Landscapes, climate and choice: Examining patterns in animal provisioning across the Near East c. 13,000-0 BCE

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Quaternary International. Accepted Version of Manuscript, March 2021

Abstract

Understanding the organisation of food production is vital for understanding ancient societies. Multiple factors may influence decision making, including the local environmental capacity of a given area and individual and cultural preferences. This study compares zooarchaeological data from sites across the length and breadth of the Holocene Near East with modelled patterns of land use. The goal is to determine how far variation in the capacities of local landscapes impacted the choices made in animal production. Our approach allows us to investigate trends through time as well as between different regions of the Near East. The spatial and temporal scales employed also mean we can investigate the relationship between food production and climate trends. We find substantial patterning in the choices made in animal production, reflecting complex and regionally diverse production approaches. We demonstrate a prioritisation of individual and societal preferences to produce specific animals which is rarely impacted by either short or long term changes in aridity. We also find that the emergence of urban sites has a major impact on provisioning structures, and argue that the resulting organisational forms may have resulted in urban sustainability at the expense or rural sites.

Introduction

Human societies rely upon the stable availability of food resources to underpin their economic structure. This is the case across all types of human society, but the organisation of stable and reliable production is most vital for the maintenance of more complex forms because they require the redistribution of surplus to support higher proportions of non-food producing labour. In studies of the organisation of food production systems, multiple factors may influence decision making, including the local environmental capacity of a given area and individual and cultural preferences. In recent years, much attention has been paid to the impact of local environmental capacity on food production choices made by ancient societies (e.g. Gaastra et al 2020a; Riehl 2012, 2017; Riehl et al 2014; Vignola et al. 2017). With advances in our understanding of past variation in both landscape and climate, it has become possible to study the relationship between societal preferences in food production and the constraints placed upon these by local environmental variation and climate changes. The identification of changes to production are important for understanding the impact of climatic events upon past societies. Did societies (or rather their economic basis) collapse during these events? Did they make significant changes to production to cope or did they continue previous patterns in the face of a changing environment? A previous study of the interplay between climatic oscillations and societal preferences in food production (Gaastra et al 2020a), focusing on northern Mesopotamia and the southern Levant, utilised comparisons of rainfall variation across the Near East during climatic oscillations in aridity to examine this relationship. The study identified some changes to animal food production during periods of aridity which were largely confined to areas of lower rainfall. In this paper the time frame for analysis has been extended and the geographical scope has been expanded to include regions which were not covered in the previous study (namely southern Mesopotamia, Anatolia, the Caucasus, and Iran). This study compares animal provisioning data for the greater Near East from c. 13,000 to 0 BCE to examine spatial and temporal trends in animal production systems.

Rainfall is only one source of environmental variation across the Near East, and factors such as topography and soil properties are significant in determining productive capacity. Low rainfall can also be mitigated by other sources of water such as rivers and streams or water management systems (Wilkinson 2003). In this paper we use a more precise proxy of local environmental capacity – that of landuse potentiality – than in the previous study. We determine potential land use by aggregating a range of factors, including rainfall, soil depth, and various topographic indices such as slope and elevation. We also factor in relevant large scale irrigation systems. For the ancient Near East, the categories produced move from no land use through to intensive land use categories (Table 1).

Examination of patterns of animal provisioning between landuse potentiality zones and archaeologically defined regions allows for an improved understanding of the interrelationship between cultural preferences in animal production and the constraints of varying local environments. In addition to the limitations of different landuse zones, societies of the ancient Near East were faced with both gradual and punctuated changes to the climate during the Holocene. Several of these punctuated changes, also known as Rapid Climate Change (RCC) events, have been linked to the collapse of ancient civilisations (Kaniewski & Van Campo 2017; Knapp & Manning 2016; Lawrence et al. 2016; Ur 2010, Weiss 2017; Weiss et al. 1993; Wiener 2014) as well as adaptations in production strategies designed to mitigate their effects (Riehl 2017; Rosen 2007; Wilkinson et al. 2014). Detailed examination of variation in ancient production systems can help to determine how the interplay of societal and climatic pressures affected the choices made in food production for communities in different environments, societies and regions. Previous investigations of this interplay between societal and climactic constraints suggested that the relationship between climate and food production is not straightforward.

Climate of the Near East 13,000 to 0 BCE

Climate reconstructions incorporate a variety of proxy sources, including ice cores, speleothems, pollen sequences, lake levels and anthracology. Different evidence types are dependent on different drivers and each has spatial and temporal constraints. Here we provide a general overview of the current understanding of climate variation during the Holocene at the level of the Near East. For greater detail on local changes, we refer the reader to the literature cited here and its component sources (see also Robinson et al. 2006; Enzel et al. 2008; Roberts et al. 2011, 2018; Jones et al. 2019). Our dataset begins in the Late Pleistocene, covering the Bølling Allerød (c.12,500 - 10,750 cal BCE) and Younger Dryas (c.10,750 - 9500 cal BCE). The onset of the Bølling Allerød interstadial was associated with Meltwater Pulse IA, triggering abrupt warming that is widely attested in stable isotope data across the Near East (Maher et al 2011; Roberts et al. 2018). After this period of gradual warming and rising sea levels during the Bølling Allerød, there was a rapid return to dramatically cooler conditions during the Younger Dryas (Bar-Matthews et al 1997; Hartman et al 2016; Jones et al 2019). Although it is generally agreed that the Younger Dryas simultaneously shows a trend toward drier conditions (Bar-Matthews et al. 1999, 2003; Verheyden et al. 2008; Robinson et al. 2006; Rossignol-Strick 1995), some uncertainties remain (Hartman et al. 2016; Meadows 2005). Climate changes during the Younger Dryas may have been a factor in the transition to agriculture, although this remains a matter of substantial debate (Bar-Yosef 2011; Bar-Yosef & Belfer-Cohen 2002; Bar-Yosef et al. 2017; Belfer-Cohen & Goring Morris 2011; Maher et al 2011; Rosen & Rivera-Collazo 2012).

During the Early Holocene (c.9500-6000 cal BCE) the climate remained both cooler and wetter than the present day, with a shift toward warmer and wetter conditions compared to the preceding period (Bar-Matthews et al. 1997, 1999; Eriş et al 2018; Roberts et al. 2008; Rossignol-Strick 1999; Verheyden et al. 2008). Despite significant regional variation, events of punctuated aridity are suggested to have occurred around 8200 cal BCE, 7300 cal BCE and 6200 cal BCE (Fleitmann et al. 2008; Flohr et al. 2016; see also contributions in Biehl & Nieuwenhuyse 2016). That of 6200 cal BCE has in particular been suggested to have impacted the Neolithization of Anatolia and the Aegean (Weninger et al. 2006, 2014; but see Düring 2016), but this impact is regionally diverse (Flohr et al. 2016; Maher et al. 2011). The transition from the wetter Early Holocene to a comparatively drier Middle Holocene (c.6000-2000 cal BCE) begins c.6200 cal BCE with the most intense of these arid events (Bar-Matthews and Ayalon 2011; Bar-Matthews et al 1997; Clarke et al 2016; Jones et al 2019; Roberts et al 2011; Walker et al 2012; Walker et al 2019). Two patterns characterise the climate of the Near East during the Middle Holocene. Over the long term there is a gradual decrease in precipitation and rise in mean annual temperatures. Over the short term, multiple punctuated wet and dry events are indicated from the palaeoclimatic data (Bar-Matthews & Ayalon 2011; Eriş et al 2018; Clarke et al. 2016; Roberts et al 2011; Staubwasser & Weiss 2006).

The Middle Holocene also sees the appearance of urban sites across several regions of the Near East. These appear first in Mesopotamia, most notably during the Uruk civilisation. The arid phase of c.3200-3170 cal BCE has been postulated as a cause in the 'collapse' of the Uruk civilization, although this remains the subject of some debate (Charles et al. 2010; Staubwasser & Weiss 2006; Weiss 2017; Wilkinson 2000a). Urban sites remain present in southern Mesopotamia throughout this phase, with a more complex and episodic pattern in northern Mesopotamia. During the period of comparatively increased precipitation up to c.2800-2700 cal BCE and the period of increasing aridity afterwards, urban sites develop in multiple additional regions of the ancient Near East. The Middle Holocene transitions into the Late Holocene with a punctuated phase of increased aridity from c.2200-1900 cal BCE (Bini et al. 2019; Carolin et al. 2019; Kaniewski et al. 2018; Mayewski et al. 2004). This has been widely identified in proxy datasets, although its exact duration, extent and geographical homogeneity remain debated (Bar-Matthews and Ayalon 2011; Bini et al. 2019; Kaniewski et al. 2018; Jones et al. 2019; Mayewski et al. 2004; Walker et al. 2019). This is considered by some as a cause of the 'collapse' of civilisations (Cullen et al. 2000; Ur 2010; Weiss 2016; Weiss et al. 1993; Wiener 2014, although see also Langgut et al. 2016). As with the Uruk collapse, the relationship between this arid phase and the 'collapse' of the civilisations such as the Akkadian Empire remains debated, as does the wider applicability of this model in other areas of the Near East and eastern Mediterranean (Cookson et al. 2019; Kuzucuoğlu and Marro 2007; Middleton 2019; Schwartz 2007, 2017; Ur 2015).

After the 2200-1900 cal BCE aridity event, the climate of the Near East sees a return to relatively more humid conditions, although remaining more arid than the third millennium BCE peaks of humidity (Langgut et al. 2013, 2016; Roberts et al. 2011). This ends with a phase of punctuated aridity c.1250-1100 BCE which has been argued as a causal factor in the Late Bronze Age collapse of urban civilisations in the Levant, Aegean, Mesopotamia, Anatolia and Egypt (Bar-Mathews & Ayalon 2011; Kaniewski et al. 2010, 2013; Drake 2012; Finné et al. 2017; Kaniewski et al. 2010, 2013, 2017; 2019; Langgut et al. 2013; Weiss et al. 1993; Wiener 2014; Wilkinson 1997; although see Knapp & Manning 2016 for discussion of problems of temporal resolution). After this period, rainfall increases somewhat for a short period until the early first millennium BCE, when conditions become drier and more comparable with those of the present day (Cookson et al. 2019; Sinha et al. 2019).

Two patterns of interest to this study thus characterise the climate of the ancient Near East. The first is the overall long-term trend toward increasing aridity from c.6000 cal BCE. The second is a series of punctuated aridity events which occurred within the context of these long-term trends and have been argued as causal factors in the collapse of civilisations. Given that much of our study area is a dryland environment, increasing aridity – short or long-term – would have negatively impacted food producing capacity. If arid periods destabilised food production systems, societies would have needed to either modify production practices or find mitigating techniques to continue desired production in a changing landscape. One mitigating effort which has been suggested is an increase in hunting to supplement diets (Saña Seguí 2000; Zeder 2003). Another mitigation might be changes to the livestock species kept and the ways in which these were managed. The primary livestock taxa kept for food production (cattle, pigs, and ovicaprines – sheep and goats) have different tolerances for water availability and different capacities for mobility between feeding grounds. Ovicaprines are the most aridity-tolerant livestock taxa, followed by cattle and then by pigs as the least arid-tolerant (Dahl and Hjort 1976; Mace 1993; Zeder 2003). Both cattle and ovicaprines can be moved en masse between different grazing areas with relative ease, but this is less straightforward with pigs (Greenfield 1999). If increased aridity (short- or long-term) ultimately forced societies to restructure patterns of livestock-derived food production we would therefore expect to see an increase in more arid-adapted ovicaprines at the expense of less arid-adapted cattle and pigs. If societies also implemented mitigating efforts to maintain the production of desired livestock taxa, such as by increasing their mobility, we might expect to see this reduction in water-intensive taxa most strongly expressed in the more immobile taxa (pigs).

Methods

This dataset comprises 1,863,197 macromammal (e.g. hedgehog-sized or larger) remains from 997 phases of 464 sites across 8 geographical regions and a 13,000-year time span (see Figure 1 for sampled site locations). The details of these sites and their zooarchaeological samples are provided in SI1. Reference information for the individual samples of the dataset is given in SI2. Samples included in this dataset were only selected after meeting the necessary selection criteria (see below) on taxonomic and chronological specificity. The scale of this dataset was chosen to allow for comparison of changes to animal production across the range of landscapes and regions of the Near East. This provides geographic as well as chronological scope for comparisons of animal production strategies between societies to determine the effects of landscape variation and changes in climate.

Reconstruction of Land Use Potentiality

Our previous analysis of past changes to animal production considered the impact of modern rainfall estimates. However, rainfall alone does not take into account critical factors for the productive potential of site environs such as irrigation potential and altitudinal variation. This study applies a more integrated approach using the land use potentiality of site environs.

Broad categories of potential land use were based on the classification system devised for the LandCover6k project (for details see Morrison et al. in press; see also Gaillard et al. 2018; Harrison et al. 2020; Morrison et al. 2018). Where applicable, LandCover6k descriptive variables were also used to further divide these categories (e.g., to separate between dry-farming and irrigated agricultural zones). Four primary datasets were used to reconstruct land use potential in the study area. These include elevation and slope, calculated from a 30 m SRTM digital elevation model; soil depth, derived from remotely sensed data (soilgrids.org, Hengl et al. 2014, 2017), and average annual precipitation data (TAVO 1984; Hewett et al in prep).

Elevation is a fundamental factor in agricultural productivity, representing a proxy for the length of the growing period due to temperature variation. In the Middle East, higher elevations are generally associated with cooler temperatures, longer winters with lower minimum temperatures, and shorter summers. As a result, these areas generally do not support traditional Near Eastern cereal crop species (e.g. wheat and barley), which require minimum temperatures of ca. 5° C for pollination, and minimum temperatures of ca. 13-15° C for full biomass production (Raes et al. 2018). Elevation categories are constructed to roughly correspond to major divisions between phytogeographic zones. Absolute elevations are considered separately for lowland areas (Mesopotamia, the Levant; Figure 1A) and high-land areas (Anatolia, Iran, the Caucasus; Figure 1B), to account for adaptation of agricultural production to high altitudes, but in all cases, areas above 2000m are considered unsuitable for agricultural production (Wilkinson 2003; 197-8). Water availability is one of the primary limiting factors for agricultural productivity in the Middle East and is reflected through mean annual precipitation. Areas receiving more than 300 mm of precipitation annually are considered to represent optimal agricultural zones, while areas receiving between 200-300 mm of precipitation are considered marginal zones for agricultural production (Kalaycı 2013; Wachholtz 1996; Wilkinson 1994, 2000; Wilkinson et al. 2014; Wirth 1971). Areas receiving less than 200 mm of precipitation per year are considered unsuitable for dry-farming agriculture, but areas receiving 100-200 mm of annual precipitation are considered suitable for grazing animals. Unlike the other variables used in our land use model, which are fixed throughout the study period, here we use two sets of estimates for regional rainfall based on modern rainfall distributions shifted using work from Soreq Cave, where variations in isotope values in speleothems have been converted to quantified changes in rainfall (mm/year) (Bar-Matthews, Ayalon and Kaufman, 1997, 1998; Bar-Matthews and Ayalon, 2011; Orland et al., 2014). The first of these uses rainfall estimates from 7000 cal BCE and the second from 4000 cal BCE. We use the 7000 cal BCE map for sites from 13000-6000 cal BCE, and the 4000 cal BCE map for all sites after 6000 cal BCE. These two dates were chosen because they represent approximate mean conditions for the Early and Mid-Late Holocene phases respectively. In future we will produce a series of land use maps at a finer chronological resolution.

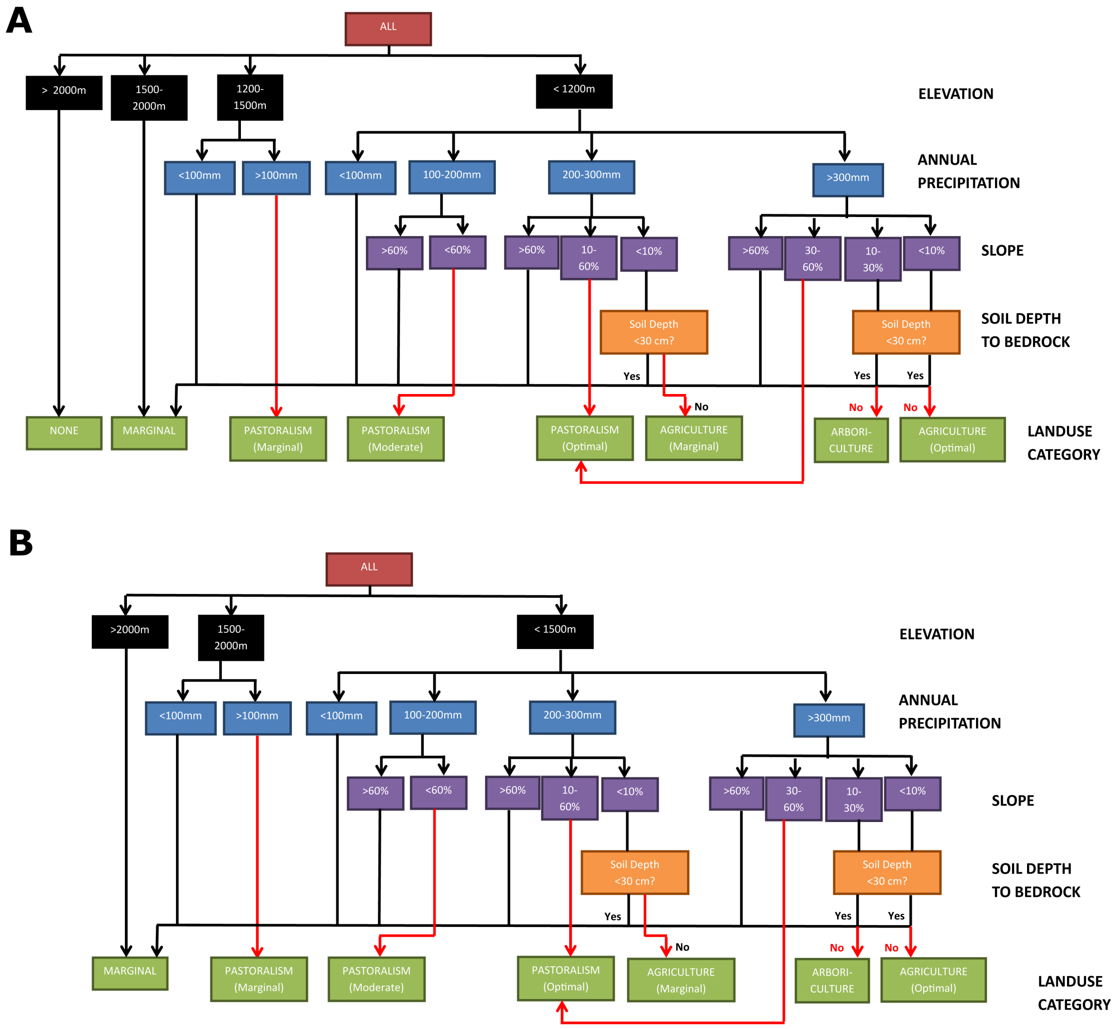

Figure 1: Flowcharts illustrating variables used for assigning landuse categories. Agriculture (irrigated) was applied in a separate manual operation as described in the text and in Table 1. Colours in this flowchart are used to differentiate levels of classification in the determination of landuse zones and do not relate to the colour-coding of landuse zones used in the remainder of this study.

Rainfall-based reconstructions of water availability do not take into account the potential for human modification of natural affordances in order to bring more land under cultivation. The most significant of these is water management infrastructure. Much of the southern Mesopotamian alluvium receives less than 200 mm

Zone	Land Use	Elevation (m)	Rainfall (mm)	Slope (%)	Soil Depth (cm)
lowlands	None	>2000			
highlands	Minimal	>2000			
lowlands	Minimal	1500-2000			
highlands	Pastoralism (Marginal)	1500-2000	>100		
highlands	Minimal	1500-2000	<100		
lowlands	Pastoralism (Marginal)	1200-1500	>100		
lowlands	Minimal	1200-1500	<100		
highlands	Minimal	1200-1500	>300	>60	
highlands	Pastoralism (Optimal)	1200-1500	>300	30-60	
highlands	Arboriculture	1200-1500	>300	10-30	>30
highlands	Minimal	1200-1500	>300	10-30	<30
highlands	Agriculture (Optimal)	1200-1500	>300	<10	>30
highlands	Minimal	1200-1500	>300	<10	<30
highlands	Minimal	1200-1500	200-300	>60	
highlands	Pastoralism (Optimal)	1200-1500	200-300	10-60	
highlands	Agriculture (Marginal)	1200-1500	200-300	<10	>30
highlands	Minimal	1200-1500	200-300	<10	<30
highlands	Minimal	1200-1500	100-200	>60	
highlands	Pastoralism (Moderate)	1200-1500	100-200	<60	
highlands	Minimal	1200-1500	<100		
lowlands	Minimal	<1200	>300	>60	
lowlands	Pastoralism (Optimal)	<1200	>300	30-60	
lowlands	Arboriculture	<1200	>300	10-30	>30
lowlands	Minimal	<1200	>300	10-30	<30
lowlands	Agriculture (Optimal)	<1200	>300	<10	>30
lowlands	Minimal	<1200	>300	<10	<30
lowlands	Minimal	<1200	200-300	>60	
lowlands	Pastoralism (Optimal)	<1200	200-300	10-60	
lowlands	Agriculture (Marginal)	<1200	200-300	<10	>30
lowlands	Minimal	<1200	200-300	<10	<30
lowlands	Minimal	<1200	100-200	>60	
lowlands	Pastoralism (Moderate)	<1200	100-200	<60	
lowlands	Minimal	<1200	<100		
lowlands	Agriculture (Irrigated)	located within 3km of a known irrigation channel			

Table 1: : Landuse zones and their descriptions.

of precipitation annually, making it unsuitable for rainfed agriculture. From at least the Chalcolithic period, irrigation was therefore employed to bring large areas of this region under cultivation (Wilkinson et al. 2015). Irrigated areas were estimated for the 4000 cal BCE reconstruction by creating a 5 km buffer around known water channels in the southern Mesopotamian alluvium (Wilkinson 2003; Wilkinson et al. 2015; the dataset of known channels was compiled from Algaze 2001; Gasche 2004, 2005, 2007; Hritz 2010; Jotheri 2016; Pournelle 2003). In later periods, particularly the Iron Age, large irrigation systems are also found in Northern Mesopotamia and the Levant. However, we have not included these here since they are not located in the vicinity of any of our sites.

Topography has a significant impact on land use. Cultivation in sloping terrains increases the danger of soil erosion, causing declining soil fertility (Fischer et al. 2002). Areas with slopes ¡10% are here considered suitable for production of cereal crops; areas with slopes of 10-30% are considered more suitable for arboricultural production (Fischer et al. 2002). Areas with ¿30% slope are considered suitable for grazing, up to a maximum slope of 60% (FAO 1991). Soil depth is also a significant factor in potential land use because shallow soils limit plant growth and present constraints for agricultural productivity (Fischer et al. 2002). Categorization of agricultural zones is here based on the minimum effective rooting depth requirements of primary cereal crop species known to have been grown in ancient times, such as wheat and barley (Raes et al. 2018).

While there were likely significant long-term landscape changes to both slope and especially soil depth over the time period considered here, due to factors such as erosion, alluvial and colluvial deposition, there remain no large-scale reconstructions of palaeolandscape change for the Middle East. Regional-scale modelling of geomorphological processes would help with this problem but is too computationally demanding to perform at large geographic scales (for micro-regional modelling, see Barton et al. 2010a, b; 2015). As a result, modern topography and slope are used here, with the recognition that these datasets may not accurately capture past conditions, especially at small scales.

The landuse zone of each site was assigned according to the dominant landuse zone present within a 24x24 km range around each site according to the landuse raster developed following the above classification criteria and rainfall hindcasting as described in Hewett et al (forthcoming).

Urbanism

Within zooarchaeological research, urban settlements are distinctive for their status as consumers rather than producers of food (Stein 1987, 1988). In keeping with the criteria from previous studies (e.g. Gaastra et al 2020b) sites were divided in this study into rural and urban categories based on settlement size (relative to regional values), internal planning and the presence of elite/public buildings. While the specific species consumed varies according to cultural preferences, studies across multiple cultures of the ancient Near East have identified the common pattern of divergent species and age proportions eaten between urban and rural sites (e.g. Boessneck 1992; Boessneck, et al. 1984; Crabtree 1990; Curet and Pestle 2010; deFrance 2009; Grant 2002; T. L. Greenfield 2014, 2015; Grigson 2007; Marom et al. 2014; Marom & Zuckerman 2012; Mudar 1982; Sapir-Hen, et al. 2016; Sasson 2010; Stein 1988; Vila 1998; Wattenmaker 1987; Wattenmaker 1998; Zeder 1988, 1991, 1998a, 1998b, 2003). Potential differences in animal provisioning between urban and rural settlements thus complicates the analysis of landuse zones. Due to differences in settlement organisation in the past, and site detection and research priorities in the present, the proportion of urban and rural settlements are often unequal within regions as well as within different zones. In an attempt to differentiate climate forcing and urban-rural site type proportions as drivers of observed changes to animal provisioning, it is necessary to distinguish between urban and rural settlements in all comparisons of animal provisioning by region and landuse zone. This allows for patterns of animal provisioning to be compared more directly across time and space (e.g. rural vs. rural and urban vs. urban) and settlement category.

Breaking up Time and Space

The spatial and temporal scales, as well as the geographic variability across our study area necessitated the division of animal bone samples into both regional and chronological categories. Regional categorisation was the most straightforward, with sites assigned to a geographical region based both upon their locations as well as the local archaeological chronological framework. The timespan of analysis and the goals of this study required that sites be divided into chronological bands which were as narrow as possible while still allowing for the comparison of broadly contemporaneous sites across all regions. Given the variation in the precision of chronological phasing possible through time, a sliding scale of chronological grouping was used to allow for the maximum possible comparison of samples while still retaining sufficient sites from more broadly dated periods (e.g. the Late Epipalaeolithic and the Pre-Pottery Neolithic). Thus, all sites dated to the Late and Final Epipalaeolithic (c.13,000-9500 BCE) were collapsed into a single chronological phase. All sites dated c.9500-5000 BCE were assigned to 500-year phase groups and all sites c.5000-0 BCE were assigned to 250-year phase groups. Where available, radiocarbon dates were used to assign sites to phase. Where this was not possible, sub-phases within the local chronology were used. Where the available radiocarbon dates for a phase extended beyond a single phase group, these were included only if ¿75% of the dated range fell within a single phase group. Not all faunal samples could be included in these groups. Those sites which provided data only on samples from combined phases (e.g. Early + Middle Bronze Age) could not be assigned to one phase group and were removed from the dataset. Sites which contained faunal samples from multiple phase (e.g. Early and Middle Halaf) within the same 250-year bracket were included in the dataset with individual samples combined into a single phase-sample. This was not done, however, when these individual samples came from both urban and rural incarnations of a site. In these cases, urban and rural samples were maintained as separate to examine animal provisioning for rural vs. urban sites.

Domestication and Taxonomic Comparisons

Our timeframe covers hunter-gatherer groups, the domestication of plants and animals and the transition to predominately domesticate-food-based societies, and several thousand years of societies producing food primarily from domestic resources. The process of animal domestication during the (Pre-Pottery) Neolithic of the Near East necessitated some special consideration for the organisation of this dataset. The well-known difficulty of discriminating between wild and domestic forms of archaeological animal remains, coupled with indeterminacy in the chronological timeframe for the domestication of particular animals (e.g. pigs and cattle), means that many analysts of samples dated 8500-6000 cal BCE (61 out of 154 samples) reported identified remains of wild/domestic taxa to the genus level only, without information on the proportions of probable wild or domestic individuals included. Two options were available for mitigating against this wild/domestic indeterminacy. The first was to include all indeterminate animals as wild, the second was to consider all such as domestic. The first of these options is unhelpful as potentially domestic indeterminate remains would be combined into the 'large wild' category. Thus, the second option was chosen for this study. All ovicaprines (sheep and goats), pigs and cattle – whether wild or domestic – were classified as domestic proportions for the purposes of site comparison for all sites dated prior to c.6000 BCE. This was chosen as the best option for the comparison of animal food provisioning between sites regardless of their position along the spectrum of animal domestication. This also means that Late Epipalaeolithic sites appear to contain domestic animals. These proportions, however, indicate the proportional consumption of these taxa (wild or domestic) in relation to both one another as well as to the consumption of other species of wild animals. These combinations were not made for data after c.6000 BCE as the widespread proliferation of morphologically-domestic (e.g. of smaller body size) animals somewhat mitigates against difficulties in differentiating between wild and domestic animals recovered.

Indeterminacies in differentiating wild and domestic forms is not completely removed following the proliferation of morphologically domestic animals, however. It is not always possible to distinguish between wild and domestic forms of a given animal for every skeletal element recovered. Thus, the indeterminate categories of *Bos sp.* (wild or domestic cattle) and *Sus sp.* (wild or domestic pigs) are frequently used by analysts to classify recovered animal remains for which domestication status cannot be satisfactorily determined. Animal remains classified to these indeterminate categories were present in 117 (88% of total) samples. For site samples dating post-c.6000 BCE these indeterminate remains were classified pro rata as wild or domestic following the method established by Orton et al. (2016; Gaastra & Vander Linden 2018; Gaastra et al. 2020a, 2020b). Equids, which include domestic horses (*Equus caballus*) and donkeys (*Equus asinus*) as well as wild onager (*Equus hemionus*), are notoriously difficult to differentiate from individual bones and teeth (Clutton-Brock 1986). This difficulty means that most samples in this study (922 or 94%) classified most or all equids only as *Equus sp.*, making it impossible to allocate equid remains pro rata as was done with *Bos sp.* and *Sus sp.* This means that equid remains are combined for both wild as well as (from the fourth millennium BCE onwards) domestic equids. While domestic equid proportions on sites are uniformly low across the dataset, this indeterminacy also means that domestic equids classified as *Equus sp.* count as wild in comparisons of proportions of wild vs. domestic taxa present at sites. This also means that equids (wild or domestic) could not be assigned to the broader 'large game' category in correspondence analysis and instead formed an independent category of 'equid wild/domestic'. Macromammal bone counts were grouped according to domestic species (ovicaprines, cattle, pigs and dogs) combined wild/domestic equids and hunted wild game divided between small (wolf size and smaller) and large (wolf size and larger) body size classes following the method of previous analyses (Gaastra et al. 2020a, 2020b).

Techniques of Analysis

Data were analysed using a combination of statistical methods, all undertaken in R (R Development Core Team 2013). Zooarchaeological data from sites and phases which met the selection criteria (above) were combined into a single correspondence analysis in R using the R package 'ca' version 0.71.1 (Nenadić & Greenacre 2007). The output of this analysis was compared visually as well as through comparison of proportions of individual taxa present at sites for each region and landuse zone through time. These were made using dot plots with the R package 'ggplot2' version 3.3.3 (Wickham 2009). In order to determine the statistical significance of differences identified from visual comparison of correspondence analysis outputs, the mean and standard deviation of site samples in the correspondence analysis output (dimensions one and two) were compared by landuse zones for each region. This was calculated and graphed using the R package 'tidyverse' version 1.3.0 (Wickham et al. 2019).

Results

Hunting Provisioning from the Late Epipalaeolithic to the end of the Pre-Pottery Neolithic A (c.13000 to 8500 cal BCE)

Our dataset begins 13,000-9500 cal BCE. During these phases the Near East was populated by hunter-gatherer groups. While the species which later became domesticated livestock were hunted as wild animals only during this period, regional variation can be seen in their proportions relative to other wild taxa. These taxa primarily formed only a minor proportion of hunted animals with the majority being gazelle, deer, wild equids and small game such as hare. Variation between regions and between landuse zones of each region can be seen (Figure 4). In the southern Levant the proportion of future livestock taxa (wild cattle, pigs and ovicaprines) is overall higher in the less fertile zones, although uniformly so. Within sites of these zones, ovicaprines dominate amongst hunted 'livestock' species, whereas wild cattle and pigs were hunted in greater proportions in more fertile zones, albeit with "ivestock' taxa forming a more minor overall contribution. Wild 'livestock' taxa also form only a minor proportion of Late Epipalaeolithic faunal assemblages of northern Mesopotamia, within which ovicaprines predominate over cattle or pigs. These taxa also form only a minor proportion of hunting in the Caucasus with a predominance of cattle and ovicaprines over pigs. Only in Anatolia do wild 'livestock' taxa form a significant – although not dominant - proportion of the Late Epipalaeolithic hunted diet, with a strong focus on the hunting of ovicaprines over cattle or pigs/boar.

These regional and landscape trends in animal exploitation continued during 9500-8500 cal BCE, with 'livestock' taxa forming a larger proportion at all sites, particularly those within less fertile landuse zones (Figures 5 and 20). This division can be clearly seen in the southern Levant, where ovicaprines dominate (followed by cattle) at the single sample represented from the less fertile zones but with 'livestock' taxa overall forming a more minor provisioning contribution at sites in more fertile zones which see a more equitable exploitation within wild 'livestock' taxa (Figures 5 and 20-23). The northern Levant mirrors the southern Levant in these periods, with the single represented site located in a less fertile zone and containing high proportions of 'livestock' taxa with a predominance of ovicaprines. The proportion of 'livestock' taxa in northern Mesopotamia between 9500-8500 cal BCE increases overall, with higher proportions seen at sites of the arboriculture zone. Here we see a greater emphasis on the hunting of cattle and pigs and with (presumably also wild) ovicaprines declin-

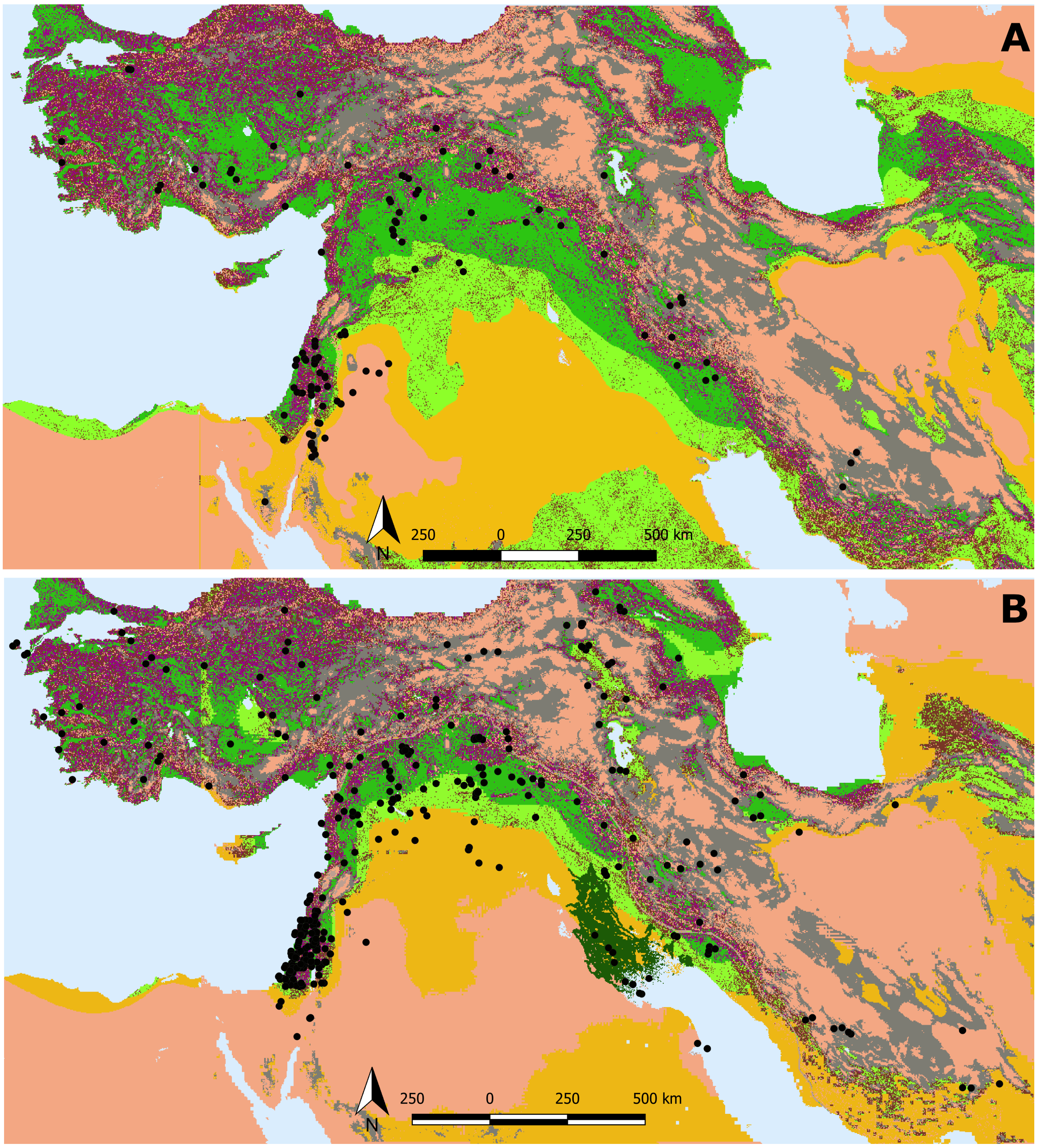

Figure 2: Map of the distribution of the sites which provided animal bone data used in this study superimposed from c.13,000-6000 cal BCE (A) and c.6000-0 BCE (B) superimposed upon the distribution of landuse zones across the Near East c.7000 cal BCE (A) and c.4000 cal BCE (B).

ing across all zones between 9500-8500 cal BCE (Figures 6, 20 and 21). 'Livestock' taxa in Anatolia, again represented by only one sample, continue to provide a significant proportion of faunal assemblages with a continued but less dominant focus on the exploitation of ovicaprines in favour of higher relative proportions of cattle and pigs/boar compared with the preceding phase. Given the paucity of available sites, however, it cannot be determined if this represents a chronological change from the Late Epipalaeolithic or a change in landscape exploitation between Late Epipalaeolithic sites in the lower uplands (classified as arboriculture in our framework) and PPNA lowland optimal agriculture sites.

Neolithic Animal Domestication and the Early Holocene: 8500-6000 BCE

From c.8500 cal BCE the domestication and spread of ovicaprines, cattle and pigs across the Near East increases variation in animal provisioning both across and between regions (Figures 6-10). This stage of the Early Holocene also covers three periods of increased aridity (8500-8000 cal BCE, 7500-7000 cal BCE and 6500-6000 cal BCE), during which aridity-induced provisioning changes would be expected to include an increased contribution of non-livestock taxa (hunting) to diets and/or an increase in the representation of more arid-adapted sheep and goats at the expense of cattle and pigs.

Over 8500-6000 cal BCE the southern Levant demon-

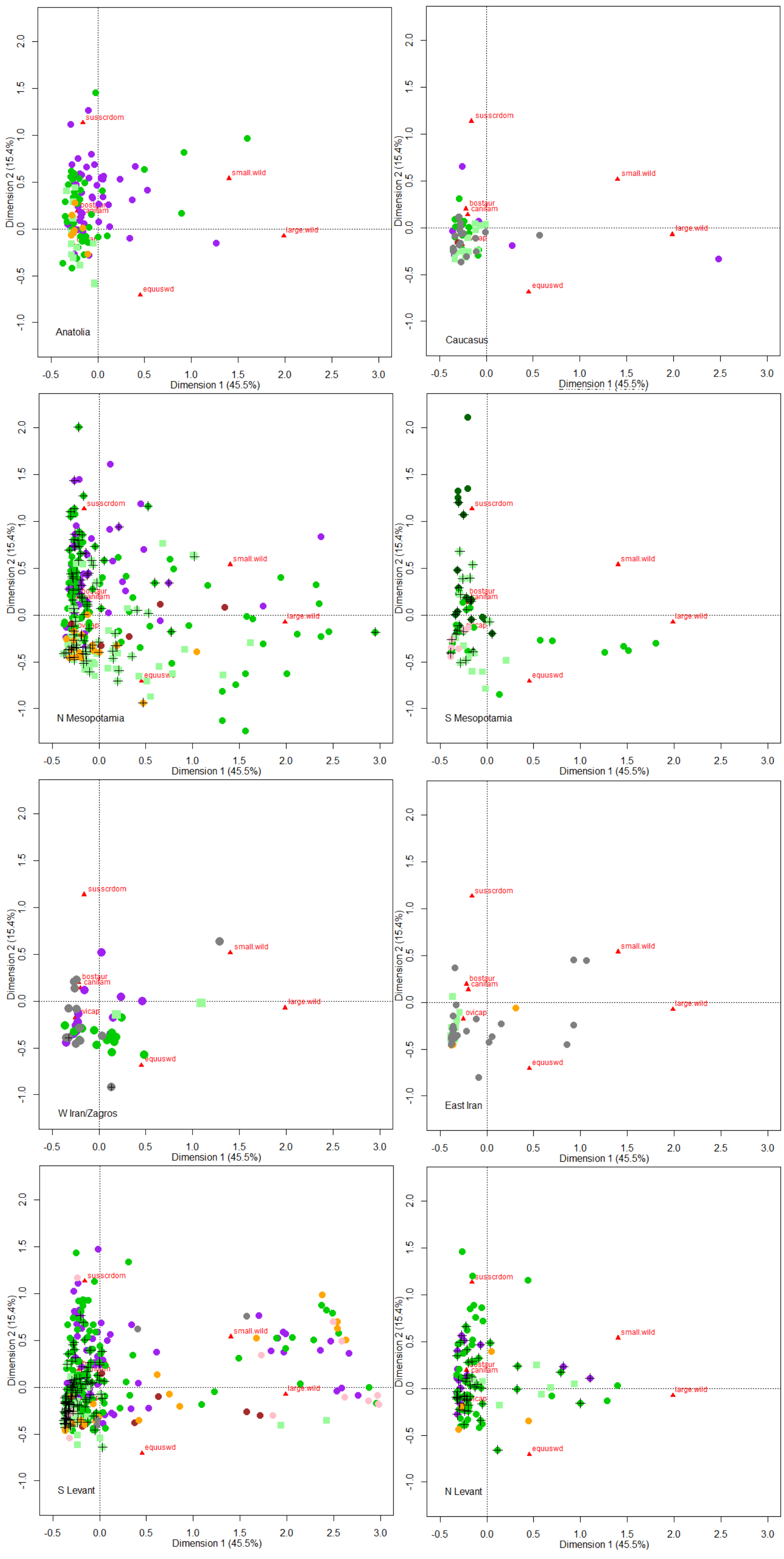

Figure 3: Correspondence Analysis comparisons of individual regions across all phases according to the landuse zone of sites.

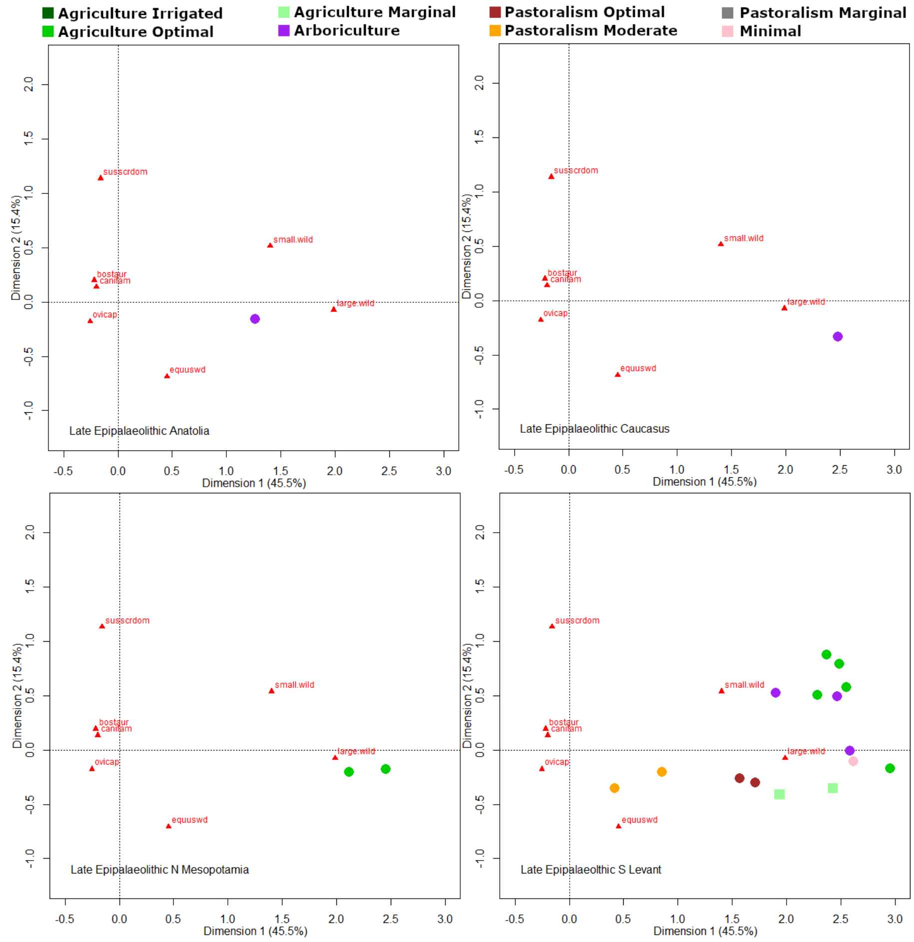

Figure 4: Correspondence Analysis of sites according to landuse zone for individual regions c.13,000-9500 cal BCE.

strates two patterns of animal exploitation with no changes to provisioning evident during punctuated aridity phases. These primarily continue earlier patterns, with divergence in the intensity of the hunting/herding of ovicaprines compared with cattle and pig (wild or domestic). As can be seen also in Figures 20 and 21, the proportion of both livestock taxa overall and of ovicaprines as a proportion of livestock taxa varies independently of landuse zones. Sites with both low (0-39%) and high (73-99%) proportions of livestock taxa occur equally across both more and less fertile zones in all phases. Both groups of sites demonstrate similar patterns of exploitation to that of 9500-8500 cal BCE, with a greater predominance of ovicaprines as a proportion of livestock taxa in less fertile zones and higher proportions of cattle and pigs in more fertile zones, even though the overall proportion of livestock taxa present at sites varies without respect to landuse zone (Figure 6-10, 20 and 21). Across these periods the only change evident is a steady increase overall in the proportion of livestock taxa present on sites with no evident variation in this trend during phases of punctuated aridity. Ovicaprine proportions within livestock taxa at sites likewise increase gradually over these periods. Cattle and pig proportions respectively decline in tandem with the increased representation of livestock taxa across zones as hunting of these animals at sites in more fertile zones is replaced by the herding of ovicaprines. Cattle proportions remain comparatively low until after c.7000 cal BCE when their proportions increase at sites in more fertile zones, presumably from a proliferation of domesticated cattle. The northern Levant mirrors the southern Levant during 8500-6000 cal BCE, with a steady increase in livestock taxa proportions across these periods, also with no apparent variation during periods of punctuated aridity (although fewer samples are available from these phases than from the southern Levant). Ovicaprines predominate across less fertile zones with proportions of cattle and pigs here intermediate between the more and less fertile zones of the southern Levant (Figures 6-10, 20 and 21). From 7000-6000 cal BCE the range of landuse zones represented increases. Clear division can now be seen in the proportions of ovicaprines, cattle and pigs by zone, with cattle and pigs more abundant at sites in more fertile zones. No change in these distributions is seen between 7000-6500 cal BCE and the punctuated aridity during 6500-6000 cal BCE.

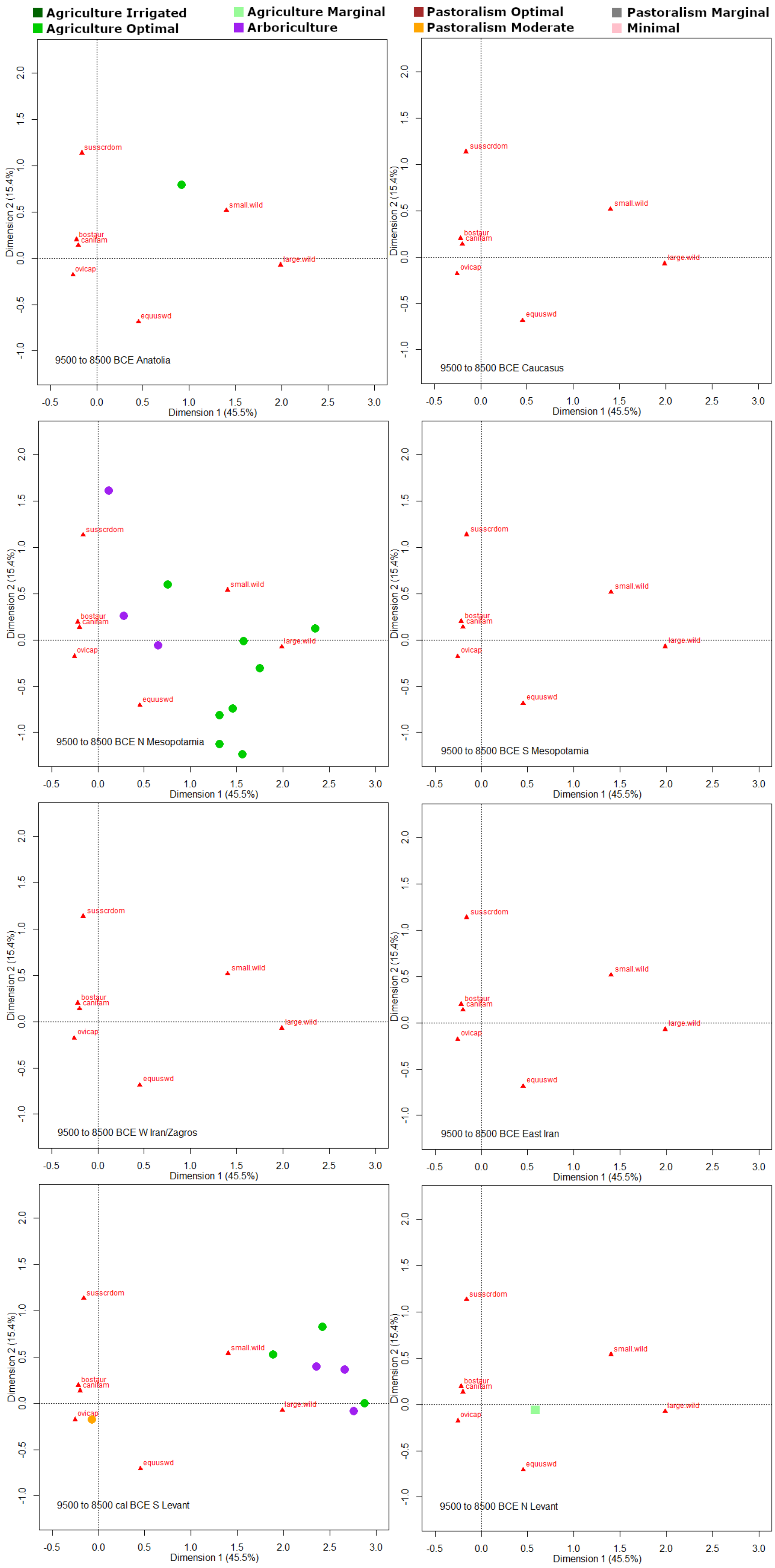

Figure 5: Correspondence Analysis of sites according to landuse zone for individual regions c.9500-8500 cal BCE.

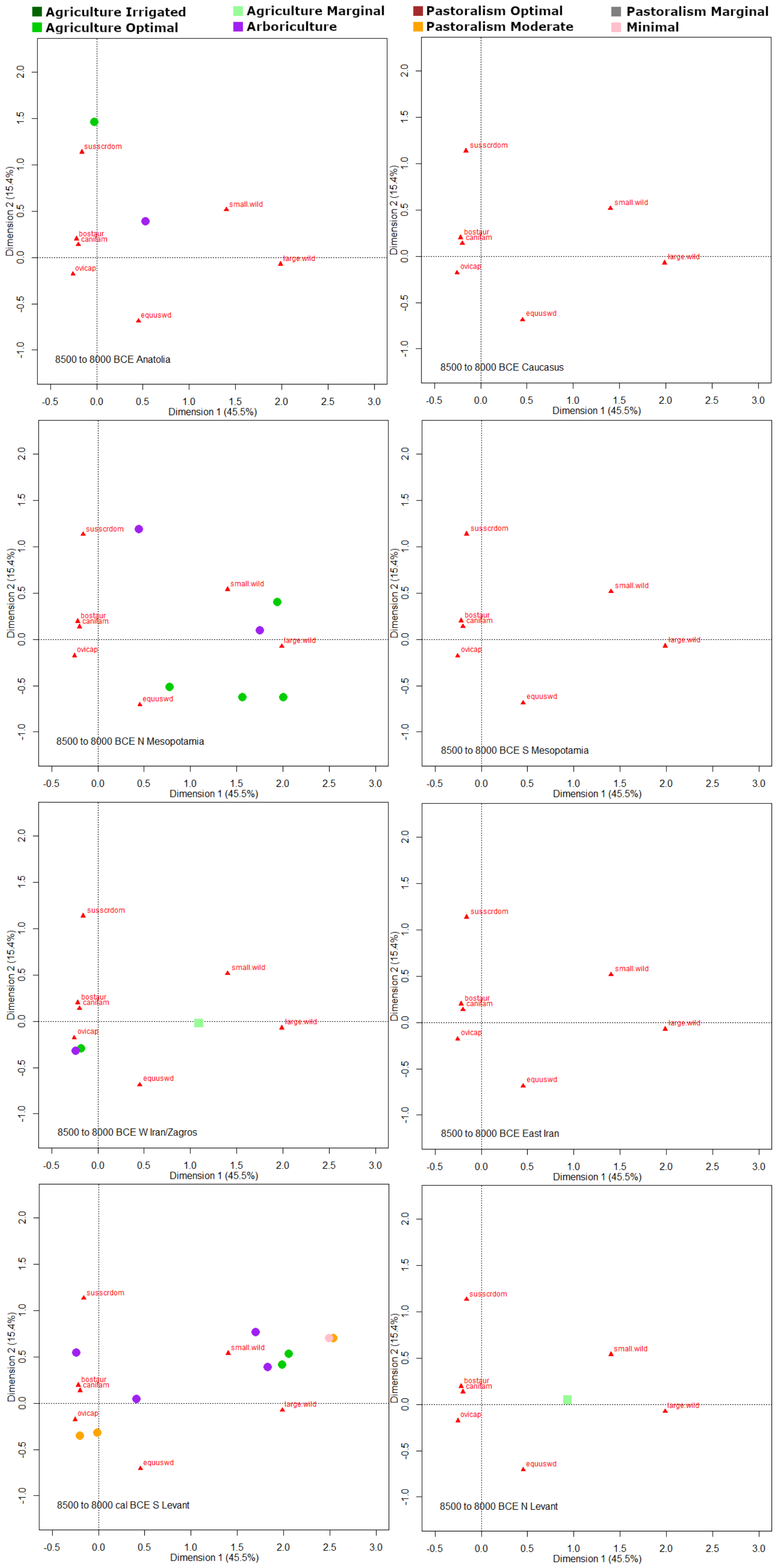

Figure 6: Correspondence Analysis of sites according to landuse zone for individual regions c.8500-8000 cal BCE.

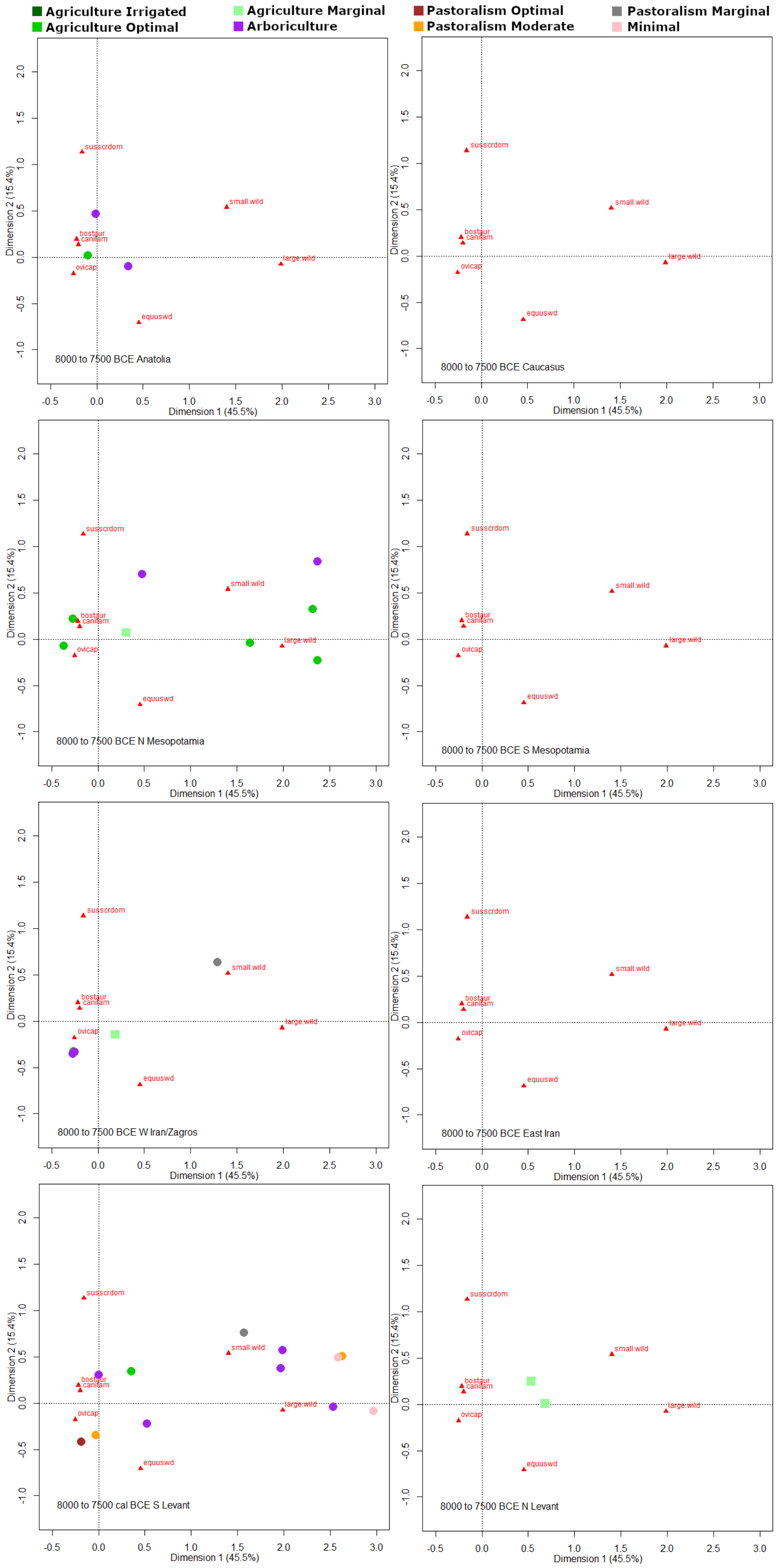

Figure 7: Correspondence Analysis of sites according to landuse zone for individual regions c.8000-7500 cal BCE.

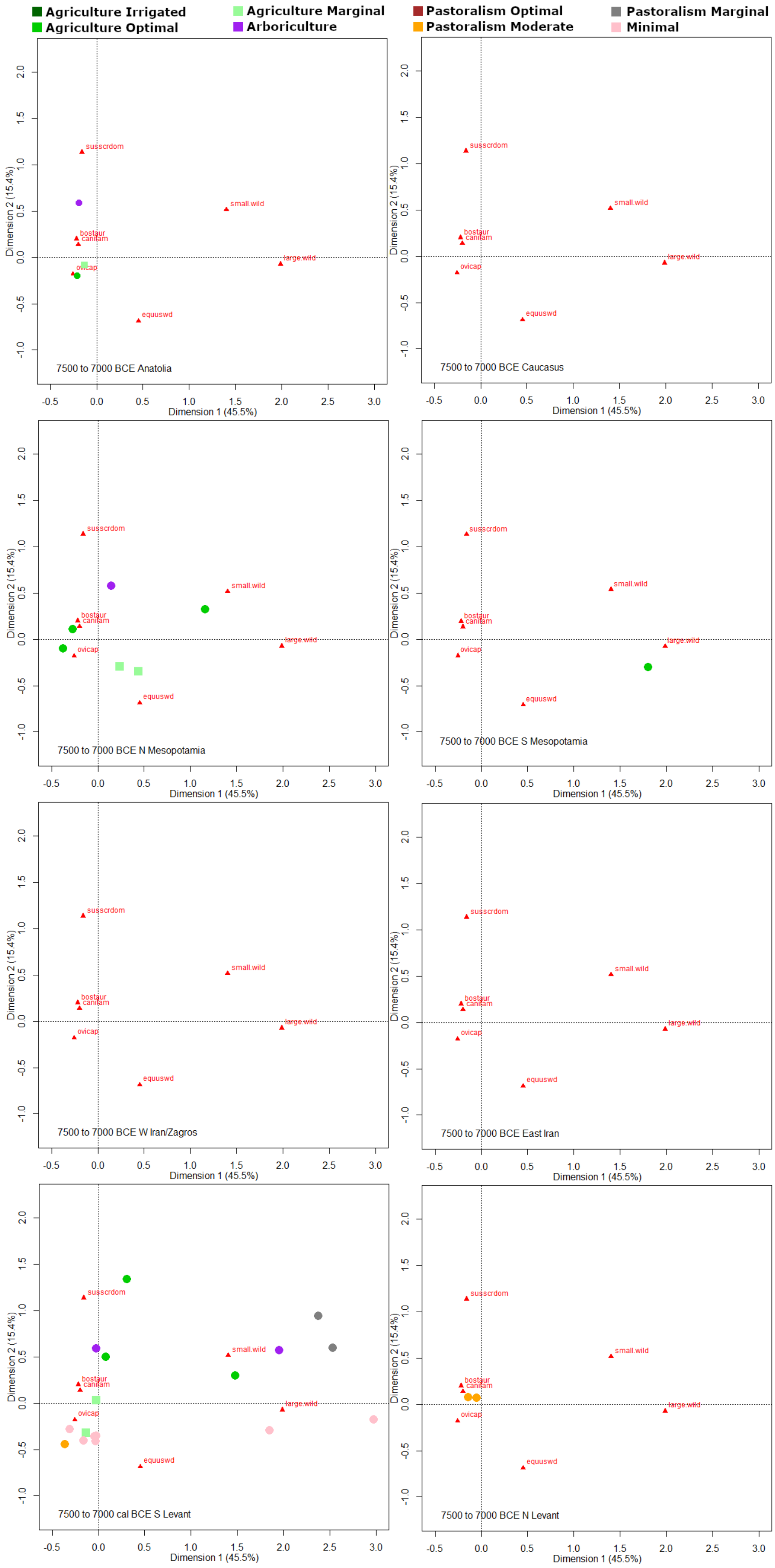

Figure 8: Correspondence Analysis of sites according to landuse zone for individual regions c.7500-7000 cal BCE.

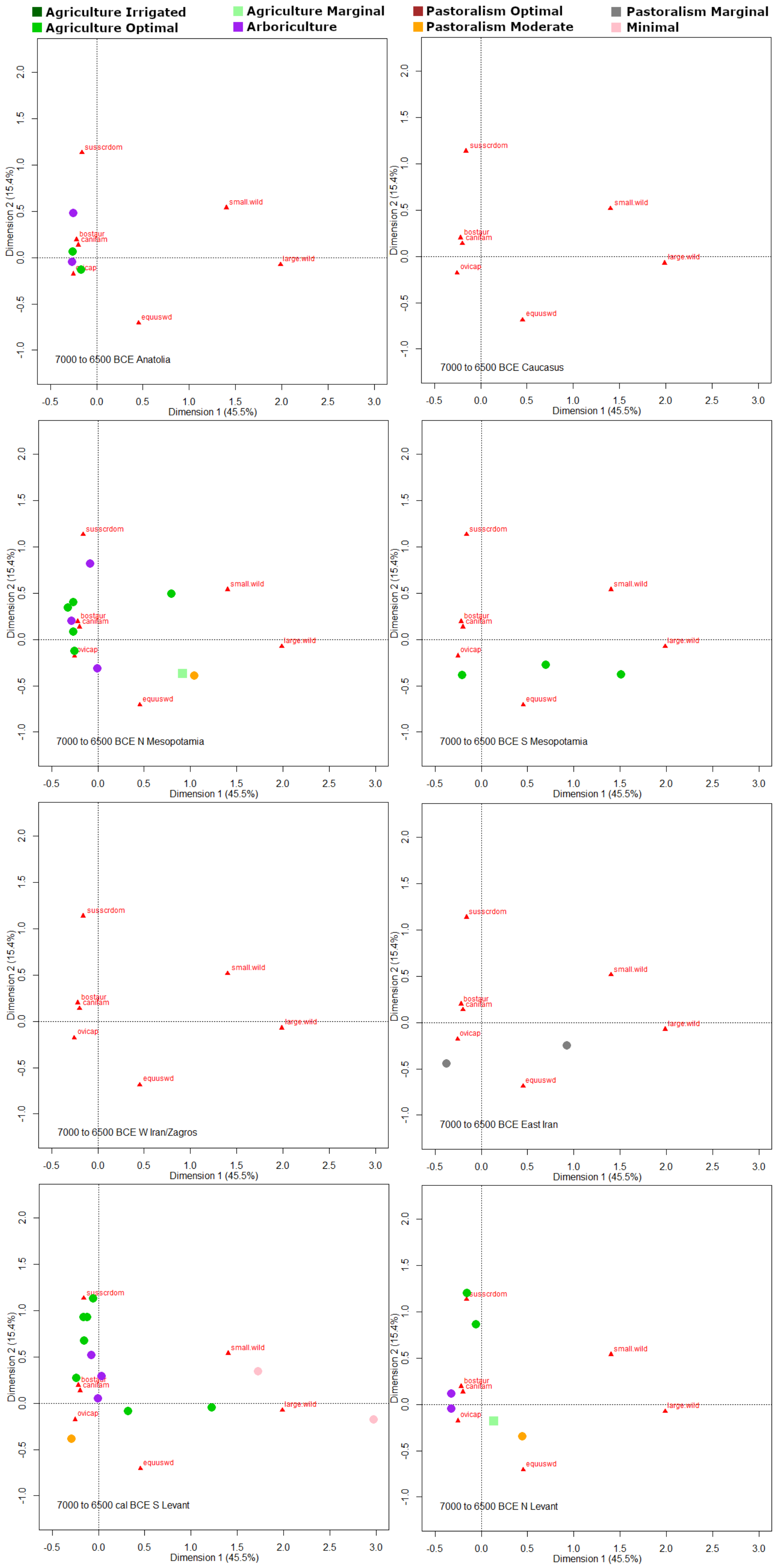

Figure 9: Correspondence Analysis of sites according to landuse zone for individual regions c.7000-6500 cal BCE.

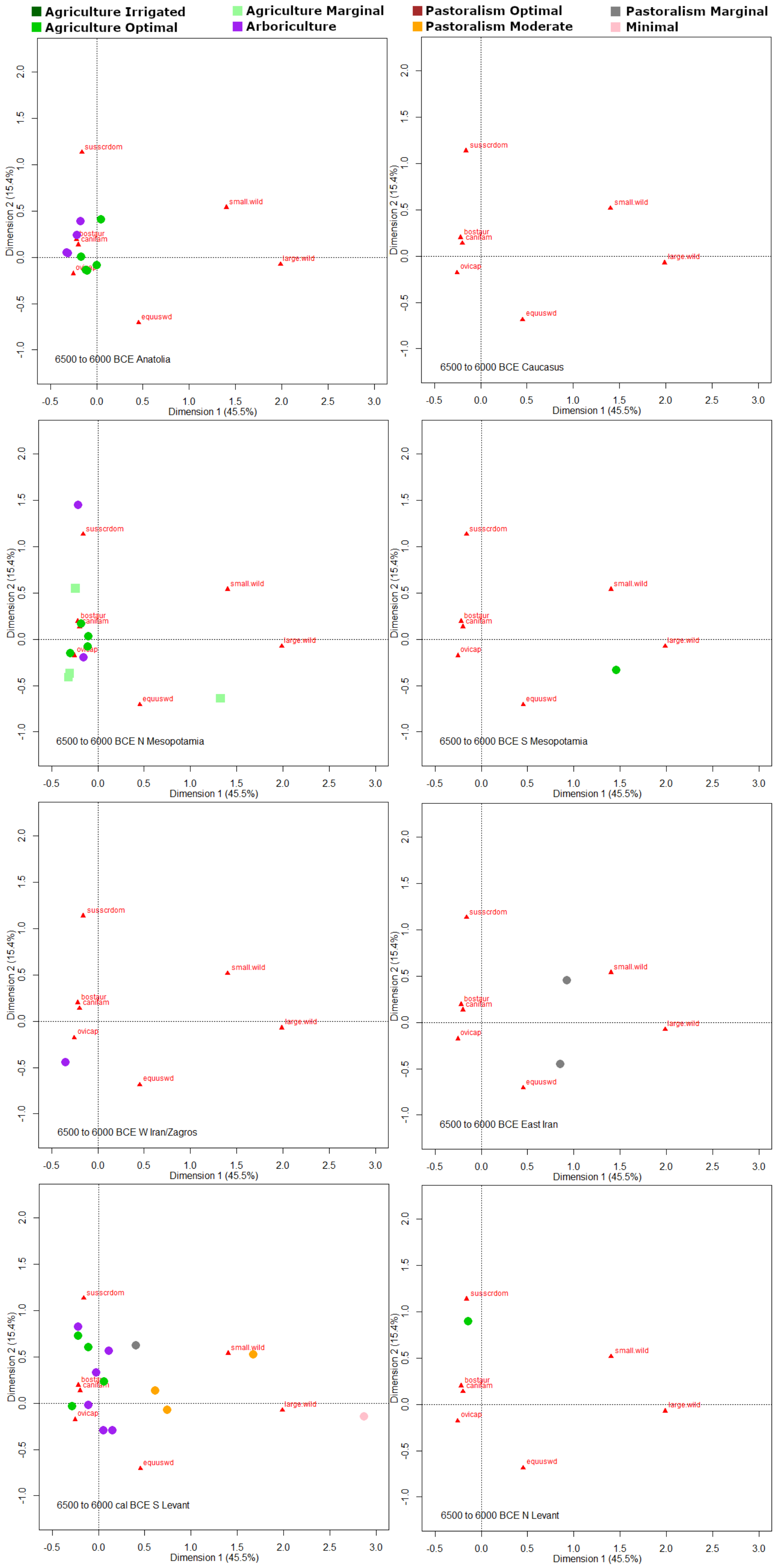

Figure 10: Correspondence Analysis of sites according to landuse zone for individual regions c.6500-6000 cal BCE.

Due to a paucity of available data, sites in western Iran appear in our database only from c.8500 cal BCE. Here the representation of livestock taxa is lower in less fertile landuse zones although ovicaprines dominate equally across all but the least fertile zones. No provisioning differences are discernible during phases of punctuated aridity. Also due to a paucity of available data, eastern Iran is not represented in the dataset before 7000 cal BCE. Here the limited available samples suggest both high and low proportions of livestock taxa during 7000-6500 cal BCE but only high levels of hunting (and correspondingly low proportions of livestock taxa) during the aridity of 6500-6000 cal BCE. The pattern seen in western Iran also broadly holds for sites of southern Mesopotamia, which is not represented until c.7500 cal BCE and demonstrates distinctly lower proportions of livestock taxa compared with the same landuse zones in western Iran, but with the same systematic dominance of ovicaprines as a proportion of livestock taxa (Figures 8-10). No changes to provisioning are discernible here between more and less arid phases. Northern Mesopotamia demonstrates progressively increasing proportions of livestock taxa (decreased hunting) throughout 8500-7500 cal BCE with clear patterning of sites by zone from c.8000 cal BCE. Livestock and ovicaprines dominate first at sites of the more fertile landuse zones with this change occurring more gradually at sites of less fertile zones. After c.7500 cal BCE proportions of cattle and pigs increase slightly at sites in more fertile (particularly upland) zones. This pattern continues across the arid phases of 7500-7000 cal BCE and 6500-6000 cal BCE as well as the more humid 7000-6500 cal BCE with no evident variation. Anatolia demonstrates the reverse pattern to Mesopotamia and western Iran, with a dominance of livestock taxa across sites in all zones and the highest proportions of ovicaprines moving through time from arboriculture (up to 8000 cal BCE) to lowland sites regardless of zone fertility (Figure 21). Cattle and particularly pigs are present in higher proportions at sites in more upland zones until 6500-6000 cal BCE when (likely domestic) cattle and pigs increase at sites in fertile lowland zones as well. No indications of provisioning restructuring are seen during arid phases within these overall trends.

Middle Holocene farming c.6000 to 4000 cal BCE

The tandem exploitation system of the 8500-6000 cal BCE southern Levant ends after c.6000 BCE. During 6000-5000 cal BCE only data from more fertile zones are present. Cattle and pigs decrease slightly overall as a proportion of livestock taxa compared with the Early Holocene, although this is not seen uniformly across all sites. Hunting levels do not vary as widely as during the Early Holocene, but higher levels of hunting are indicated at sites of the arboriculture zone compared with the optimal agriculture zone. No samples were available for comparison from sites in less fertile zones during these phases. Over 5000-4000 cal BCE data from a greater range of sites shows the continuation of increased hunting, now evident at sites of less fertile zones rather than those of the arboriculture. Sites of less fertile zones also contain lower proportions of cattle and pigs within livestock taxa compared with sites of the more fertile landuse zones, in particular those of the arboriculture zone (Figure 12). Data from the northern Levant 6000-5000 cal BCE are also only available primarily from more fertile zones, which indicate a continuation of Early Holocene patterns of provisioning. The single site represented from a less fertile landuse zone demonstrates no divergence in hunting or livestock proportions from those of the more fertile zone. During 5000-4000 cal BCE only sites of these more fertile landuse zones are represented and indicate an overall increase in ovicaprine proportions resulting from an increase in proportions of cattle, but with a decrease in proportions of pigs.

Sites of 6000-5000 cal BCE western Iran demonstrate higher cattle and pig proportions in more fertile zones. Pig proportions decrease and hunting levels increase over 5000-4000 cal BCE compared with 6000-5000 cal BCE, although no data is available for comparison from sites in less fertile zones. Sites of eastern Iran indicate little hunting (excepting one site) in all zones. Minor differences are apparent in cattle proportions, which are higher for sites in more fertile landuse zones, although this increase is not significant (Figures 22 and SI4). This pattern continues during 5000-4000 cal BCE, with increased hunting seen in at least one site of the more marginal zones.

Southern Mesopotamian sites 6000-4000 cal BCE show an increased variation in livestock proportions compared with earlier phases (Figures 11, 12 and 20). Data from sites of the irrigated agriculture zone demonstrate higher cattle and pig proportions compared both with other zones of southern Mesopotamia as well as with other landuse zones across all regions during these phases. These high proportions continue from 6000-5000 cal BCE as well as during 5000-4000 cal BCE. Cattle and pig proportions also increase across the other fertile zones of this region during 5000-4000 cal BCE, while ovicaprines remains dominant at sites in less fertile zones. Sites in northern Mesopotamia 6000-5000 cal BCE see higher levels of hunting at sites located in less fertile zones (Figure 11). Cattle proportions are higher at sites in more fertile zones. This patterning remains during 5000-4000 cal BCE, albeit with less clear divisions in levels of hunting or cattle or pig proportions according to zone.

Levels of hunting at sites in Anatolia remain low across 6000-4000 cal BCE. During 6000-5000 cal BCE cattle proportions are higher at sites in more fertile landuse zones, with pig proportions higher also at sites of the arboriculture zone. From 5000-4000 cal BCE the cattle proportions remain constant at sites in less fertile zones but drop significantly at the single represented site in the more fertile zones. No pattern is evident in proportions of pigs over these phases, which are less common than in neighbouring northern Mesopotamia.

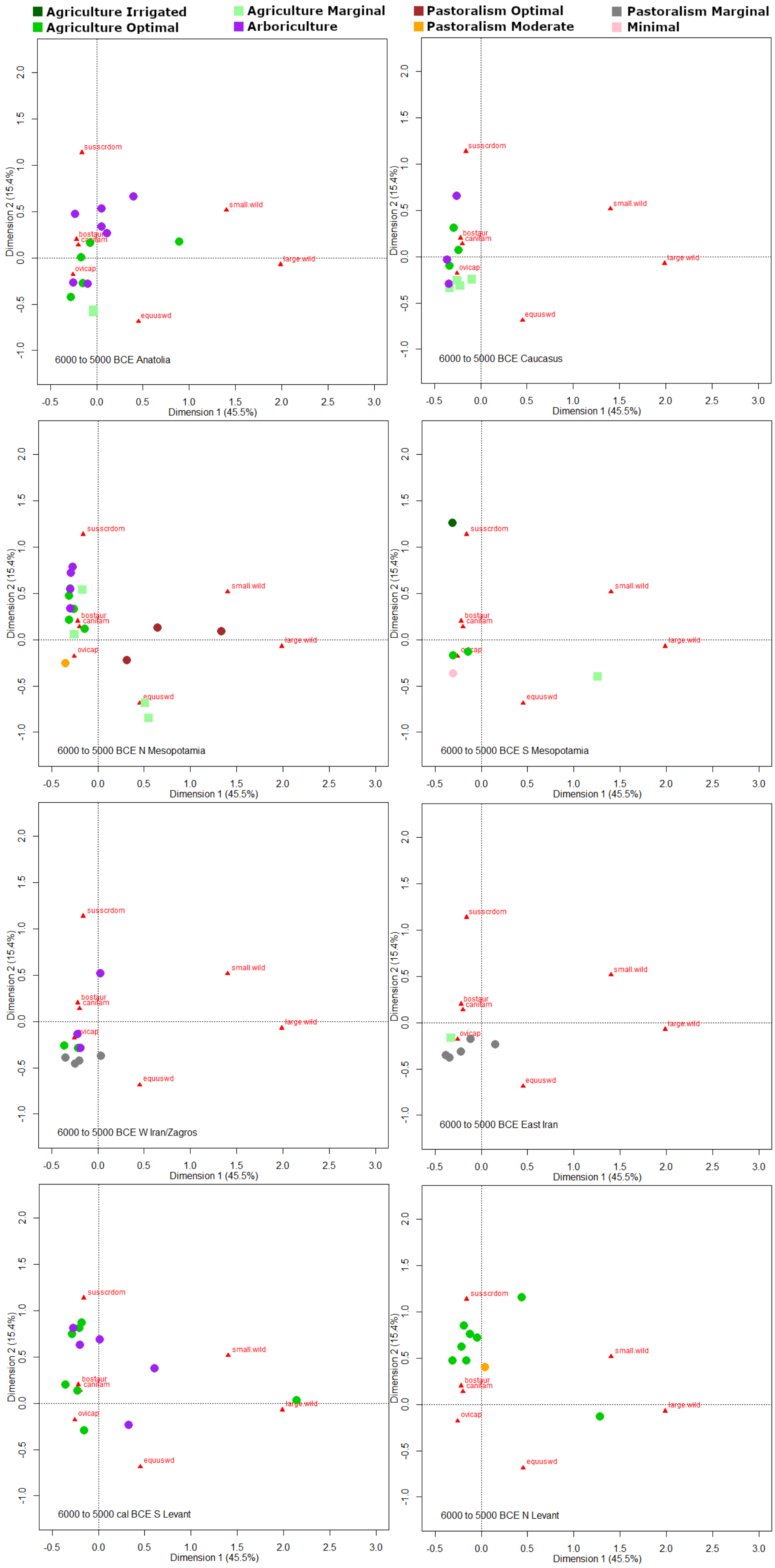

Figure 11: Correspondence Analysis of sites according to landuse zone for individual regions c.6000-5000 cal BCE.

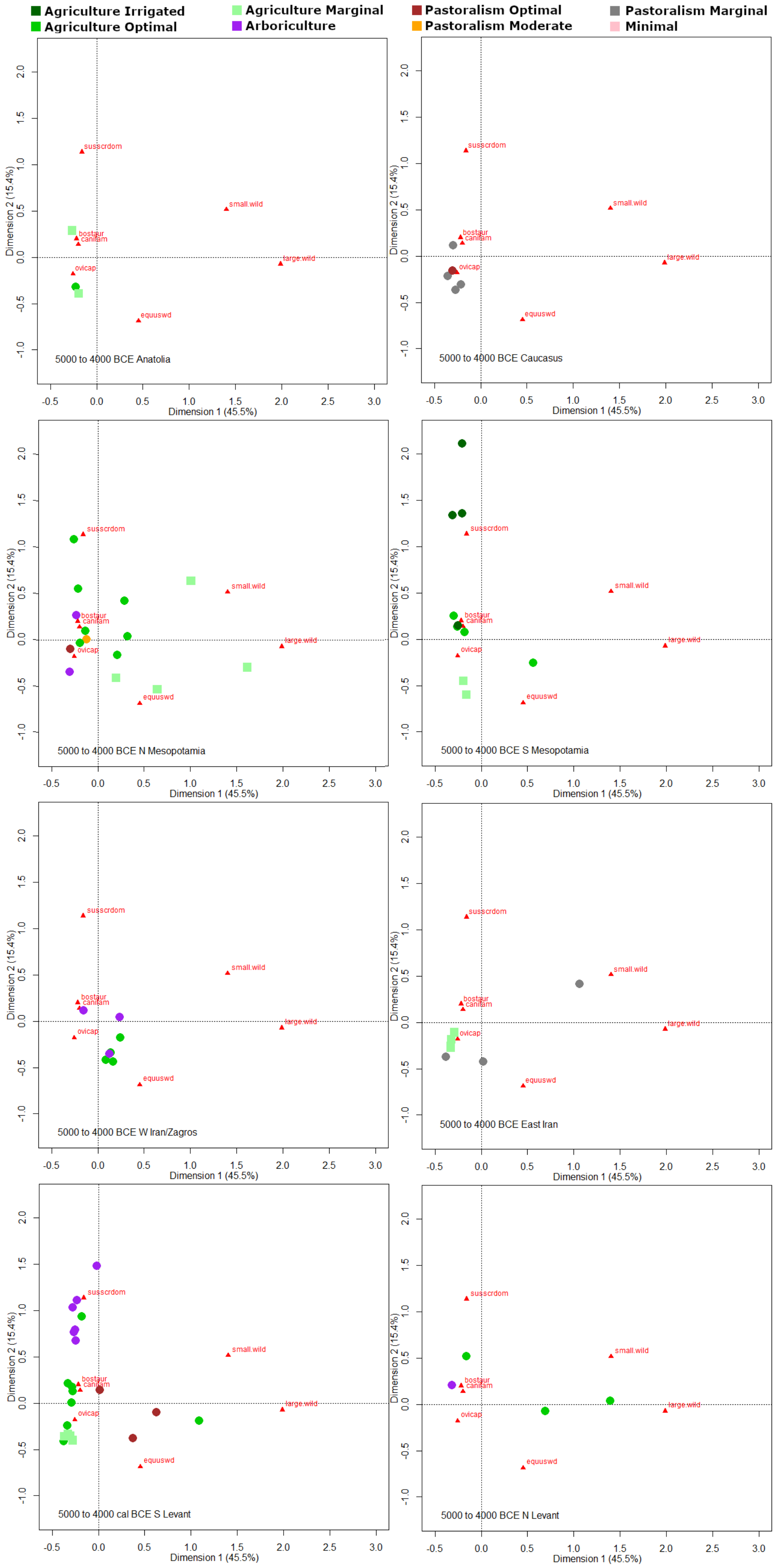

Figure 12: Correspondence Analysis of sites according to landuse zone for individual regions c.5000-4000 cal BCE.

Sites in the Caucasus display consistently low levels of hunting across 6000-4000 cal BCE. It is difficult to determine if any contemporary variation was present between sites in more or less fertile landscapes, as no data is available from sites of less fertile zones 6000-5000 cal BCE and none is available from sites of more fertile zones 5000-4000 cal BCE. The proportion of cattle at sites in less fertile zones 5000-4000 cal BCE is nearly double that of sites in more fertile zones 6000-5000 cal BCE, however, suggesting an overall increase in cattle proportions.

Middle Holocene settlements and cities: 4000-2250 cal BCE

During this stage of the Middle Holocene, urban settlements appear in many regions of the Near East. Southern Levantine sites of 4000-3250 cal BCE see proportions of cattle increase overall from 6000-4000 cal BCE, although these do not divide by zone (Figures 13 and 22). Proportions of pigs decrease at sites of the arboriculture zone but increase at sites of the optimal agriculture zone, with the result that these two zones appear to switch places compared with 5000-4000 cal BCE. Increased aridity 3250-3000 cal BCE continues this with a decrease in pig proportions across all zones. Urban sites first appear in the southern Levant during this phase. While cattle are present in greater proportions at urban sites compared with rural sites of the same zone, this difference is only slight and proportions vary across both urban and rural sites. These trends continue over the phases 3000-2250 cal BCE albeit with a decrease in cattle at rural sites of the less fertile zone and a further decrease in pigs at rural sites (Figures 15, 22 and 23). Urban sites of these phases contain lower proportions of pigs than rural sites of the same zone. Decreasing cattle at rural sites may be explained by their transference to urban sites which demonstrate higher cattle proportions than either rural sites or 3250-3000 cal BCE urban sites. Data from the 4000-3250 cal BCE northern Levant come only from sites of the optimal agriculture zone which demonstrate marked decreases in cattle proportions from 6000-4000 cal BCE and increases in pig proportions, distinctly so in at least one site. The northern Levant is represented for 3250-3000 cal BCE only by urban settlements of fertile zones which display similar cattle proportions to 4000-3250 cal BCE rural sites, although with decreased pig proportions. Rural sites of 3000-2250 cal BCE demonstrate slightly decreased cattle proportions overall compared with 4000-3250 cal BCE (particularly for sites of the optimal agriculture zone). Pig proportions at rural sites in all zones have markedly decreased. This may be due to the transference of pigs or of pig production to urban sites, which see increased cattle and pig proportions compared with both rural sites and urban sites of 3250-3000 cal BCE.

Rural sites of 4000-3250 cal BCE western Iran continue to demonstrate similar levels of hunting and proportions of cattle as seen 5000-4000 cal BCE, at least for sites in more fertile zones (Figures 13, 20 and 22). Rural sites 3250-3000 cal BCE are represented only by less fertile landuse zones with sharply decreased hunting and negligible pigs but cattle proportions comparable to 4000-3250 cal BCE (Figure 14). 3000-2250 cal BCE sees a continuation of 4000-3250 cal BCE patterns. The single represented urban site shows no differences in provisioning from rural sites. Rural settlements of 4000-3250 cal BCE eastern Iran continue to see reduced hunting in more fertile zones. Cattle proportions decline from 6000-4000 cal BCE with less divergence between sites by zone. Pigs continue to be present only at sites in more fertile zones. During 3250-3000 cal BCE cattle proportions increase slightly at rural sites of more fertile zones but dominate at the single represented urban site in the less fertile zone. Pigs remain present only at rural sites in more fertile zones. These patterns continue 3000-2250 cal BCE although the difference in proportions of cattle between urban and rural sites is reduced from that seen 3250-3000 cal BCE.

Cattle and pig proportions at southern Mesopotamian rural sites 4000-3250 cal BCE decrease starkly at sites of the more fertile optimal agriculture zone from 5000-4000 cal BCE, although little change is seen at sites of the less fertile zone. Urban sites of the irrigated agriculture zone (only), by contrast, demonstrate significantly higher proportions of cattle. Pigs are effectively absent from urban sites across all zones. 3250-3000 cal BCE sees a continuation of 4000-3250 cal BCE patterns, albeit with a slight increase in pigs at urban sites. Between 3000-2250 cal BCE only rural sites in less fertile zones are represented and demonstrate increased proportions of both cattle and pigs compared with the same zone 4000-3250 cal BCE. Urban sites of 3000-2250 cal BCE invert 4000-3000 cal BCE patterns in having lower proportions of cattle relative to rural sites but far higher proportions of pigs. Northern Mesopotamian rural settlements 4000-3250 cal BCE demonstrate lower hunting levels and higher pig proportions at sites of more fertile zones. Cattle proportions overall are lower than 5000-4000 cal BCE and not patterned by zone. Urban settlements demonstrate two patterns. Cattle are present in larger proportions at urban settlements but are again not patterned between zones. Pigs are far more abundant only at urban sites in more fertile zones. Rural sites see a minute decrease overall in the proportions of cattle and pigs during 3250-3000 cal BCE. Urban sites see a decrease in cattle and pig proportions at sites in more marginal zones, but a decrease only in pigs at those of more fertile zones. During 3000-2250 cal BCE rural sites continue previous patterns. Urban settlements demonstrate cattle proportions equal to or slightly higher than that of rural sites of the same zone although this difference is far less marked than 4000-3000 cal BCE. Urban sites do, however, continue to demonstrate higher proportions of pigs than rural sites of the same zone.

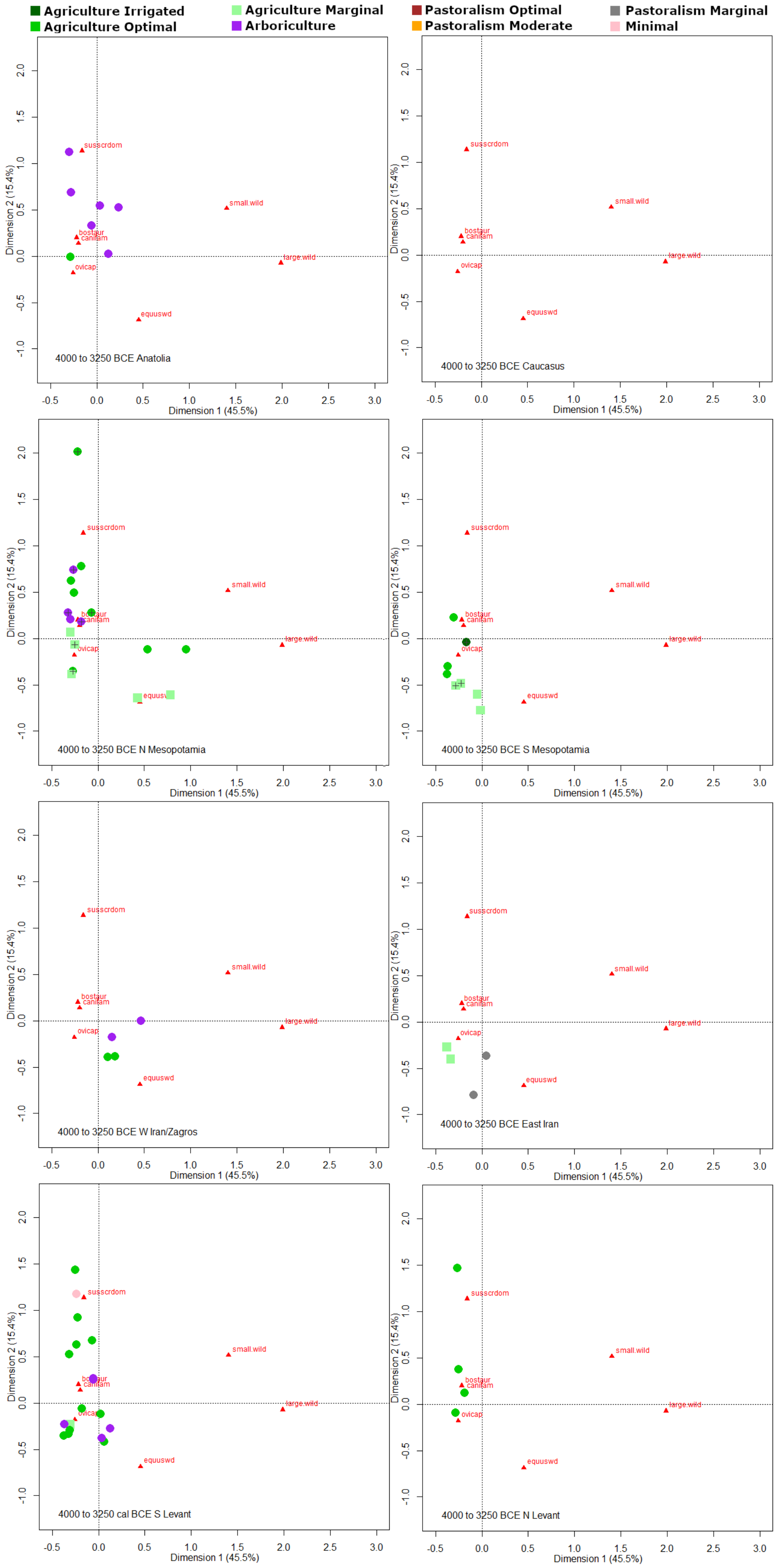

Figure 13: Correspondence Analysis of sites according to landuse zone for individual regions c.4000-3250 cal BCE. Urban sites are here highlighted with a black cross (+).

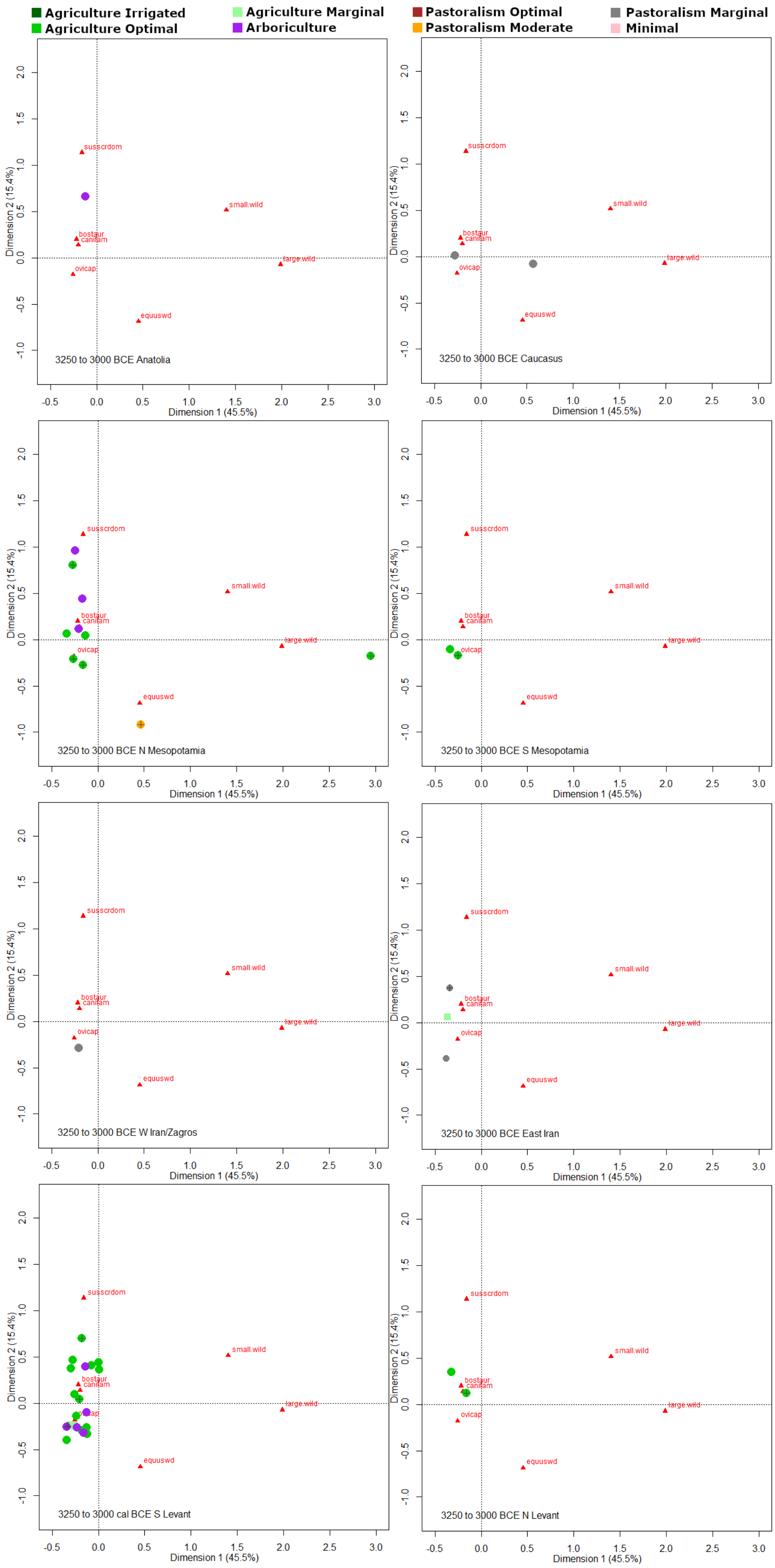

Figure 14: Correspondence Analysis of sites according to landuse zone for individual regions c.3250-3000 cal BCE. Urban sites are here highlighted with a black cross (+).

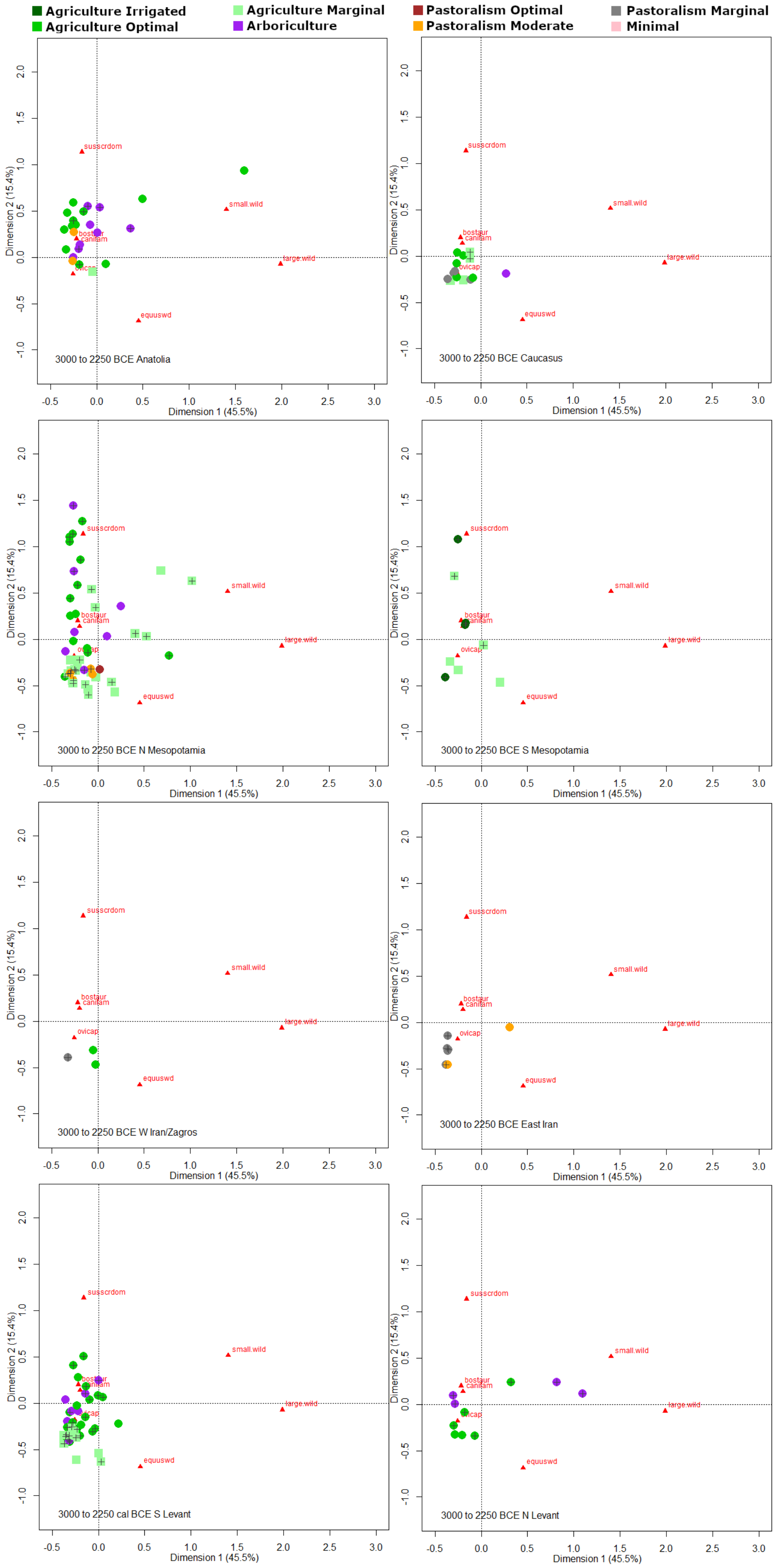

Figure 15: Correspondence Analysis of sites according to landuse zone for individual regions c.3000-2250 cal BCE. Urban sites are here highlighted with a black cross (+).

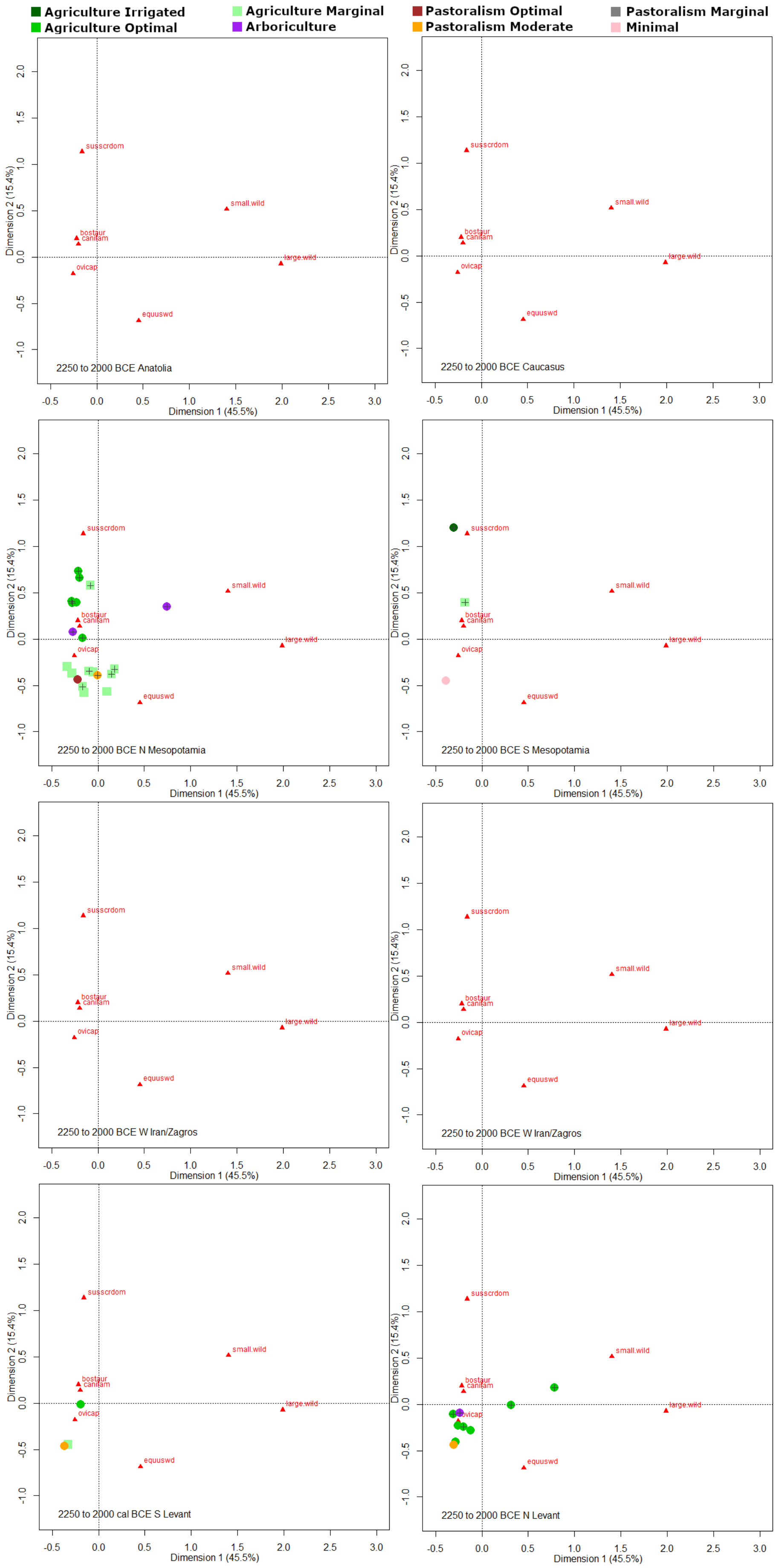

Figure 16: Correspondence Analysis of sites according to landuse zone for individual regions c.2250-2000 cal BCE. Urban sites are here highlighted with a black cross (+).

Anatolia 4000-3250 cal BCE is represented only by sites of more fertile zones. Cattle proportions at lowland sites decrease from preceding levels, continuing a trend seen since c.6000 cal BCE. At upland sites (not represented 5000-4000 cal BCE) cattle proportions continue unchanged from 6000-5000 cal BCE. Pig proportions at sites in both zones have increased slightly from 6000-4000 cal BCE. 3250-3000 cal BCE is represented by a single urban site which is distinguishable from rural sites of 4000-3250 cal BCE only by an increased proportion of pigs. Over 3000-2250 cal BCE rural sites in all but the least fertile zone demonstrate high proportions of cattle. Pig proportions decrease from 4000-3250 cal BCE and do not divide between zones. Urban settlements do not demonstrate consistent differences in hunting, cattle or pigs compared with rural sites within the same zone. No data are available from 4000-3250 cal BCE settlements in the Caucasus. During 3250-3000 cal BCE rural sites located in less fertile zones indicate increased cattle proportions compared with the last available data (5000-4000 cal BCE) forming an ongoing trend toward increasing cattle since c.6000 cal BCE. Over 3000-2250 cal BCE rural sites continue to demonstrate high proportions of cattle, albeit with a slight decrease at sites of the least fertile zone compared with 3250-3000 cal BCE. Urban sites, first represented during these phases, demonstrate more hunting than rural sites of the same zone as well as significantly higher proportions of cattle.

2250-2000 cal BCE: Early Bronze Age Collapse?

The Late Holocene in the Near East begins with a phase of punctuated aridity, which has been argued as a cause of the ‘collapse’ of Early Bronze Age societies across multiple regions (Cullen et al. 2000; Lawrence et al. 2021; Ur 2010; Weiss 2016; Weiss et al. 1993; Wiener 2014). As before, we would expect aridity-necessitated restructuring of animal production to involve the reduction in cattle and pig proportions in favour of more arid-adapted ovicaprines. Rural sites of the southern Levant 2250-2000 cal BCE from more fertile zones show no change in either hunting levels or proportions of cattle compared with 3250-2250 cal BCE, although the proportion of pigs does slightly decrease. In less fertile zones sites show more significant changes compared with preceding periods with a decrease in both hunting and proportions of cattle. In contrast with the southern Levant, urban sites remain in the 2250-2000 cal BCE northern Levant. As before, only sites from the optimal agriculture zone are represented. Compared with 3000-2250 cal BCE rural sites see a slight decrease in the proportion of cattle and a corresponding increase in the proportion of pigs. Urban sites demonstrate a significant increase in the proportion of cattle and decrease in the proportion of pigs. No site data are available from western Iran and the Zagros mountains for the period 2250-2000 cal BCE. From eastern Iran this phase is represented only by the urban site of Shahr-I Sokhta which shows a decreased representation of cattle at a level between that of urban and rural sites of the same zone from 3000-2250 cal BCE phases.

Data are available from only one rural site of 2250-2000 cal BCE southern Mesopotamia. Located in the minimal landuse zone, no comparative data is available from preceding phases. During 2250-2000 cal BCE urban sites of fertile zones show an increase in the proportion of both cattle and pigs while those of less fertile zones also show an increase in proportion of cattle but no change in the proportion of pigs compared with 3000-2250 cal BCE (Figures 16, 22 and 23). Rural sites of 2250-2000 cal BCE northern Mesopotamia in more fertile zones continue to display higher proportions of both cattle and pigs compared with 3000-2250 cal BCE than those in less fertile zones. Pig proportions at rural sites also increase, at least at sites in the most fertile landuse zone. Urban sites of northern Mesopotamia show slight increases compared with 3000-2250 cal BCE in the proportion of cattle within the more fertile zones with a mixed pattern in less fertile zones. The proportion of pigs remains largely unchanged at urban sites in more fertile zones but decreases slightly in less fertile zones. Compared with rural sites of 2250-2000 cal BCE, urban sites contain lower proportions of cattle and similar proportions of pigs and are thus not distinctive in provisioning relative to rural sites. No data are presently available sites of either Anatolia or the Caucasus during the phase 2250-2000 cal BCE.

2000-1250 cal BCE: The Late Holocene Part One

Urban settlements re-emerge in the southern Levant during 2000-1250 cal BCE. Rural site pig proportions increase from the proportions seen during the preceding phase and return to levels comparable to those of 3000-2250 cal BCE levels while cattle continue 2250-2000 cal BCE levels (Figures 17 and 22). Urban sites demonstrate greater proportions of cattle and lower proportions of pigs compared with rural sites as with 3000-2250 cal BCE albeit with increased divergence between rural and urban sites. Northern Levantine rural settlements 2000-1250 cal BCE alter earlier patterns with higher proportions of cattle compared with 3000-2000 cal BCE and highest at sites located in less fertile landuse zones. Pig proportions remain higher at sites in more fertile zones. Urban sites continue with similar proportions of cattle and pigs to those of 2250-2000 cal BCE. No data are available from western Iran during 2000-1250 cal BCE. Rural sites of eastern Iran continue low levels of hunting although cattle proportions have diminished significantly since c.3000-2250 cal BCE. Hunting is equally minor at urban sites with cattle proportions higher vs. rural sites although significantly lower than any sites of 3000-2250 cal BCE. Pigs are absent from both rural and urban sites.

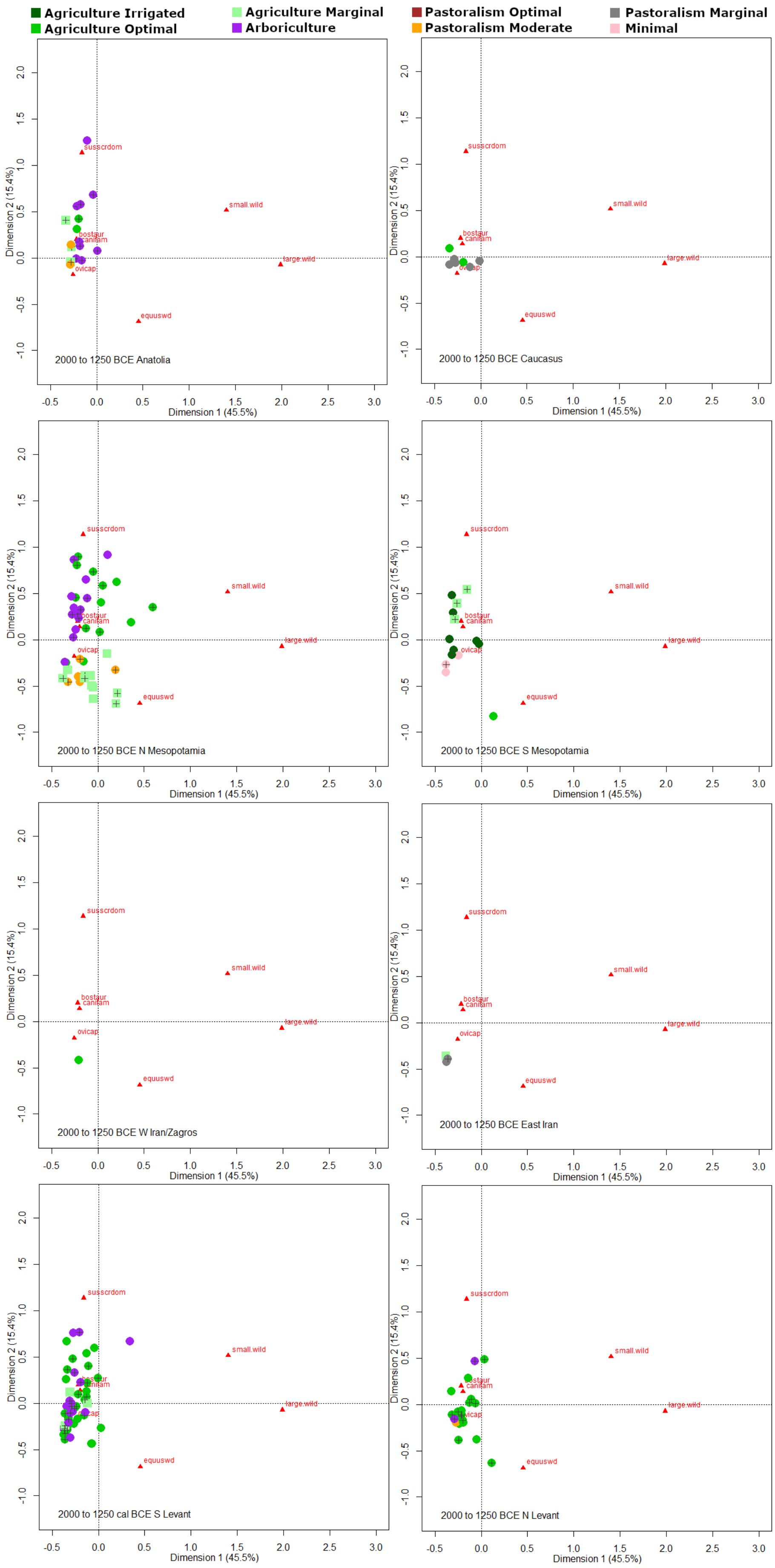

Figure 17: Correspondence Analysis of sites according to landuse zone for individual regions c.2000-1250 cal BCE. Urban sites are here highlighted with a black cross (+).

Rural settlements of southern Mesopotamia continue 3000-2000 cal BCE animal provisioning with more fertile zones demonstrating higher levels of hunting and higher proportions of cattle (Figure 17). Urban settlements contain similar proportions of cattle across zones as well as compared with rural sites. Urban sites of more fertile landuse zones demonstrate an increased proportion of pigs - in keeping with those of 3000-2000 cal BCE – although this is far less marked than previously. Rural settlements of northern Mesopotamia revert to 3000-2250 cal BCE animal provisioning. Cattle are common at rural sites in all zones, although both cattle and pigs comprise smaller proportions in less fertile zones. Urban sites likewise revert to 3000-2250 cal BCE patterns and demonstrate higher proportions of cattle than rural sites (excepting those of the marginal agriculture zone). The proportions of cattle at urban sites of 2000-1250 cal BCE are higher than during 2250-2000 cal BCE, suggesting that they may have played a more important role in urban site provisioning than pigs, which previously were important distinguishers of urban sites but now are present on urban sites at similar proportions to rural sites of the same zone.

Rural settlements of 2000-1250 cal BCE Anatolia demonstrate higher proportions of cattle at rural sites in more fertile zones although this variance is less than 3000-2250 cal BCE. The proportions of pigs at rural sites increases compared with 3000-2250 cal BCE for sites in more fertile zones although this proportion decreases slightly in less fertile zones. Urban sites continue 3000-2250 cal BCE significantly increased cattle proportions at urban sites compared with rural sites in the same zone. The proportions of pigs at urban sites (which during 3250-2250 cal BCE were higher than those of rural sites in the same zones) are lower than those of rural sites in the same zone as well as lower than urban sites of these zones during 3000-2250 cal BCE. As with northern Mesopotamia, this appears to indicate changes in urban animal provisioning preferences in second millennium BCE Anatolia. Data from the 2000-1250 cal BCE Caucasus are available only from rural settlements. These exhibit a continuation of patterns seen since c.6000 cal BCE of low levels of hunting and increasingly higher proportions of cattle across sites of both more and less fertile landuse zones. Pigs are kept only in very low proportions but are more abundant at sites in more fertile zones.

1250-1000 cal BCE: The Late Bronze Age Collapse

During the aridity of 1250-1000 cal BCE southern Levantine rural settlements see no change in levels of hunting or proportions of cattle, although proportions of pigs decrease compared with 2000-1250 cal BCE (Figures 18, 22 and 23). The proportions of cattle at urban sites continue to be higher than rural sites of the same landuse zone, although lower in each zone than 2000-1250 cal BCE urban sites. Pig proportions at urban sites have also decreased compared with previously, although pig proportions remain higher at urban than rural sites due to a larger drop in pig proportions at rural sites. Rural sites in the northern Levant show an increase in the proportions of both cattle and pigs compared with 2000-1250 cal BCE. This increase is present also at urban sites, although is much smaller with a significant narrowing of divergence between urban and rural sites during this phase. Data from western Iran has been missing from our dataset since c.2250 cal BCE; thus it is difficult to directly compare rural sites of 1250-1000 cal BCE earlier phases. Compared with the last available (3250-2250 cal BCE) data rural sites demonstrate a decrease in hunting which had been increasing since c.6000 cal BCE excepting a significant drop during 3250-3000 cal BCE. Rural sites also demonstrate the lowest proportions of cattle and pigs seen from sites of this region and zone since c.7000 cal BCE. No data are presently available from easter Iran for 1250-1000 cal BCE.

Data from southern Mesopotamian rural sites are available only from less fertile landuse zones, which continue patterns from 2000-1250 cal BCE. Urban sites see decreased cattle proportions alongside a minor increase in pig proportions. Changes to animal provisioning during this phase of aridity can be seen at rural sites in northern Mesopotamia. Only data from rural sites of the optimal agriculture zone are available, which demonstrate lower levels of hunting and lower cattle and pig proportions compared with 2000-1250 cal BCE. Urban sites in more fertile zones indicate no such changes, with a continuation of cattle proportions and significantly increased pig proportions. Urban sites of less fertile zones demonstrate a slight decrease in cattle proportions but with the same significant increase in pig proportions as urban sites of more fertile zones. The phase of aridity c.1250-1000 cal BCE is seen in Anatolia through slight decreases to cattle and pig proportions at both rural and urban sites of all zones. The divergence between urban and rural sites has also decreased from 2000-1250 cal BCE. Data from the Caucasus during 1250-1000 cal BCE are available only from rural sites of the less fertile zone. Cattle and pig proportions have increased compared with 2000-1250 cal BCE (Figures 18 and 22). This continues the trend of gradually increasing proportions of cattle since c.6000 cal BCE, even in more marginal zones during a phase of increased aridity.

1000 to 0 BCE: The Late Holocene part two

Southern Levantine sites 1000-0 cal BCE continue patterns from 2000-1000 cal BCE. Rural sites in more fertile zones demonstrate lower cattle proportions than 1250-1000 cal BCE although these increase at sites in less fertile zones (Figures 19 and 22). Pig proportions at rural sites of less fertile zones increase from 1250-1000 cal BCE while remaining lower than 2000-1250 cal BCE. 1000-0 BCE urban sites demonstrate higher cattle and lower pig proportions than rural sites of the same zone.

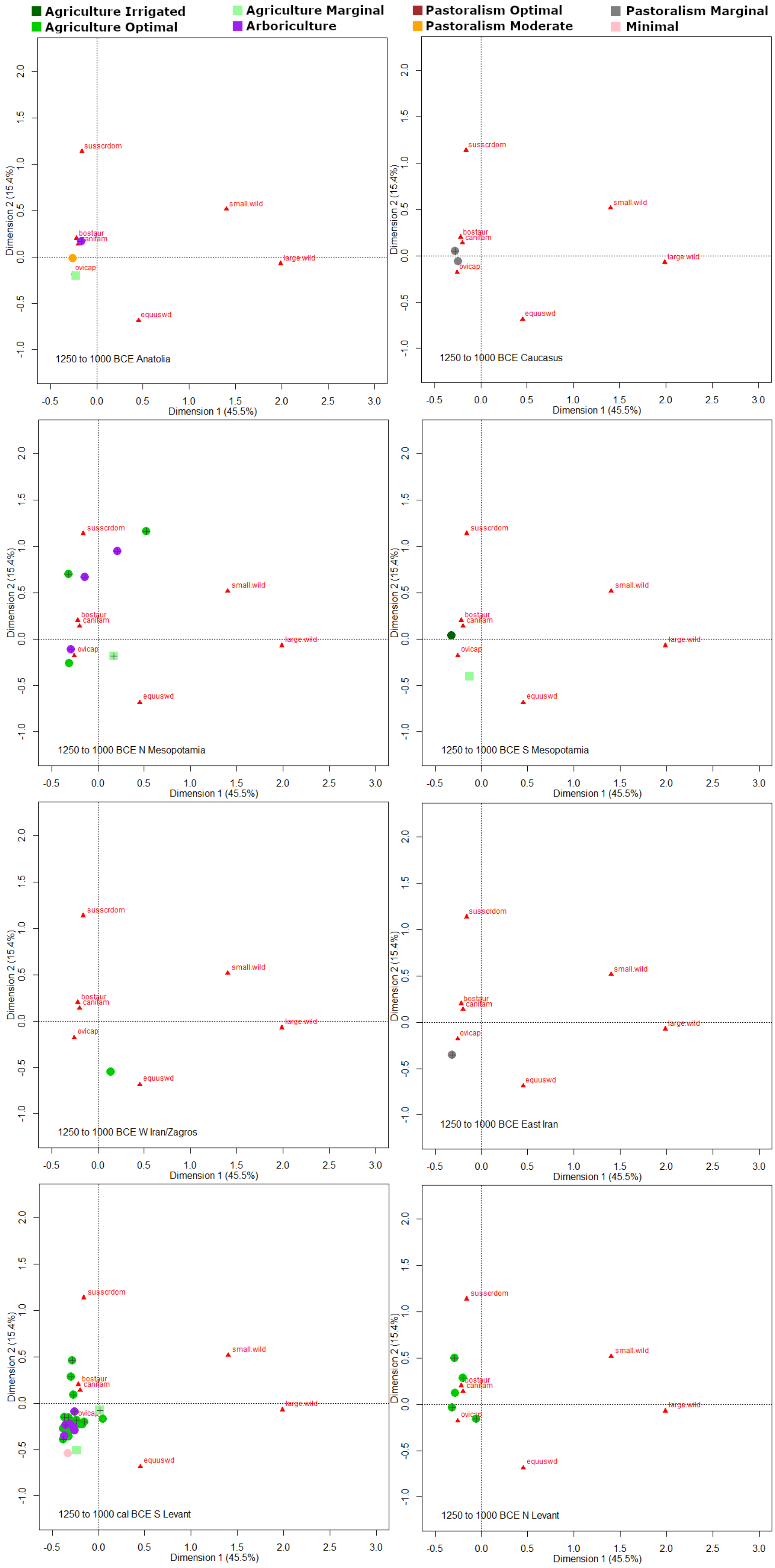

Figure 18: Correspondence Analysis of sites according to landuse zone for individual regions c.1250-1000 cal BCE. Urban sites are here highlighted with a black cross (+).

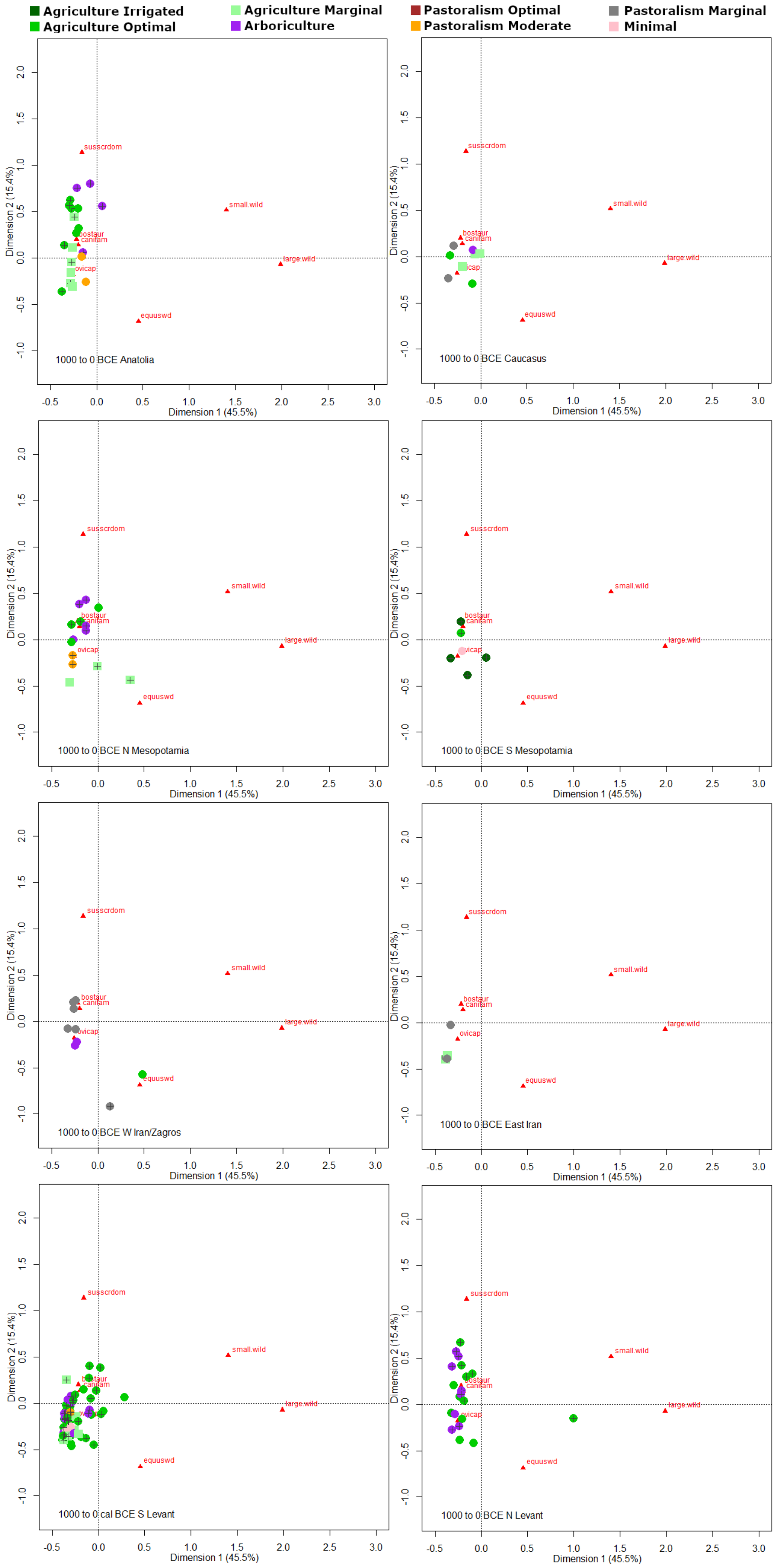

Figure 19: Correspondence Analysis of sites according to landuse zone for individual regions c.1000-0 cal BCE. Urban sites are here highlighted with a black cross (+).

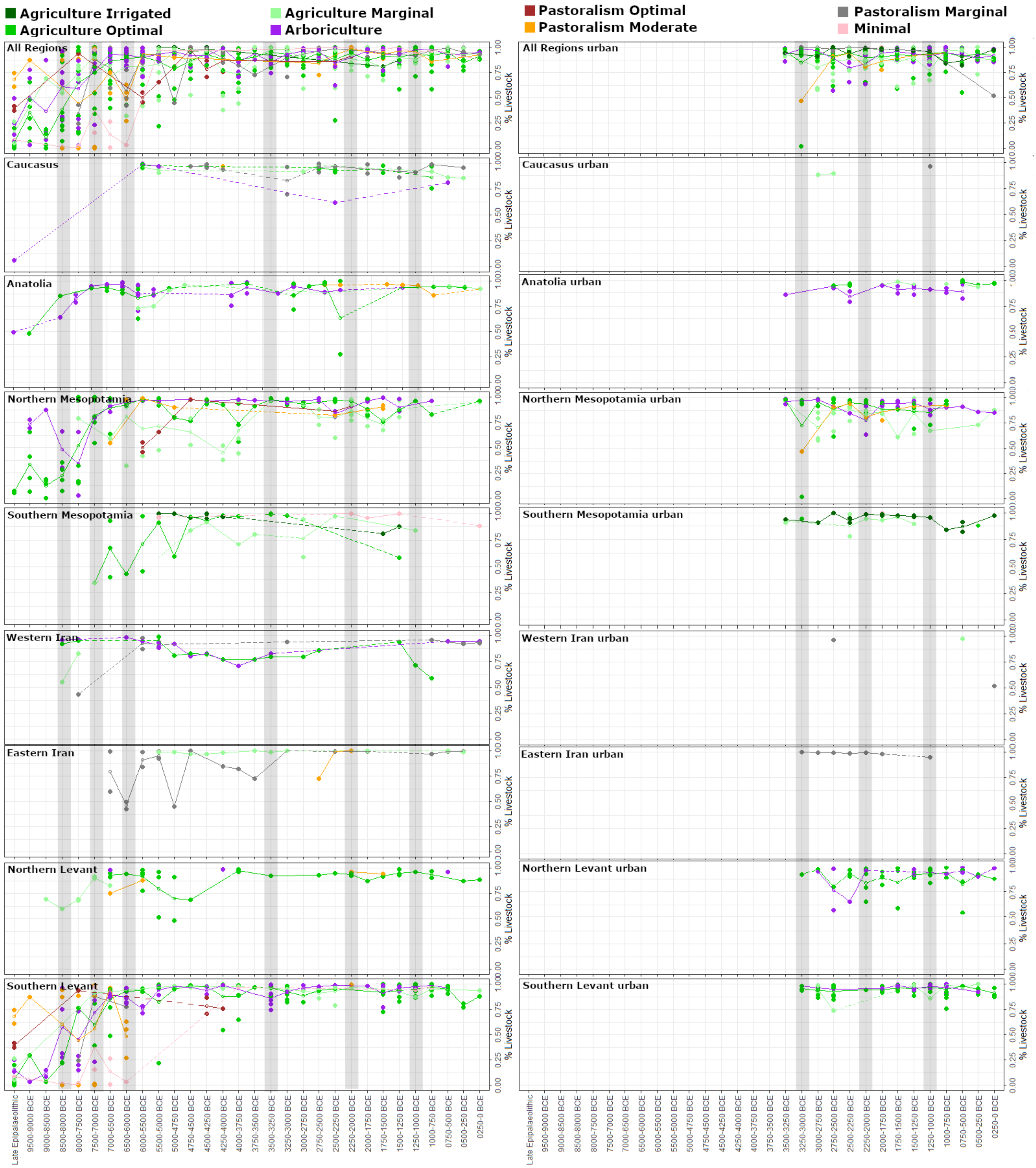

Figure 20: Proportion of livestock taxa present at rural and urban sites across the Late Holocene according to region and landuse zone. Trend lines are given here for the mean proportion of livestock present within each landuse zone by region.

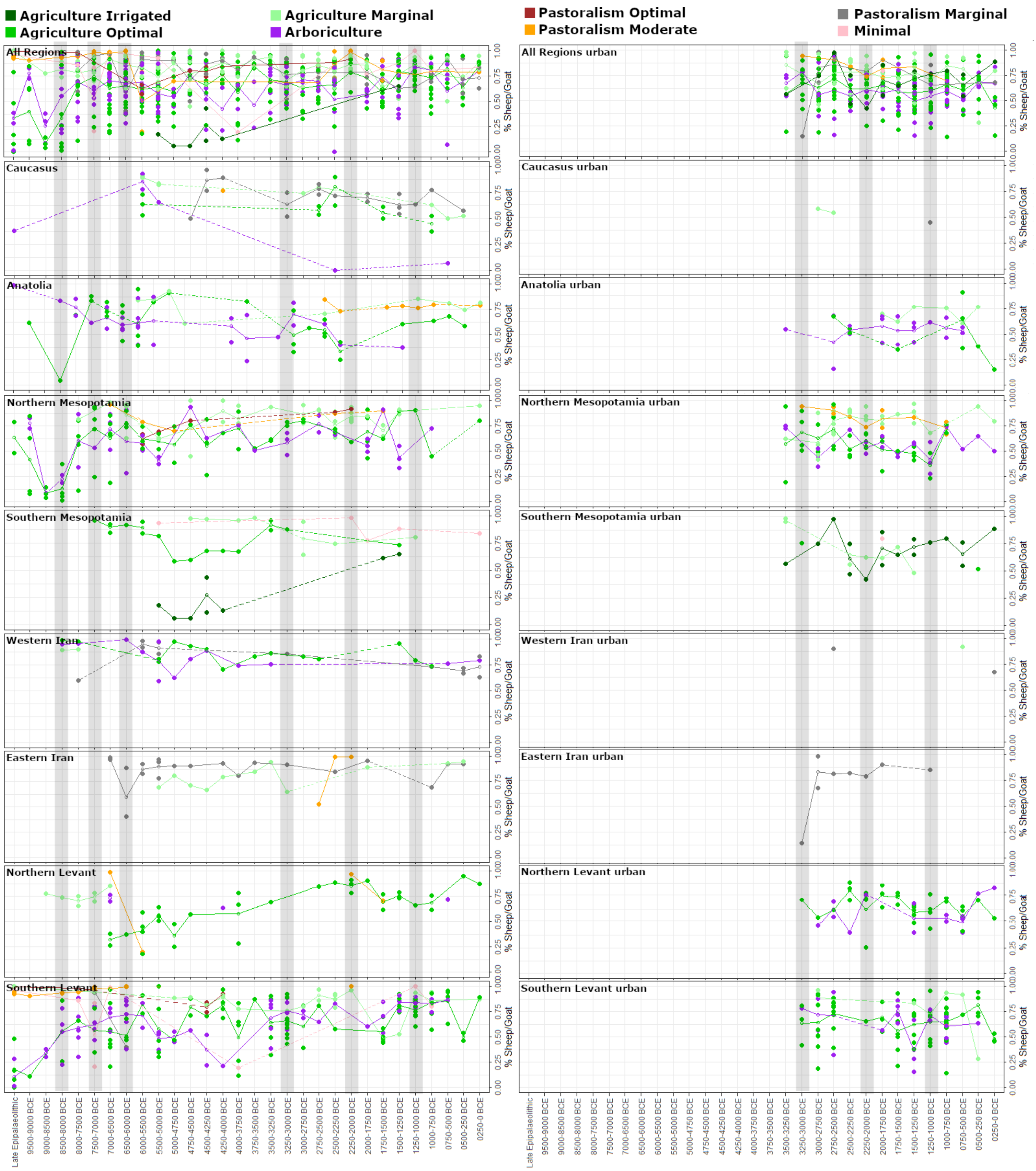

Figure 21: Proportion of ovicaprines present within livestock taxa at rural and urban sites across the Late Holocene according to region and landuse zone. Trend lines are given here for the mean proportion of livestock present within each landuse zone by region.

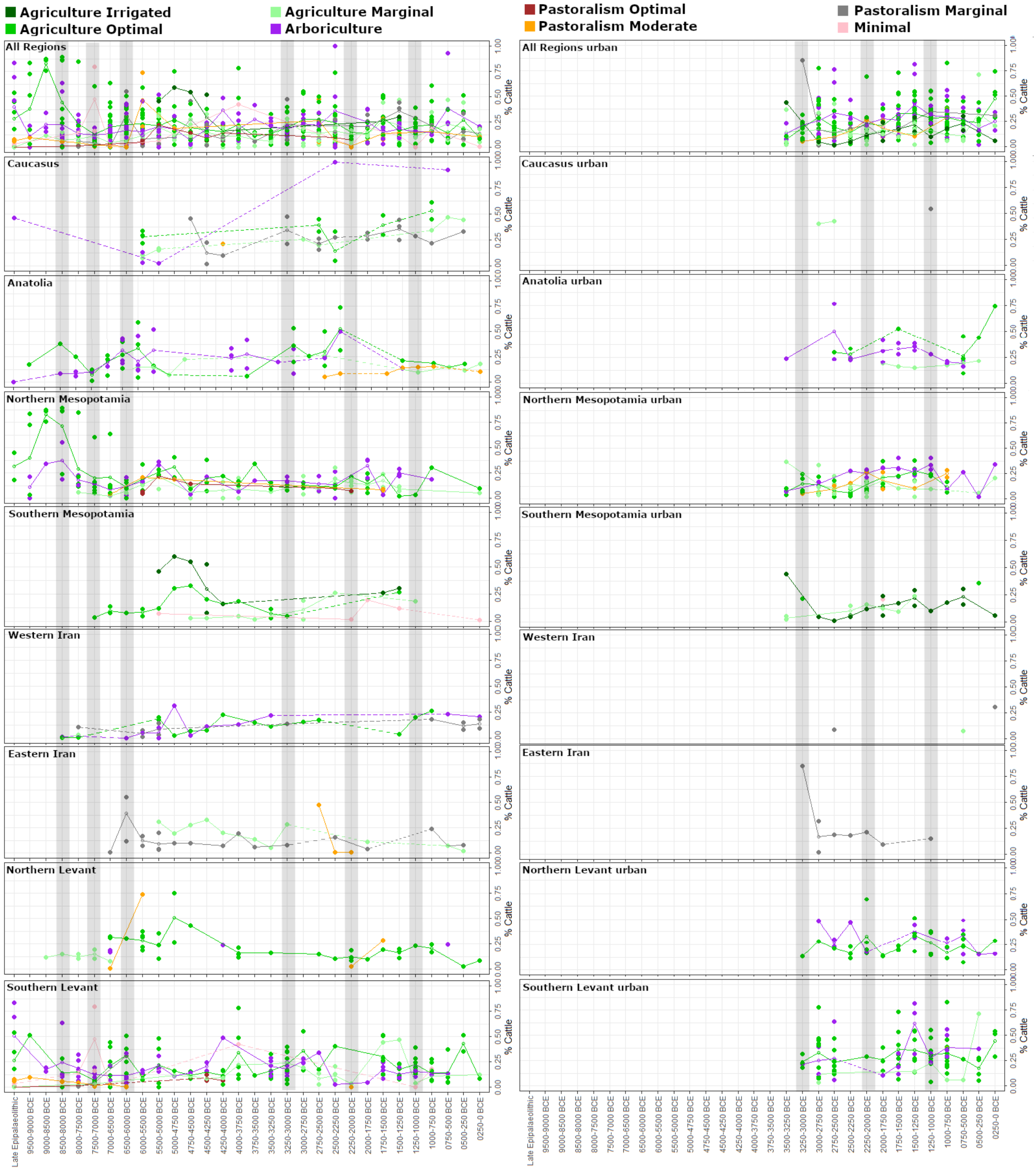

Figure 22: Proportion of cattle present within livestock taxa at rural and urban sites across the Late Holocene according to region and landuse zone. Trend lines are given here for the mean proportion of livestock present within each landuse zone by region.

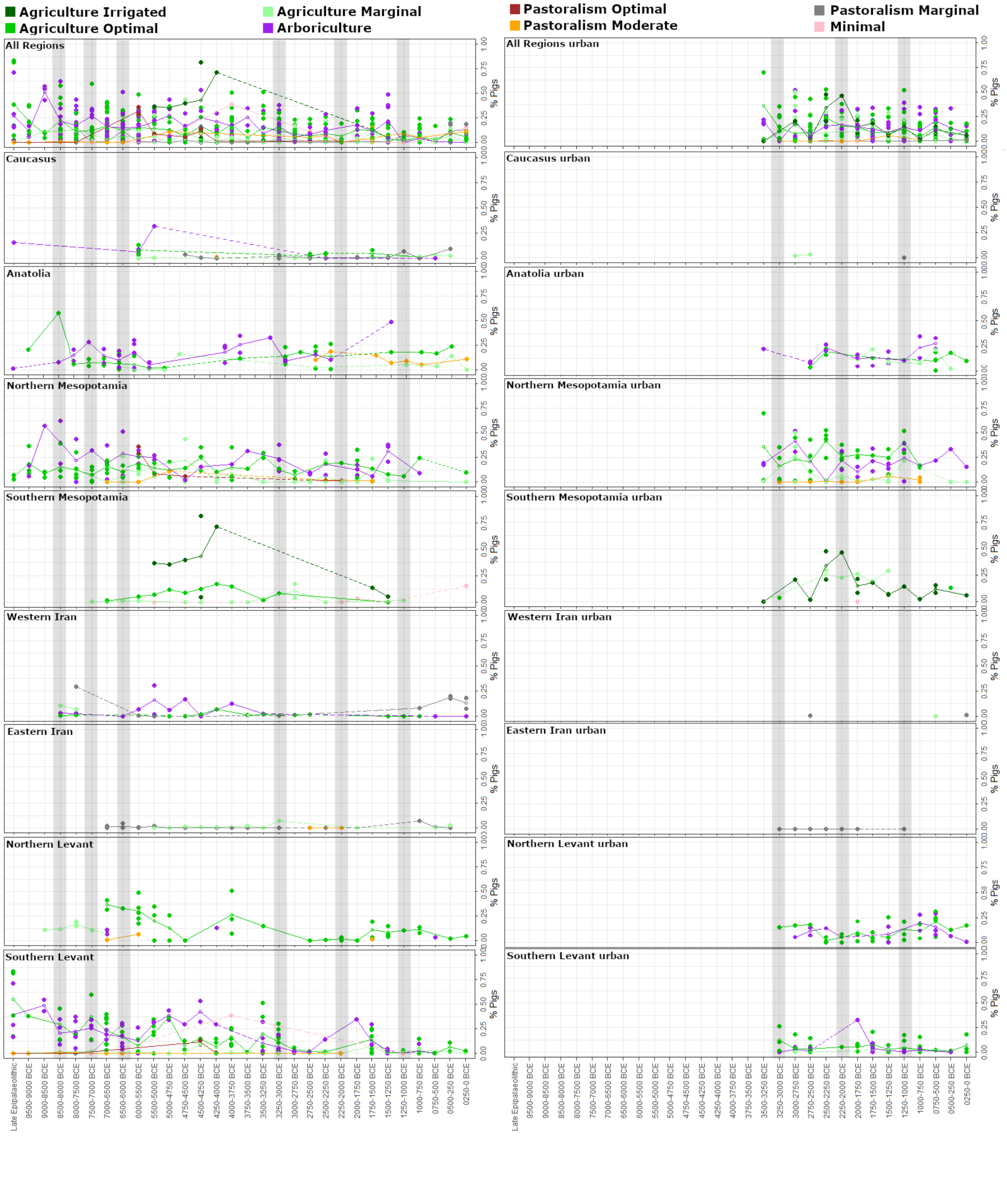

Figure 23: Proportion of pigs present within livestock taxa at rural and urban sites across the Late Holocene according to region and landuse zone. Trend lines are given here for the mean proportion of livestock present within each landuse zone by region.

In each zone cattle proportions have increased to 2000-1250 cal BCE rather than 1250-1000 cal BCE levels with a greater divergence between urban and rural sites than any previous phase of this region. Northern Levantine rural settlements of 1000-0 cal BCE show a return to urban-rural patterns of 3000-2000 cal BCE. Rural sites evince decreased cattle and pig proportions compared with 1250-1000 cal BCE and comparable with 2000-1250 cal BCE levels. Cattle and pig proportions at urban sites also returned to earlier levels, in this case those of 3000-2250 cal BCE (after the loss of increased urban pig consumption during 2000-1250 cal BCE). Rural settlements of 1000-0 BCE western Iran demonstrate higher proportions of cattle compared with 1250-1000 cal BCE. These are higher at rural sites in more fertile zones, although pig proportions are higher at sites in less fertile zones. Hunting levels remain low across rural sites. Urban settlements of 1000-0 cal BCE demonstrate higher levels of hunting than rural sites of the same zone as well as increased cattle and decreased pig proportions. Rural sites of 1000-0 cal BCE eastern Iran demonstrate an inverse pattern to 2000-1250 cal BCE. While hunting levels remain low, the cattle proportions are now higher at settlements in less fertile zones. Pigs re-appear, present in low levels but slightly more numerous at rural sites in less fertile zones (as seen also in western Iran). Urban sites continue the earlier pattern absent pigs and an increased proportion of cattle relative to rural sites of the same zone.

Rural and urban settlements of 1000-0 cal BCE southern Mesopotamia are not available for the same landuse zones. Rural sites demonstrate a distinct reduction in cattle proportions compared with 2000-1250 cal BCE in favour of increased pigs (Figures 19, 22 and 23). Urban sites show increased cattle but decreased pig proportions relative to 1250-1000 cal BCE. Urban site provisioning in southern Mesopotamia appears to have shifted away from pig towards cattle provisioning, which may explain their reduction on rural sites. Rural sites of 1000-0 cal BCE northern Mesopotamia return to 2000-1250 cal BCE patterns with higher cattle and pig proportions at sites in more fertile zones. Rural settlements of less fertile zones demonstrate more hunting, more closely resembling those of 1250-1000 cal BCE. Urban sites of 1000-0 cal BCE demonstrate no differences in provisioning compared with rural sites.

Rural sites of 1000-0 cal BCE Anatolia demonstrate similar cattle proportions to 2000-1000 cal BCE. Pig proportions at rural sites in more fertile zones return to 2000-1250 cal BCE levels but in less fertile zones remain at 1250-1000 cal BCE levels. Urban sites continue to exhibit higher proportions of cattle than rural sites of the same zone although are less divergent. Pig proportions are higher at urban sites compared with rural ones of the same zone although are less common Anatolia overall compared with 2000-1250 cal BCE. Rural sites of the 1000-0 cal BCE Caucasus continue earlier patterns, albeit with more hunting. Cattle form a higher proportion of livestock at rural sites in more fertile zones, although cattle proportions are higher at rural sites in all zones compared with earlier phases, continuing increasing proportions of cattle seen in this region through time.

Discussion

This study has examined the impact of landuse potentiality upon choices made in animal production through time and between regions. Within this we have also divided rural and urban sites to examine differences in production and provisioning. We have identified variations in the provisioning of animals between regions, as well as between landscape types within individual regions, from c.13,000 cal BCE. Where the wild progenitors of livestock taxa form a dominant proportion of diets, wild ovicaprines are consistently hunted in greater numbers. Where livestock taxa form a minor proportion of diets individual taxa proportions are more balanced (Figures 4, 5 and 20-23; see also SI3 Table 2). The contribution of livestock taxa to diets increases through time across all regions as domesticated animals proliferate. Some patterns remain between neighbouring regions, although these are not always consistent. Commonalities are more often seen in the proportions of individual taxa while greater variation is seen in levels of non-livestock taxa consumption. Similarities between neighbouring regions do not translate into directly comparable taxonomic proportions, even for the same landuse zones. The divergence of provisioning between sites of the same landuse zone according to region can be seen in SI4. While statistical difference is not universally present between sites of the same landuse zone from different regions, significant differences in provisioning are common even between sites of the same landuse zone from adjoining regions. While sites in more fertile zones often contain increased proportions of cattle and/or pigs, this pattern is not consistent between regions or even for the same zones of neighbouring regions. Three episodes of increased aridity occurred during these Early Holocene phases of animal domestication and domesticate proliferation, during which no region demonstrated changes to animal provisioning.

Regional priority in animal provisioning patterns evident from the onset of the Holocene continue throughout the Middle Holocene, as seen from the results of this study and their statistical assessment in SI4. This means that sites of the same landuse zone between regions – even between adjacent regions – are not necessarily comparable as regional preferences may trump expected landuse zone limitations. As the gradual drying trend begins in the Middle Holocene, we would expect adaptations in animal provisioning towards increasing aridity to appear (more ovicaprines and fewer cattle and pigs). When landuse zones are compared for all regions, ovicaprine proportions are often relatively higher at sites of less fertile zones. However, these differences in proportions are predominately stable over time and are not consistent across all regions and show no consistent increase through time. Some regions develop

Phase	Landuse	Livestock	Cattle	Pig	S/G
13,000-9500 cal BCE	All	20.7%	19.5%	19.2%	55.4%
9500-8500 cal BCE	All	27.5%	32.5%	34.3%	27.7%
8500-8000 cal BCE	All	52.8%	23.1%	17.1%	55.2%
8000-7500 cal BCE	All	56.7%	21.0%	12.4%	66.6%
7500-7000 cal BCE	All	71.6%	11.8%	9.9%	70.9%
7000-6500 cal BCE	All	81.3%	13.1%	13.5%	73.4%
6500-6000 cal BCE	All	78.1%	19.9%	11.2%	68.9%
6000-5000 cal BCE	All	86.8%	17.7%	12.4%	69.4%
5000-4000 cal BCE	All	88.6%	17.9%	12.7%	69.4%
4000-3250 cal BCE	All	89.0%	17.1%	13.4%	69.5%
3250-3000 cal BCE	All	88.2%	23.1%	10.0%	66.8%
3000-2250 cal BCE	All	90.2%	20.7%	8.9%	70.4%
2250-2000 cal BCE	All	89.3%	17.0%	8.7%	74.3%
2000-1250 cal BCE	All	91.4%	23.6%	9.6%	66.9%
1250-1000 cal BCE	All	92.9%	23.1%	7.1%	69.8%
1000-0 cal BCE	All	92.9%	23.4%	7.0%	69.6%

Table 2: Mean values of livestock taxa and proportions of individual taxa represented for all regions and landuse zones of the Near East according to phase group. Phases of increased aridity have been highlighted in brown.

long-term trends. Levels of hunting and proportions of cattle increased over the Middle Holocene across western Iran. Proportions of cattle increased through time in the Caucasus irrespective of zone or climate oscillations. Proportions of cattle were consistently higher at sites in more fertile zones of eastern Iran, with proportions of both cattle and pigs higher in more fertile zones of southern Mesopotamia. Pigs were present in higher proportions at sites in more fertile zones of the southern Levant but only at upland sites in western Iran while Anatolia oscillated between higher proportions at only sites in upland zones or those in more fertile zones. These trends were not consistent contemporaneously across the same zones, but rather are demarcated by a given region over time. While the proportions of cattle and pigs are higher at sites in more fertile zones in some regions, this pattern is not consistent across both species, across individual zones between regions, nor necessarily between regions as a whole through time.

Evident from this analysis is that proportions of ovicaprines vs. cattle and pigs change not in response to the gradually increasing aridity of the Middle Holocene but rather due to the development of urban settlements in each region. The increased proportions of either cattle, pigs, or both at urban sites varies according to region as well as by the cultural/civilisational preferences by phase within regions. The difference in proportions of these taxa between urban and rural sites also varies more between regions and through time than between contemporaneous zones of different regions. Within this overall primacy of regional preference, some trends are apparent for the Middle Holocene. In most regions, pig proportions decrease through time, although with short-term inconsistencies. The rate of decrease, as well as the absolute proportions, again vary primarily within rather than between regions. However, where pigs decrease across the Middle Holocene, they nearly always decrease first at rural sites in the least fertile landuse zones of each region (regardless of which zone is the least fertile of that region).

In some regions, the representation of cattle and pigs decreases at rural sites as livestock reared at rural settlements were apparently transferred to urban ones. The form of this transfer is less certain, although may have taken the form of production at directly owned elite or royal estates changing to meet urban consumptive demands, the payment of animals as food rents or tributes or other potential mechanisms (e.g. Grossman & Paulette 2020). In other regions, the stability in proportions of these taxa at rural sites alongside their elevation at urban sites suggests an overall increase across the region. Variation in levels of divergence between urban and rural sites vary first between and then within regions. Chronological changes are evident in the regional taxonomic preferences of urban sites as regional links change. The northern Levant is an excellent example, with urban provisioning patterns paralleling those of northern Mesopotamia (3250-2250 cal BCE), then those of the southern Levant (2250-1250 cal BCE), then back to northern Mesopotamia again (1250-0 cal BCE). A second example is seen from Southern Mesopotamia, where high proportions of cattle and almost no pigs characterise urban settlements of the Uruk period (4000-3000 cal BCE), before switching in the Early Dynastic (3000-2250 cal BCE) to high proportions of pigs and a minority of cattle and then switching again in the Akkadian period (2250-2000 cal BCE) to high proportions of pigs and cattle. Across all regions compared in this study, increased cattle proportions at urban vs. rural sites is demonstrated in the greatest number of regions with the increased representation of pigs more limited to Anatolia, Mesopotamia and some phases of the northern Levant. The increased proportion of pigs present on urban sites is commonly interpreted as indicating cheap on-site meat production, as pigs mature rapidly and can subsist upon human refuse within the settlement generating the dual advantage of street cleaning and meat production (Mudar 1982). Their corresponding decrease at rural sites, however, suggests that urban pig production may have been insufficient to meet demands and that additional pigs may have been imported from rural settlements, although additional research would be required to determine this. Whether this change in pig presence during the Early Bronze Age relates to increased on-site urban production or rural-urban importation via improvements in live animal transport, urban meat consumption preferences or new pressures on meat production demands from an increased density of urban populations remains to be determined.

Three punctuated aridity phases are notable during the Middle to Late Holocene. Each has been argued as a cause of episodes of collapse, including political instability, urban abandonment and wider population decline. Two of these occur during the Middle Holocene. If these phases of aridity necessitated changes to animal production regimes, we would expect to see a decline in more water-intensive livestock (cattle and pigs) and a corresponding increase in more arid-adapted animals (ovicaprines). The 'Uruk collapse' phase (3250-3000 cal BCE) in southern Mesopotamia, however, demonstrates not an increase but rather a decrease in proportions of ovicaprines, especially at urban sites. Some decrease in pigs is seen in northern Mesopotamia in both urban and rural sites, although these are minor and do not extend to cattle. The southern Levant also sees a slight pig decrease, but at the same time also sees the development of urban settlements (Gaastra et al 2020b). Multiple regions (Anatolia, the Caucasus, eastern Iran and possibly western Iran) also demonstrate increased proportions of water-intensive cattle at rural sites even in more marginal landuse zones. This begs the question of how extreme the effects of this aridity were, and whether they were equally felt in all regions. The 'Early Bronze Age Collapse' phase (2250-2000 cal BCE) is also inconsistent. Rather than increasing, ovicaprines decrease in southern Mesopotamia, at least in cities. Northern Mesopotamia loses the distinction between urban and rural sites, although this is caused by an increase in pigs at rural sites rather than their decrease at urban sites and is thus unlikely to indicate aridity-induced restructuring. The only significant restructuring evident during this punctuated aridity is the sharp decrease in cattle (from 12-2%) at rural sites in the least fertile zone of the southern Levant. It is noteworthy that this is the only region represented during this phase which lacked urban settlement systems at the time of increased aridity, positing the question of whether the structure of urban settlement systems may have added stability to production regimes. While some minor restructuring is indicated, each 'collapse' is primarily confined to changes in one region, or even one zone of one region.

During the Late Holocene we would again expect to see increased proportions of more arid-tolerant livestock at the expense of more water-intensive taxa. As with the Middle Holocene, this pattern is mixed. Some regions do demonstrate an increase in ovicaprines at the expense of cattle and pigs, although most show no overall change or even a reduction in ovicaprines in favour of cattle and/or pigs. Common patterns are not limited to neighbouring regions and the proportions of individual taxa at sites within a given zone continue to vary more by region than by zone across regions. Our final aridity collapse phase, the 'Late Bronze Age Collapse' (1250-1000 cal BCE) differs from previous aridity phases in demonstrating more impacts. Multiple regions restructure their provisioning toward a greater focus upon more arid-tolerant ovicaprines (western Iran, southern Mesopotamia and potentially Anatolia). Some regions may have restructured at rural sites, with urban sites thereby maintaining access to desired levels of preferred livestock (northern Mesopotamia). Other regions restructured by giving up pigs in order to maintain cattle (southern Levant). The Caucasus - following its own path since 6000 cal BCE – continued its trajectory of increasing cattle production. It is not until the first millennium BCE that we can see some changes to animal production consistent with mitigating against increased aridity which occur outside of punctuated aridity. Unsurprisingly, as with changes seen during phases of punctuated aridity, these are limited both in changes made as well as in geographical scope. Most regions saw no change and continued Middle Holocene animal provisioning patterns unabated (northern Levant, southern Mesopotamia, western Iran, the Caucasus, eastern Iran). Some regions increased their ovicaprine focus, but only at sites in less fertile zones (northern Mesopotamia). A minority of regions (Anatolia and the southern Levant) retained adaptations made during 1250-1000 cal BCE.

Conclusions

This expanded analysis of the impact of variation in both climate and local environment upon choices made in animal provisioning for societies of the Holocene Near East has demonstrated that communities made provisioning decisions with regard to the capabilities and limitations of local environments. While common trends are evident between settlements in different landscapes of the same region, these were not necessarily the same between societies of the same landscapes in different regions. These overall do not show significant changes to animal provisioning in response to increasing aridity, either in the long or short term. What this study has demonstrated is instead a prioritisation of individual and societal preferences to produce specific animals. These preferences rarely bow to short or long term changes in aridity, with the suggestion instead being of increased effort being made across sites in a range of local environments and different regions of the Near East to maintain desired patterns of animal production. Previous analysis of two of the regions studied here also suggested that provisioning restructuring was uncommon across the Holocene Near East, but where needed was seen at sites in more marginal landscapes. This present study shows the picture to be more complicated than overall comparisons of landuse fertility, and to be filtered first and foremost by regional preferences. Where changes in response to increased aridity are evident these are generally minor tweaks rather than complete overhauls, they are primarily (but not entirely) limited to sites in the most marginal zone of a given region – irrespective of the absolute fertility or marginality of that zone - and are characteristic of punctuated episodes of aridity rather than long-term aridity trend.

Changes in hunting levels are one aspect of provisioning which have previously been suggested as mechanisms by which to mitigate against adverse local conditions for livestock food production (Saña Seguí 2000; Zeder 2003). While some changes to levels of hunting are seen, they do not consistently pattern across or between regions either by landuse zone or through time. Hunting levels appear instead to vary widely even within a given region, zone and phase and should best be considered an indication of choice at the local level and not indicative of broader provisioning restructuring. Within domestic livestock production, identifiable changes most often include a reduction in pigs, with cattle production rarely sacrificed to aridity practicalities. These are one of our two more water-intensive livestock species and the one which does not migrate easily. Their loss suggests that the mobility of ovicaprines and cattle may have made them desirable livestock for production irrespective of the increased water requirements for cattle. The investment of greater effort into maintaining desired levels of production in the face of changing climates may be characteristic only of animal production, with its capacity to move animals to different food sources, compared with the fixed nature of agricultural production.

Aridity restructuring changes are more demonstrable at rural than urban sites. Both over the long term and during punctuated episodes of aridity, urban sites were able to maintain preferential access to more water-intensive cattle and pigs. For many phases, the movement of these taxa from rural to urban sites is strongly suggested. Some researchers have argued that urban settlements were inherently more fragile – collapsing during phases of aridity (see above). These data strongly suggest the contrary. The capacity for urban sites to maintain elevated proportions of water-intensive livestock strongly suggests that they were able to do so by extracting from the produce of a wide array of rural sites. The mechanism for this maintenance of desired production is difficult to determine with the available data. However, the capacity for urban settlements of a range of local environments, of different civilisations and across the Near East to 'ride out' aridity phases broadly unchanged suggests that they may have felt 'collapse' last rather than first. Taking a small fraction of produce from a range of rural satellites would spread the risk of productive failure. During times of difficulty, it would be a range of rural sites which felt the pinch as livestock levels sent to urban sites were maintained in the face of their own diminished production. While this would be less ideal for individual rural settlements, at a systemic scale the spreading of risk across rural settlements would have helped ensure stability across more routine landscape and climate variations in productive capacity. Thus, we would expect to see urban sites able to maintain themselves even as some rural satellites failed during hard times. Only when enough rural providers collapsed – or the social and political mechanisms through which rural to urban transfer was managed were disrupted – would the urban livestock gravy train be lost.

Credit Author Statement

All authors contributed equally to this work.

Data Availability

The dataset used for this study is available as a supplementary information file (SI1). Citation information for the samples used in this dataset is available as a separate supplementary information file (SI2). The R code used for this study is also available as a supplementary information file (SI5).

Acknowledgments

This research was supported by the European Research Council under the European Union's Horizon 2020 research and innovation program for the project 'CLaSS – Climate, Landscape, Settlement and Society: Exploring Human Environment Interaction in the Ancient Near East' (grant number 802424, award holder: Dan Lawrence). LW also acknowledges the support of the CRANE Project, funded by the Social Sciences and Humanities Research Council of Canada (grant number 895-2018-1015, award holder Timothy Harrison).

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