have been the driver of the pattern observed here in the DCA analysis since all domestic animals were excluded from this analysis, while the changes to the archaeobotanical pattern stemming from introduced exotics, such as cumin (*Cuminum cyminum*) and the exploitation of local wild plants not previously used, such as coriander (*Coriandrum sativum*), included species from a variety of habitats (Frumin 2014; Frumin et al. 2015).

With respect to climate, based on several different data sets (pollen records, Dead Sea levels, speleothems, sediment accumulation rates, isotopic signatures of sediments), it has been proposed that during the transition to the Iron Age the climate in the southern Levant became drier, with a marked decline in rainfall at the end of the Late Bronze Age, ca. 1250–1100 BCE (e.g. Frumkin et al. 1991; Bar-Matthews et al. 1998; Bar-Matthews and Ayalon 2004; Bookman et al., 2004; Kaniewski et al. 2013; Neumannn et al., 2007, 2010; Rosen 2007; Litt et al., 2012; Langgut et al. 2013, 2015; Ackermann et al. 2014a; 2014b).

Pollen and phytolith data, primarily from cores in the Jordan Valley, show that this change was associated with a decline in the Mediterranean forest/maquis (evergreen forest). Pollen data, including that from the immediate vicinity of Tell es-Safi/Gath (Ackermann et al. 2014b), show that the highest percentages of *Atriplex*-type pollen - taxa regarded as indicators of aridity - were found in the Late Bronze Age-Iron Age I (Rosen 2007; Neumann et al. 2010; Langgut et al. 2013). It must be noted that the Tell es-Safi/Gath pollen data should be regarded with some caution due to a heavy taphonomical bias.

The terminal Late Bronze Age collapse was perhaps followed by a recovery during Iron Age I, attested to by increased percentages of both Mediterranean shrubs and cultivated olive trees (Rosen 2007; Neumann et al., 2010; Langgut et al. 2013), though again these data are from palaeoenvironmental proxies in the Jordan Valley some distance from the research area. The isotopic sequence from Soreq Cave, probably provides the most reliable local palaeoenvironmental signal as the cave lies in close proximity to the research area. Results of this research (Bar-Matthews et al. 1998; Bar-Matthews and Ayalon 2004) have demonstrated that rainfall was ca. 20% higher in the early Holocene than today (current rainfall in the region ranges from 401-600 mm/year). By the Chalcolithic period and the Early Bronze Age, average annual rainfall was 600 mm/year, while towards the Late Bronze Age drier conditions set in, with an estimated average annual rainfall of 500 mm/year (Bar-Matthews and Ayalon 2004).

The marked decline at the end of the Late Bronze Age and the transition to the Iron Age fits in well with the rich data set of historical and archaeological evidence for a major crisis in the eastern Mediterranean region in general during this time (e.g. Kaniewski et al. 2010, 2013; Cline 2014). Following this crisis though, there is extensive historical and archaeological evidence of a resurgence of cultural development – both in the Philistine Plain and in the Levant in general, within a century or so after the Late Bronze Age/Iron Age transition (Dagan 1992, 2002; Finkelstein 1996; Uziel and Maeir 2005, 2012; Shavit 2008). In the Philistine plain and areas to the east, there is evidence of widespread olive production throughout the Iron Age, culminating with the Philistine site of Tel Miqne/Ekron becoming one of the largest producers of olive oil in the Mediterranean region during Iron Age II (e.g. Gitin 1997).

Though the archaeobiological data presented here tracks the deterioration in climate at the end of the Late Bronze Age/early Iron Age, the data do not show a marked resurgence by the Iron Age II. Reasons for this may be that the post-Late Bronze Age climatic amelioration was only a short-lived fluctuation, or else of too low intensity to be captured in the records examined here - primarily comprising cultivated plants and large to medium-sized wild mammals. Furthermore, the cultural-economic resurgence in the region was primarily based on an anthropogenic innovation, namely large-scale olive cultivation, which may have relied upon innovations in technology and land use (e.g., Ashkenazi et al. 2015), rather than rainfall.

This study illustrates the effectiveness of applying modern ecological data to study past patterns of land use and emphasizes the importance of examining multiple data-sets in order to elucidate these issues.

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Appendices

Appendix 1: Codes and Latin names of plant and animal taxa which appear in ordination Figures 3-7.

Codes in Fig. 3	Floral taxon	Codes in Fig. 4	Floral taxon	Codes in Fig. 5	Floral taxon
asp aph	*Asparagus aphyllus*	ama ret	*Amaranthus retroflexus*	bup sub	*Bupleurum subovatum*
asp aes	*Asphodelus aestivus*	amm vis	*Ammi visnaga*	cor sco	*Coronilla scorpioides*
chi iph	*Chiliadenus iphionoides*	ant leu	*Anthemis leucanthemifolia*	ech jud	*Echium angustifolium / judaeum*
ery cre	*Eryngium creticum*	arg uni	*Argyrolobium uniflorum*	fic car	*Ficus carica*
hir inc	*Hirschfeldia incana*	asp hor	*Asparagus horridus*	gal sp	*Galium sp*
hyp hir	*Hyparrhenia hirta*	bel lon	*Bellevalia longipes*	hor vul	*Hordeum vulgare*
lag cum	*Lagoecia cuminoides*	bit bit	*Bituminaria bituminosa*	lat hcic	*Lathyrus cicercula - cicera*
mer ann	*Mercurialis annua*	cen ech	*Cenchrus echinatus*	len cul	*Lens culinaris*
not syr	*Notobasis syriaca*	cen pro	*Centaurea procurrens*	linum	*Linum sp*
ono squ	*Onobrychis squarrosa*	che amb	*Chenopodium ambrosioides*	lin usi	*Linum usitatissimum*
par arg	*Paronychia argentea*	con dor	*Convolvulus dorycnium*	lol tem	*Lolium temulentum*
pha rup	*Phagnalon rupestre*	dit vis	*Dittrichia viscosa*	mal sp	*Malva sp*
pis len	*Pistacia lentiscus*	ely elo	*Elymus elongatus*	med sp	*Medicago sp*
pla afr	*Plantago afra*	ero lac	*Erodium laciniatum*	pha sp	*Phalaris sp*
pra maj	*Prasium majus*	ifl spi	*Ifloga spicata*	rum pul	*Rumex pulcher*
que cal	*Quercus calliprinos*	lan cam	*Lantana camara*	sco mur	*Scorpiurus muricatus*
rha pal	*Rhamnus palaestinus*	log gal	*Logfia gallica*	thy pas	*Thymelaea passerina*
rub ten	*Rubia tenuifolia*	lot hal	*Lotus halophilus*	vic erv	*Vicia ervilia*
sar spi	*Sarcopoterium spinosum*	lup pal	*Lupinus palaestinus*	vic sp	*Vicia sp*
sil mar	*Silybum marianum*	mar pul	*Maresia pulchella*	vit vin	*Vitis vinifera*
sin alb	*Sinapis alba*	orn com	*Ornithopus compressus*		
thr tub	*Thrincia tuberosa*	pap hum	*Papaver humile*		
tri cam	*Trifolium campestre*	pas dil	*Paspalum dilatatum*		
tri pur	*Trifolium purpureum*	pla cor	*Plantago coronopus*		
uro pic	*Urospermum picroides*	rap rap	*Raphanus raphanistrum*		
		rub ten	*Rubia tenuifolia*		
		rum buc	*Rumex bucephalophorus*		
		sor hal	*Sorghum halepense*		
		tri pal	*Trifolium palaestinum*		
		tul age	*Tulipa agenensis*		

Cont. Appendix 1 ►

Cont. Appendix 1

Codes in Fig. 6	Faunal taxon	Codes in Fig. 7	Faunal taxon
apo mys	*Apodemus mystacinus*	aci jub	*Acinonyx jubatus*
can aur	*Canis aureus*	alc buc	*Alcelaphus bucelaphus*
can lup	*Canis lupus*	cap cap	*Capreolus capreolus*
car car	*Caracal caracal*	cer ela	*Cervus elaphus*
cri mig	*Cricetulus migratorius*	dam mes	*Dama mesopotamica*
cro leu	*Crocidura leucodon*	eri eur	*Erinaceus europeaus*
cro sua	*Crocidura suaveolens*	felidae	*Felidae*
dip das	*Dipodillus dasyurus*	fel cha	*Felis chaus*
eri con	*Erinaceus concolor*	fel leo	*Felis leo*
fel cha	*Felis chaus*	gaz gaz	*Gazella gazella*
fel sil	*Felis silvestris*	hae hya	*Haena hyanea*
gaz dor	*Gazella dorcas*	hip amp	*Hippopotamus amphibius*
gaz gaz	*Gazella gazella*	lep cap	*Lepus capensis*
her ich	*Herpestes ichneumon*	mel mel	*Meles meles*
hya hya	*Hyaena hyaena*	mus mus	*Mus musculus*
hys ind	*Hystrix indica*	mus niv	*Mustela nivalis*
lep cap	*Lepus capensis*	pan par	*Panthera pardus*
mar foi	*Martes foina*	spa her	*Spalax ehrenbergi*
mel mel	*Meles meles*	sus scr	*Sus scrofa fer.*
mer tri	*Meriones tristrami*	urs arc	*Ursus arctos*
mic gue	*Microtus guentheri*	vor per	*Vormela peregusna*
mus mus	*Mus musculus*	vul vul	*Vulpes vulpes*
myo nat	*Myotis nattereri*		
pip kuh	*Pipistrellus kuhlii*		
rat rat	*Rattus rattus*		
rhi eur	*Rhinolophus euryale*		
rhi fer	*Rhinolophus ferrumequinum*		
rhi hip	*Rhinolophus hipposideros*		
rou aeg	*Rousettus aegyptiacus*		
spa ehr	*Spalax ehrenbergi*		
sun etr	*Suncus etruscus*		
sus scr	*Sus scrofa*		
tad ten	*Tadarida teniotis*		
vor per	*Vormela peregusna*		
vul vul	*Vulpes vulpes*		

Appendix 2: Categories of the physical environment used in this study for the ordination.
2.1 Vegetation types; 2.2 Soil types; 2.3 Land use types.

2.1 Vegetation types

Vegetation Cover Code	Cover Type
608	Agricultural
609	Bustan (fruit orchard)
617	Natural
626	Planted forest
650	Beach or sterile area
660	Orchards
663	Olive grove
0	Bare ground

2.2 Soil types

Soil Type Code	Soil Name & Description
B3	Brown rendzina soil on steep slopes (slope 20% or more)
B4	Brown rendzina and pale rendzina soils on moderate to relatively steep slopes (up to 20% gradient)
B6	Brown grumusol and brown rendzina
B7	Dark brown grumusol and brown rendzina
E1	Alluvial hamra soils and gleys
E2	Para-rendzina
E3	Hamra
H1	Alluvial brown grumusol
H2	Cummulic brown grumusol and reddish brown (on hills) containing carbonate
H3	Cummulic brown grumusol (on hills) and residual dark brown soils
H7	Alluvial-colluvial soils and grumusol
K1	Alluvial dark brown grumusol and alluvial silty dark brown soils
K2	Dark brown grumusol
K3	Dark brown grumusol and residual dark brown soils

2.3 Land use types

Surface Code	Surface Cover Definition
11	Built-up
13	Disturbed
31	Rock
32	Karst
33	Bare soil
34	Badlands
35	Landslides
36	Sand fields or dunes
37	Active streams
38	Dry streams
60	Garden or lawn
79	Shrubs or garigue
82	Forest and woodland with height 2-4m - Medium
85	Forest higher than 4m - Medium

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