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Bronze age fuel use and its implications for agrarian landscapes in the eastern Mediterranean

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A B S T R A C T

We compare carbonized seeds and charcoal excavated from four Bronze Age settlements in the eastern Mediterranean to infer distinctions in fuel use and the exploitation of woody vegetation amid developing anthropogenic landscapes. Charcoal evidence generally implicates combustion of fuel wood, while burned seeds commonly result from dung fuel use. Varying fuel consumption profiles reflect the availability of woody vegetation and cultivation practices that reveal temporal and geographical dynamics on Bronze Age agrarian landscapes. In the farmlands of the northern Jordan Valley, villagers at Early Bronze Tell Abu en-Nia'j and subsequently at Middle Bronze Tell el-Hayyat relied heavily on dung for their fuel needs, supplemented by burning of orchard prunings and to a lesser extent wood from nearby riparian vegetation. In this agrarian setting, limited availability of forest resources engendered exploitation of the highest diversities of cultivated crops, weedy species and woody plants. The village of Zahrat adh-Dhra'1 (contemporaneous with Tell el-Hayyat) on the arid, sparsely populated Dead Sea Plain relied less on dung fuel, and similarly harvested wood from orchards, while also utilizing the desert trees *Acacia* and *Tamarix*. Fuel use at Politiko-*Troullia*, Cyprus suggests ready access to *Pinus* and *Quercus* forests, and burning of *Olea* wood from nearby orchards, associated with little dung fuel use and the lowest taxonomic diversity of fuel sources among these four Bronze Age communities. The range of evidence for fuel use at these settlements reflects varying exploitation strategies based on plant resources and animal management in agrarian countrysides, as well as the larger influences of urbanized or non-urbanized society during the development of Bronze Age anthropogenic landscapes.

1. Introduction

A fundamental challenge for understanding the agrarian ecology of early complex societies is to integrate archeological evidence of crop management, fuel use and natural vegetation. The archeological analysis of carbonized plant remains documents the presence of specific crops and woody plant species on prehistoric landscapes (Hillman, 1984). Comparative analysis may be used to infer spatial and temporal differences in agriculture and vegetation that reflect the dynamics of human-environmental interaction and the development of agrarian ecosystems (Willcox, 1996; Miller, 1998; Miller et al., 2009; Smith and Munro, 2009).

This study investigates these inter-related facets of Bronze Age agricultural society in the eastern Mediterranean to permit inference of crop cultivation and woody vegetation in a larger context of developing anthropogenic landscapes (e.g., Miller, 2013). Our primary data derive from carbonized seeds and charcoal excavated from four Bronze Age settlements in Jordan and Cyprus. Comparative analysis among these sites allows us to investigate three general questions: (1) How do carbonized seeds, incorporated primarily through combustion of dung fuel, indicate differences and similarities in cultivated crops and wild plant cover associated with Bronze Age settlements in the eastern Mediterranean? (2) How do charcoal remains, incorporated primarily through burning of fuel wood, indicate differences and similarities in fuel sources and woody vegetation available to Bronze Age villagers? (3) How do comparisons of fuel use and vegetation illuminate the ways in which these communities implemented agrarian ecologies and molded anthropogenic landscapes in geographically distinct Mediterranean settings, with and without the influences of early urbanism?

2. Geographical and cultural context

The four focal settlements for this study lie along the Jordan Rift in the Southern Levant (i.e., the lands of modern Israel, Palestine and western Jordan) and on the Mediterranean island of Cyprus (Fig. 1). Tell Abu en-Ni'aj (hereafter Ni'aj) and Tell el-Hayyat (Hayyat) in the northern Jordan Valley, and Zahrat adh-Dhra'1 (ZAD) in the Dead Sea basin are situated below sea level. Hayyat and Ni'aj occupy nearly identical habitats; Ni'aj is perched on edge of the Jordan River floodplain, while

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Fig. 1. Map of Eastern Mediterranean region showing the locations of Politiko-*Troullia*, Cyprus and Zahrat adh-Dhra'1, Tell el-Hayyat and Tell Abu en-Ni'aj, Jordan.

Hayyat sits in fields only 1.5 km immediately to the east. Politiko-*Troullia* (*Troullia* or PT) lies at the heart of Cyprus, just above 400 m elevation in the foothills of the Troodos Mountains (Table 1). All four settlements are situated in the eastern Mediterranean basin, which is characterized by relatively wet, cool winters and long, dry and hot summers. Temperature variation relates mainly to elevation and proximity to the Mediterranean Sea. Precipitation generally decreases from north to south as the influence of cyclonic storms declines to the south and with distance from the Mediterranean Sea. Precipitation also varies according to topography, with the least precipitation falling at the lowest elevations of the Jordan Rift.

Bronze Age society in the Southern Levant (ca. 3500–1200 BC) followed a variety of trajectories in which sedentary agrarian settlements and their populations alternately aggregated or dispersed (Falconer and Savage, 1995, 2009). The Early Bronze Age (beginning ca. 3500 BC) witnessed the development of fortified towns atop mounded *tell* sites (de Miroschedji, 2009, 2014; Greenberg, 2014; cf. Chesson and Philip, 2003). By about 2300 BC, these towns were abandoned across the

Table 1
Environmental setting for four eastern Mediterranean villages: Politiko-*Troullia*, Zahrat adh-Dhra'1, Tell el-Hayyat and Tell Abu en-Ni'aj.

Site	Social setting, settlement description, size & estimated population	Environmental setting and modern vegetation
Politiko-*Troullia*	Pre-urban, productive agrarian setting; architecture interspersed with agricultural features over 20 ha; 500–600 people	Junction of fertile Mesaoria Plain and copper-rich Troodos foothills between perennial Pediaios River and spring fed Kamaras Creek; pine forests on hillslopes and riparian forest along river
Zahrat adh-Dhra'1	Urban, marginal agricultural setting at fringe of urbanized society; architecture dispersed over 6 ha; 125–150 people	Dissected alluvial plain below sea level overlooking the Dead Sea; spring fed agriculture; desert vegetation with riparian trees along drainages and the lower reaches of the Jordan River
Tell el- Hayyat	Urban, productive agricultural setting near larger towns; architecture aggregated over 0.5 ha; 100–150 people	Fertile agricultural alluvium near the Jordan River; below sea level in the northern Jordan Valley; steppe vegetation with riparian forests along the river
Tell Abu en-Ni'aj	Urban abandonment, productive agricultural setting; architecture aggregated over 2.5 ha; 500–600 people	On edge of Lisan Marls overlooking rich agricultural land along the Jordan River; below sea level in the northern Jordan Valley; steppe vegetation with riparian forests along the river

Southern Levant, and populations shifted to farming hamlets and seasonal herding encampments during the last portion of this period, commonly termed Early Bronze IV or the Intermediate Bronze Age (e.g., Palumbo, 1991; Dever, 1995; Cohen, 2009; Prag, 2014). Subsequently, walled towns redeveloped rapidly atop Levantine *tells* during the Middle Bronze Age (ca. 2000–1500 BC) (e.g., Greenberg, 2002; Bourke, 2014; Cohen, 2014). The communities at Ni'aj and Hayyat occupied very similar geographical settings during consecutive periods of town abandonment (during the Early Bronze IV occupation of Ni'aj) and redevelopment (during Middle Bronze habitation at Hayyat) (Falconer and Fall, 2006, 2009) (Table 2). Politiko-*Troullia*, ZAD and the earlier phases at Hayyat were occupied contemporaneously in the Middle Bronze Age. However, ZAD was far removed socially and geographically from the fertile northern Jordan Rift and the Southern Levant's Middle Bronze Age towns (Edwards et al., 2001; Fall et al., 2007). Politiko-*Troullia*, inhabited at the beginning of the Middle Bronze Age (Falconer and Fall, 2013a), lay adjacent to fertile agricultural land but, in contrast to the Levant, the island of Cyprus did not experience initial urbanization until the subsequent Late Bronze Age (Peltenburg, 1996; Knapp, 2008; Steel, 2014).

3. Material and methods

The evidence from these four Bronze Age settlements was recovered and analyzed in a series of archeological projects using consistent field and laboratory methods. In addition, all four settlements represent agrarian communities practicing mixed agro-pastoralism in which paleobotanical remains were recovered from similar depositional contexts as a result of a suite of shared domestic behaviors, especially those involving combustion of dung and wood fuels. This methodological and contextual consistency permits controlled comparisons of fuel use and vegetation between villages: (1) inhabited sequentially during urban abandonment (Ni'aj) followed by reurbanization (Hayyat) (Fall et al., 2002; Falconer et al., 2004); (2) situated contemporaneously in a Bronze Age agrarian breadbasket (Hayyat) vs. desert margin (ZAD); and (3) occupied during early Levantine urbanism (Hayyat and ZAD) vs. preurban Cyprus (*Troullia*) (Falconer and Fall, 2013a).

Archeological sediments with visible burned organic content at each of these settlements were processed by water flotation to recover plant macrofossils during excavations conducted between 1982 and 2014 (see detailed methods in Klinge and Fall, 2010: 38–43). Our previous studies show that this sampling method optimizes recovery of macrobotanical remains from archeological sediments (e.g., Falconer and Fall, 2006). After flotation in the field, samples containing carbonized seeds and charcoal were poured through nested 4.75 mm, 2 mm, 1 mm and 0.5 mm mesh sieves (Falconer and Fall, 2006: 38–43; Klinge and Fall, 2010; Klinge, 2013). All material 0.5 mm or larger was sorted under a binocular microscope to separate charcoal fragments from charred seeds. Seeds and seed fragments were identified using Fall's personal reference collection and comparative literature (e.g., Helbaek, 1958; Renfrew, 1973; Zohary and Hopf, 1973; Zohary and Spiegel-Roy, 1975; Van Zeist, 1976; Hillman, 1978; Van Zeist and Bakker-Heeres, 1982; Hubbard, 1992; Jacomet, 2006), counted and organized into vegetation categories (Klinge and Fall, 2010; Klinge, 2013). Charred seeds constitute four main vegetation categories to facilitate comparative analysis between sites: cultivated cereals, cultivated legumes, fruit-bearing trees and vines, and wild species indicative of pastures and agricultural fields (Lines, 1995; Fall et al., 2002, 2007; Falconer et al., 2004; Falconer and Fall, 2006).

Table 2
Radiocarbon chronology for Politiko-*Troullia* (PT), Zahrat adh-Dhra'1 (ZAD), Tell el-Hayyat (Hayyat) and Tell Abu en-Ni'aj (Ni 'aj).

Site	Age[1]	Phases	^{14}C (#)	Age range (yr BP)	Cal yrs. BC[2] (mid-points)
PT	MBA	1–5	11	3686-3562	2081-1910
ZAD	MBA	1–2	6	3670–3280	2054–1562
Hayyat	MBA	1–5	11	3600-2930	1961-1568
Ni'aj	EBA	1–7	19	4046-3810	2572-2251

[1] EBA = Early Bronze Age; MBA = Middle Bronze Age.
[2] Calibration based on OxCal 4.2.

The charcoal fragments from each sample were segregated from the seed remains and weighed collectively. Charcoal specimens were identified taxonomically for this study by comparing photos taken using scanning electron microscopy with published keys (Fahn et al., 1986; Schweingruber, 1990; Gale and Cutler, 2000; Schweingruber et al., 2011; Akkemik and Yaman, 2012). Scanning electron microscopy (SEM) (JEOL JSM6300 at Arizona State University) was chosen: (1) to permit analysis of the charcoal fragments from *Troullia*, which are too small to analyze with a dissecting microscope; (2) to provide the best optical resolution for identification of anatomical features; and (3) to permit use of a standard methodology for all four sites. The identified charcoal fragments from each site were organized in three vegetation categories: tree, shrub and orchard species (Klinge and Fall, 2010; Klinge, 2013).

Counts of identified seed and charcoal specimens recovered from each Bronze Age village are tabulated taxonomically (see supplementary data S1). These data are used to calculate densities, ubiquity and relative frequencies for seed and charcoal taxa, as well as site-by-site diversity indices (Shannon, Gini-Simpson and Berger-Parker Indices) (see supplementary data S2 and methodological discussion in Marston, 2014: 164–169). The densities, ubiquity and relative frequencies of taxa are compared between settlements, and specimen counts for seed and charcoal vegetation categories are assessed using chi square tests for significant differences among all four sites and in pairwise comparisons between sites.

4. Results

4.1. Carbonized seeds

Seed counts for four vegetation categories differ significantly ($p < 0.0001$) between all four settlements and in all pairwise comparisons between sites (see supplementary data S1), suggesting four distinct seed assemblages. Seed densities, ubiquity and relative frequencies reveal notable points of contrast. Tell Abu en-Ni'aj, Tell el-Hayyat and Zahrat adh-Dhra'1 produce similar overall seed densities and similarly high seed ubiquity, while Politiko-*Troullia* reveals much lower density (more than an order of magnitude smaller) and ubiquity, despite the flotation of a much larger number of samples and greater overall sample volume (Table 3). This general pattern also characterizes seed densities and ubiquity from orchard taxa, which are highest at Hayyat, Ni'aj and ZAD, but much lower at *Troullia*. Cereal (*Hordeum*, *Triticum*) densities and ubiquity are highest at Ni'aj and Hayyat, and again particularly low at *Troullia*. A variety of pulses appear at Hayyat, Ni'aj and ZAD (densities and ubiquity values in descending order), but are strikingly absent from *Troullia*. Seeds from wild species are found in a range of densities from most abundant at ZAD to least abundant at *Troullia*. Wild seeds are most ubiquitous at Ni'aj, followed by ZAD, and again least common at *Troullia*. In overview, seed densities and ubiquity values point to a fundamental distinction between very modest and less common seed deposition at *Troullia* (both overall and according to vegetation categories) in comparison to all three Levantine settlements.

When viewed according to relative frequencies, the seed assemblages from ZAD, Hayyat and Ni'aj feature substantial proportions of barley and wheat (*Hordeum* spp. and *Triticum* spp., especially at Hayyat; Fig. 2) augmented by minor elements of pulses (*Cicer*, *Lathyrus*, *Lens*, *Pisum* and *Vicia*; Fig. 3). *Hordeum*:*Triticum* ratios are highest at ZAD (4.7:1), with descending values for Ni'aj (3.3:1), Hayyat (1.4:1) and *Troullia* (0.6:1) (see supplementary data S1). Wild and weed taxa form the majority of the seed assemblage at ZAD, nearly half at Ni'aj, and 25–30% at Hayyat and *Troullia*. The wild taxa from ZAD, Ni'aj and Hayyat include a variety of wild legumes and grasses; the evidence

Table 3
Seed density ratios (# seeds/kl) and [ubiquity] (% samples with taxon present) for Politiko-*Troullia*, Zahrat adh-Dhra'1, Tell el-Hayyat and Tell Abu en-Ni'aj.

	Politiko-*Troullia*[1]	Zahrat adh-Dhra'[2]	Tell el-Hayyat[3]	Tell Abu en-Ni 'aj[4]
Flotation samples (n)	110	39	60	52
Volume (liters floated)	879.4	179.6	318	366.2
ORCHARD				
Ficus carica	**251** [4]	**846** [51]	**1186** [77]	**1133** [79]
Olea europaea	**38** [9]	0	**233** [32]	**14** [6]
Vitis vinifera	**39** [9]	**329** [23]	**44** [13]	**93** [21]
Subtotal	**328** [14]	**1175** [59]	**1462** [82]	**1240** [83]
CEREALS				
Hordeum sp.	**2** [1]	**735** [44]	**1057** [82]	**1584** [87]
Triticum sp.	**38** [8]	**156** [26]	**736** [68]	**481** [69]
Cereal undiff.	**6** [2]	**367** [36]	**1135** [65]	**765** [83]
Subtotal	**46** [9]	**1258** [59]	**2928** [93]	**2829** [92]
PULSES				
Cicer arietinum	0	0	**91** [8]	0
Lathyrus cf. *sativum*	0	0	**151** [30]	0
Lens culinaris	0	0	**167** [35]	**224** [8]
Pisum sativum	0	**156** [18]	**66** [20]	**63** [21]
Vicia faba	0	0	**13** [5]	0
Pulse undiff.	0	**84** [15]	0	**44** [33]
Subtotal	0	**239** [31]	**487** [52]	**330** [52]
WILD SPECIES				
Wild legume	**4** [3]	**2121** [46]	**632** [63]	**366** [64]
Wild grass	0	**384** [39]	**327** [18]	**759** [83]
Other wild species	**96** [22]	**2795** [77]	**1164** [23]	**3048** [85]
Pistacia sp.	**29** [8]	0	0	0
Subtotal	**129** [28]	**5301** [85]	**2123** [72]	**4173** [96]
TOTAL	**503** [35]	**7973** [97]	**7000** [95]	**8572** [96]

[1]Politiko-*Troullia* data from Klinge and Fall (2010), Klinge (2013). [2]Zahrat adh-Dhra'1 data unpublished. [3]Tell el-Hayyat data from Lines (1995), Fall et al. (1998), Fall et al. (2002), Falconer and Fall (2006). [4]Tell Abu en-Ni'aj data unpublished. See Appendix S1 for seed counts and chi square results.

from *Troullia* includes seeds from *Pistacia* trees. A distinct majority of the seeds from *Troullia* (> 65% of the site's assemblage) represents orchard taxa (*Ficus*, *Olea and Vitis*), all of which are found in greater relative frequencies at *Troullia* than at any of the other settlements.

4.2. Charcoal remains

As with the seed data, charcoal specimen counts for three vegetation categories differ significantly in aggregate and pairwise comparisons (see supplementary data S1), in keeping with distinct charcoal assemblages. Tell Abu en-Ni'aj reveals the highest overall charcoal density, with a value more than four times greater than *Troullia*, and nearly 10 times higher than ZAD or Hayyat (Table 4). Charcoal densities and ubiquity do not follow similar rank orders to the same extent they do for seed values. For example, charcoal ubiquity at Ni'aj, despite its high density, is substantially lower than at the other sites, all of which produce ubiquity values at or near 100%. Ni'aj also produces the highest charcoal density values for each of the vegetation categories: trees, shrubs and orchard taxa. In comparison to Ni'aj, substantially lower tree charcoal densities are found at *Troullia* (less than half of Ni'aj's value), ZAD and Hayyat. Similarly, shrub charcoal densities are much lower at Hayyat (less than 25% of Ni'aj), while ZAD and *Troullia* have values less than 10% that of Ni'aj. Orchard charcoal densities distinguish Ni'aj most clearly from *Troullia* (<15% of Ni'aj), ZAD and Hayyat (both <5% of Ni'aj). Despite lower density values, tree charcoal remains are much more common among samples from ZAD and *Troullia* than from Ni'aj. Shrub charcoal ubiquity is highest at Hayyat and lowest at *Troullia*, although Ni'aj produces a much higher shrub density value. Unlike trees and shrubs, charcoal densities and ubiquity for orchard taxa describe the same rank order among sites, with the highest values at Ni'aj and the lowest at ZAD.

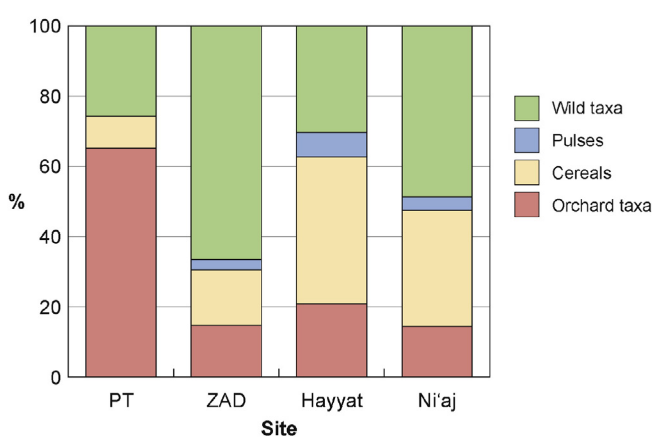

Fig. 2. Relative seed frequencies (%) by vegetation categories at Politiko-*Troullia* (PT), Zahrat adh-Dhra'1 (ZAD), Tell el-Hayyat (Hayyat) and Tell Abu en-Ni'aj (Ni'aj).

The charcoal assemblages reflect varying combinations of tree, shrub and orchard species (Fig. 4). Substantial proportions of charcoal from all four settlements represent tree taxa (from 39% at Ni'aj to 77% at ZAD). Fuel wood profiles vary between a predominance of upland trees at *Troullia* (especially *Pinus* and *Quercus*), contrasting with evidence for *Tamarix* and riparian trees at Ni'aj and Hayyat, which are supplemented with *Acacia* wood at ZAD (Fig. 5). While statistically distinct, charcoal counts from *Troullia* and ZAD are more similar than any other pairwise comparison, due in part to the predominance of tree charcoal at both sites. Shrub charcoal represents a wide variety of taxa (measuring from <5% at *Troullia* to nearly 33% at Hayyat), with the Hayyat assemblage distinguished by substantial remains of Chenopodiaceae. Charcoal from orchard taxa at the three Levantine settlements ranges between 13% at ZAD to 45% at Niaj, and includes varying combinations of *Ficus*, *Olea*, *Punica* and *Vitis* (with *Punica* absent at Hayyat and *Olea* absent at ZAD). The orchard charcoal at *Troullia*, on the other hand, comes exclusively from *Olea*.

4.3. Fuel resources & species diversity

Seed:charcoal ratios, whether based on seed weight or counts, clearly show the greatest relative seed deposition at Ni'aj (Table 5). Ratios based on seed and charcoal weight indicate near parity at Hayyat, and greater deposition of charcoal at *Troullia* and ZAD. Ratios based on seed count and charcoal weight illustrate the greater relative importance of seed deposition at Ni'aj particularly well, especially in comparison to values more than an order of magnitude lower for the other three sites. Both sets of ratios show the greatest relative deposition of charcoal at ZAD, followed by *Troullia*, Hayyat and Ni'aj (in descending order). Calculation of Shannon and Gini-Simpson diversity indices (Table 6; Appendix S2) reveals a greater range in diversity between settlements based on wood taxa than seed taxa. The highest taxonomic diversity characterizes the charcoal remains found at Ni'aj, with diminishing values for Hayyat and ZAD. The lowest diversity is apparent for wood species at *Troullia*. Taxonomic diversity among seed assemblages covers a narrower range from the greatest diversity at Hayyat, followed by descending values at Ni'aj, ZAD and *Troullia*. When viewed jointly, these results show more pronounced diversity among the taxa consumed as fuel in the northern Jordan Valley (at Ni'aj and Hayyat) and the lowest taxonomic diversity, whether based on seeds or charcoal, at *Troullia* on Cyprus.

5. Discussion

This study uses data derived from seeds and charcoal to infer fuel preferences and availability in a context of agricultural economy, local vegetation and plant use. All four focal settlements provide evidence

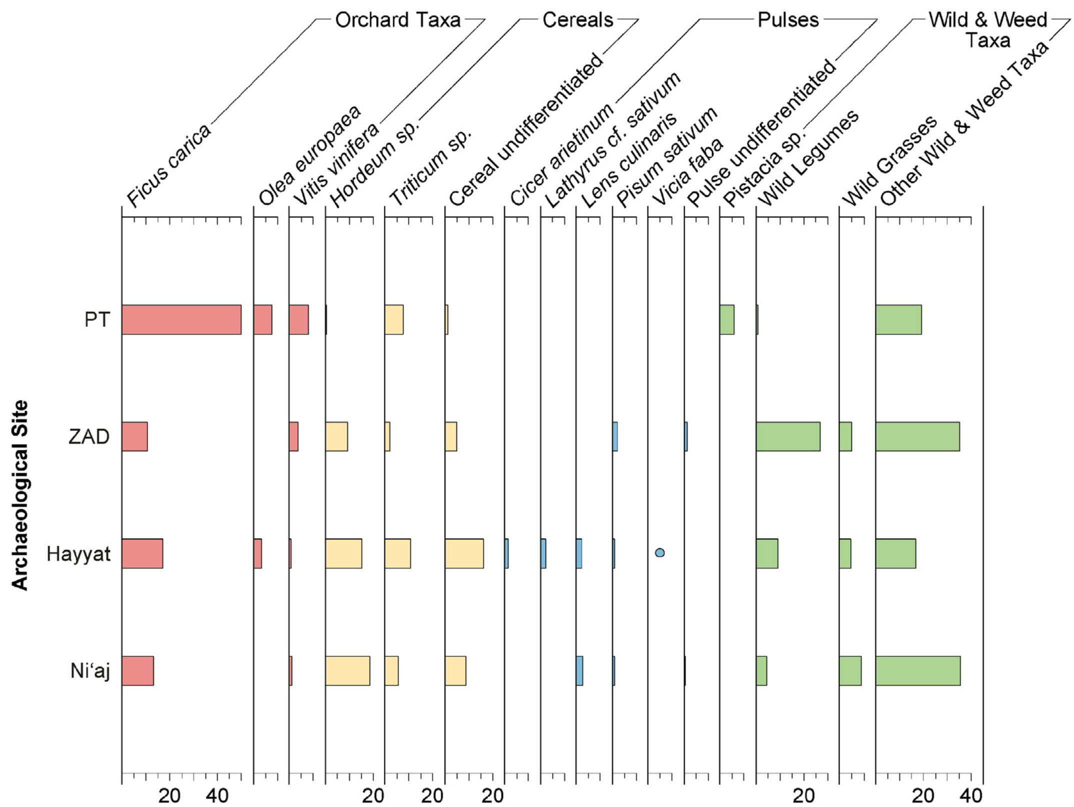

Fig. 3. Relative seed frequencies (%) for plant taxa at Politiko-*Troullia* (PT), Zahrat adh-Dhra'1 (ZAD), Tell el-Hayyat (Hayyat) and Tell Abu en-Ni'aj (Ni'aj).

of differing arrays of carbonized seeds ranging among perennial orchard species, annual cereals and pulses, and wild and weedy taxa. The charcoal evidence includes a wide variety of trees, shrubs and orchard species, which collectively represent the woody vegetation available as fuel from the landscapes around these villages. With these considerations in mind, comparative analysis of identified carbonized seeds and charcoal specimens permits inference of spatial and temporal distinctions in woody vegetation and fuel use on ancient eastern Mediterranean landscapes.

5.1. Charcoal and carbonized seeds as indicators of fuel use

Charred botanical remains provide a particularly valuable means of inferring the agrarian ecologies of early complex societies (Miller, 2013). The deposition of seeds and charcoal in archeological sites results from a wide variety of activities related to fuel combustion, processing of crops, burnt structures or food remains (see critical discussion of charcoal deposition in Western, 1971). Charcoal remains provide evidence for the intentional selection and consumption of woody vegetation, particularly as locally available sources of fuel and construction materials for ancient communities (Smart and Hoffman, 1988; Lev-Yadun et al., 1996; Asouti, 2003; Asouti and Austin, 2005; Hunt et al., 2007; Deckers et al., 2008; Deckers and Pessin, 2010; Deckers, 2011; Kimiaie and McCorriston, 2013). Ancient wood foragers tended to choose their wood sources according to their value or suitability for an intended use, as well as the amount of effort and time needed to process them (Marston, 2009: 2193). Charcoal from wood harvested for construction tends to be found in the remains of burned structures, while fuel use is reflected in charcoal produced by pyrotechnic behaviors (Marston, 2009: 2194). In ancient contexts, charcoal combustion may be a byproduct of a variety of pyrotechnic domestic or industrial activities ranging from cooking to metallurgy to firing of pottery (Levy et al., 2002; Hunt et al., 2007; Scott and Damblon, 2010; Théry-Parisot et al., 2010). Archeologically, charcoal evidence reflects a common preference for wood fuel (Nesbitt, 1995; Lev-Yadun et al., 1996; Willcox, 1996; Kimiaie and McCorriston, 2013) and thereby the availability of woody vegetation on ancient landscapes (Smart and Hoffman, 1988; Vernet, 1997; Willcox, 2002; Asouti and Austin, 2005).

Similarly, carbonized seeds are deposited archeologically as a result of multiple activities, including refuse burning, crop processing, burning of stored supplies and fuel consumption (e.g., McCreery, 1980; Lucas et al., 2012), particularly through combustion of animal dung (Miller, 1998). Some of these activities may produce carbonized remains in specific contexts. For example, accidental burning of stored material often leaves concentrated evidence in storage rooms or jars. Other activities, like burning of agricultural refuse or crop processing, may be episodic or seasonal (Miller, 1990), while evidence of burned animal dung includes seeds and other plant parts formerly embedded in cakes prior to burning and their subsequent deposition in trash deposits (Miller, 1990; Gallagher, 2014: 31). Carbonized seeds also provide unique insights into fuel use and availability of wood. As forests become diminished with less available fuel wood, animal dung provides the main alternative fuel source in traditional agrarian economies (Winterhalder et al., 1974; Anderson and Ertug-Yaras, 1998; Sillar, 2000; Rhode et al., 2007). Dung burning should be considered the primary source of carbonized seeds in ancient communities with little access to wood fuel (Miller and Smart, 1984; Gallagher, 2014: 31). Accordingly, burning of dung fuel for cooking or heating creates widespread carbonized remains in settlements located on landscapes with limited or overexploited woody vegetation (Willcox, 1974; Miller, 1985). Pioneering research by Miller demonstrates that carbonized seeds recovered archeologically from domestic trash deposits most commonly represent wild or cultivated plants consumed by domestic flocks (especially in cultivated fields), incorporated in animal dung and subsequently burned as dung fuel (Miller and Smart, 1984; Miller, 1996, 1997a, 1997b; Schwartz et al., 2000: 445–446). Thus, carbonized seeds also open a window on ancient landscapes by providing insights into cultigens, wild and weed species, and the relative availability of woodlands and forest resources.

Table 4
Charcoal density ratios (# specimens/kg charcoal) and [ubiquity] (% samples with taxon present) for Politiko-*Troullia*, Zahrat adh-Dhra'1, Tell el-Hayyat and Tell Abu en-Ni'aj.

	Politiko-*Troullia*	Zahrat adh-Dhra'	Tell el-Hayyat	Tell Abu en-Ni'aj	
Flotation samples (n)	110	39	60	52	
Weight of charcoal (g)	356.96	401.43	515	83.35	
Taxon					Reference for charcoal identification
TREES					
Subgroup Upland Trees					
cf. *Amygdalus*	0	0	0	**121** [12]	Fahn et al., 1986: 145–146; plate 59A
Arbutus andrachne	0	0	0	**24** [5]	Schweingruber et al. 2011: 359; slides 5, 6, 13, 14
Ceratonia siliqua	0	0	**2** [2]	0	Fahn et al., 1986:114; plate 36
cf. *Crataegus*	**3** [2]	**7** [3]	0	0	Fahn et al., 1986: 148–149
Cupressus sp.	**17** [13]	0	**4** [4]	0	Schweingruber et al. 2011: 141; slides 4, 5, 9, 10
Pinus sp.	**322** [73]	0	0	**12** [2]	Schweingruber et al. 2011: 121; slides 1–9
cf. *Pistacia*	0	**2** [3]	**4** [4]	**12** [2]	Fahn et al., 1986: 63–65
Quercus sp.	**50** [19]	0	**10** [9]	**85** [9]	Schweingruber et al. 2011: 403–410
Subgroup Desert/Riparian Trees					
Acacia sp.	0	**70** [52]	0	0	Fahn et al., 1986: 117–118
Tamarix sp.	0	**135** [83]	**97** [50]	**376** [30]	Akkemik and Yaman, 2012: 276–279
Ziziphus sp.	**6** [2]	**2** [3]	**10** [6]	0	Fahn et al., 1986: 144–145; plate 58D
Subgroup Riparian Trees					
Platanaceae	**20** [8]	0	0	0	Akkemik and Yaman, 2012: 224–225
Salicaceae	0	**10** [7]	**4** [4]	0	Akkemik and Yaman, 2012: 264–265
Salix sp.	0	0	0	**12** [2]	Akkemik and Yaman, 2012: 264–265
cf. *Populus*	5	0	**4** [2]	**194** [21]	Akkemik and Yaman, 2012: 262–263
Vitex sp.	0	0	0	**121** [7]	Schweingruber et al. 2011: 732–733
Tree Subtotal	**423** [88]	**227** [97]	**134** [63]	**959** [65]	
SHRUBS					
Asteraceae	0	0	**12** [7]	0	Akkemik and Yaman, 2012: 94–97
Capparis	**3** [2]	**7** [10]	**2** [2]	0	Schwiengruber, 2011: 230–231
Chenopodiaceae	0	0	**54** [19]	0	Schweingruber et al. 2011: 262–263
Cistus sp.	0	**2** [3]	0	0	Akkemik and Yaman, 2012: 106–107
Ephedra sp.	0	0	**4** [2]	0	Schweingruber et al. 2011: 150–151
Euphorbiaceae	0	0	0	**49** [7]	Akkemik and Yaman, 2012: 132–133
Fabaceae	0	0	0	**12** [2]	Fahn et al., 1986: 119; plate 39 C-D
Lamiaceae	0	**7** [7]	0	0	Akkemik and Yaman, 2012: 198–199
Loranthaceae	**14** [4]	**5** [3]	0	**12** [2]	Schweingruber et al. 2011: 540–541
Malvaceae	0	0	0	**12** [2]	Schweingruber et al. 2011: 542–543
Monocot	0	**7** [7]	**12** [7]	**146** [12]	Fahn et al., 1986: 179; plate 82 A-B
cf. *Myrtus*	**11** [4]	0	**4** [2]	**24** [2]	Fahn et al., 1986: 134; plate 50 A-B
Nerium oleander	0	0	**4** [4]	0	Akkemik and Yaman, 2012: 90–91
Ranunculaceae	0	0	0	**12** [2]	Fahn et al., 1986: 139; plate 54 D-E
cf. *Rubus*	0	0	0	**12** [2]	Schweingruber et al. 2011: 650–653
cf. *Rubia*	0	0	**2** [2]	0	Schweingruber et al. 2011: 666–667
Solanaceae	0	0	0	**73** [2]	Fahn et al., 1986: 160–161; plates 67–68
Zygophyllaceae	0	0	0	**24** [2]	Fahn et al., 1986: 177; plate 79 C-D
Shrub Subtotal	**28** [13]	**30** [28]	**93** [33]	**376** [26]	
ORCHARD TAXA					
Punica granatum	0	**10** [7]	0	**61** [9]	Schweingruber et al. 2011: 590–591
Ficus carica	0	**12** [7]	**10** [9]	**607** [40]	Akkemik and Yaman, 2012: 210–211
Olea europaea	**160** [46]	0	**31** [17]	**243** [19]	Schweingruber et al. 2011: 572–573
Vitis vinifera	0	**15** [7]	**16** [11]	**194** [23]	Schweingruber et al. 2011: 734–735
Orchard Subtotal	**160** [46]	**37** [14]	**56** [33]	**1105** [67]	
TOTAL	**611** [94]	**296** [100]	**297** [98]	**2732** [75]	

See Appendix S1 for charcoal counts and chi square results.

5.2. Evidence of pyrotechnology

Fuel-consumptive technology is manifested by a variety of evidence from *Troullia*, Hayyat and Ni'aj. At *Troullia*, a roofed courtyard with remnants of a rudimentary furnace, a carved limestone mold, ceramic crucibles, tap slags, ore fragments and the proximity of copper sources jointly provide a strong signature of household metallurgy that produced an array of utilitarian tools (Falconer and Fall, 2013a). Pyrotechnology at Hayyat involved broad-range pottery production and the manufacture of copper anthropomorphic and zoomorphic offertory figurines and household implements (Falconer and Fall, 2006: 48–68). Remains of an intact pottery kiln and abundant ceramic wasters, in conjunction with neutron activation analysis, suggest production of cooking pots, storage jars and possibly fine ware bowls at Hayyat (Falconer, 1987; Falconer and Fall, 2013b). Although excavation revealed no direct evidence of pyrotechnic manufacturing at Ni'aj, neutron activation implicates the manufacture of trickle-painted cups, a hallmark fine ware of Early Bronze IV (Falconer, 1987; Falconer and Fall, 2013b). In contrast to these communities, the occupants of ZAD appear not to have produced metals or ceramics, as reflected by the absence of metallurgical remains and a ceramic repertoire featuring extensive mending and curation of broken pots, presumably in response to ZAD's distance from sources of new vessels (Fall et al., 2007).

5.3. Comparison of fuel use and vegetation among bronze age settlements

Similar seed densities and ubiquity at the settlements along the Jordan Rift indicate comparable rates and widespread distribution of dung fuel combustion and deposition in comparison to much lower values at *Troullia* on Cyprus. In addition to reflecting fundamental differences in fuel sources, the lower seed density at *Troullia* may reflect diminished seed preservation in alkaline sediments (Gallagher, 2014: 21), like those found commonly on Cyprus (Hadjiparaskevas, 2001). While the charcoal density at *Troullia* is more than twice the values at

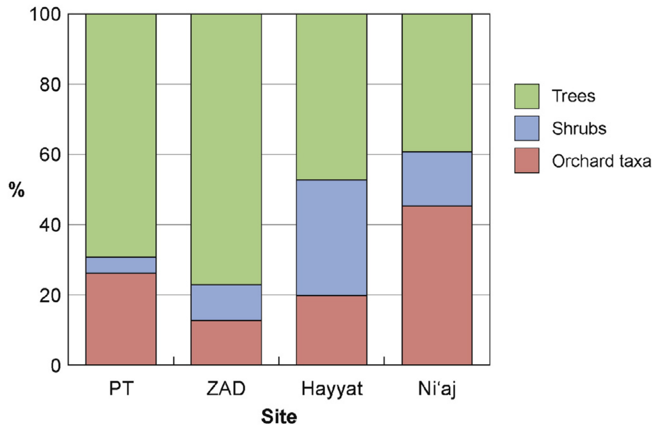

Fig. 4. Relative charcoal frequencies (%) by vegetation categories at Politiko-*Troullia* (PT), Zahrat adh-Dhra'1 (ZAD), Tell el-Hayyat (Hayyat) and Tell Abu en-Ni'aj (Ni'aj).

Hayyat or ZAD, Ni'aj provides the highest densities of both seed and especially charcoal deposition, reflecting the most intense fuel consumption for both dung and wood. In contrast, seed and charcoal densities jointly reveal the lowest rates of fuel combustion (especially dung fuel) at *Troullia*. Ubiquity values reveal other facets of fuel consumption. Seed ubiquity and densities describe parallel patterns, suggesting that dung fuel was combusted at the highest rates and most broadly across Ni'aj, Hayyat and ZAD, but at much lower rates and less commonly at *Troullia*. Charcoal ubiquity, on the other hand, is substantially lower at Ni'aj but extremely high at the other three sites, including *Troullia* (with burning of tree wood particularly common at *Troullia* and ZAD). These results portray widespread, moderate rates of fuel wood consumption at *Troullia* and similarly common but lower intensity wood burning at ZAD and Hayyat. The charcoal profile from Ni'aj suggests pockets of more concentrated and higher intensity combustion of wood from orchard taxa, riparian trees and a wide variety of shrubs.

Differing mixes of dung and wood fuel consumption captured by seed:charcoal ratios suggest the largest relative importance of dung fuel at Ni'aj, followed by Hayyat (see Table 5). Carbonized seed identifications suggest agricultural regimes at these settlements of substantial cereal horticulture coupled with smaller elements of orchard and pulse cultivation, and animal grazing in agricultural fields and pastures. Interestingly, this agricultural system and its decidedly anthropogenic landscape engendered the highest seed and charcoal diversity indices

Table 5
Seed:charcoal ratios from Bronze Age sites in the eastern Mediterranean.

	Politiko-*Troullia*[1]	Zahrat adh-Dhra'[2]	Tell el-Hayyat[1]	Tell Abu en-Ni'aj[1]
Seed:charcoal (g:g)	0.35	0.10	0.97	2.37
Seed:charcoal (#:g)	30.4	23.8	110.2	1733.1

[1] Ratios for Politiko-*Troullia*, Tell el-Hayyat and Tell Abu en-Ni'aj from Klinge and Fall (2010): Table 2.
[2] Data from Zahrat adh-Dhra', not previously published, are based on 32 samples totaling 119 l.

among these settlements. The majority of charcoal evidence from Hayyat and Ni'aj comes from shrubs and orchard taxa, rather than woodlands. Thus, these two villages apparently were situated in agrarian landscapes characterized by limited availability of woodland resources, which necessitated greater reliance on fuel wood from orchards and shrubs, and, amid this general dearth of wood, especially on dung fuel combustion. Woody taxa found in higher charcoal densities at Ni'aj feature a striking combination of riparian *Tamarix*, *Vitex* and *Populus*, and the orchard taxa *Ficus*, *Olea* and *Vitis*, suggesting an intensively exploited local fuel wood resource area encompassing orchards and riparian tree stands along the Jordan River. Neutron activation analysis and focused concentrations of charcoal remains at Ni'aj are consistent with fuel profiles for ceramic manufacturing. Charcoal specimens from Hayyat include lower densities of the same orchard species as Ni'aj, plus *Tamarix* and Chenopodiaceae, representing less intensive utilization of the orchard, riparian and weedy taxa that would have populated the edge of the Jordan River floodplain and the fields above it in the northern Jordan Valley. Interestingly, the villagers of Hayyat clearly supported metallurgical and ceramic industry in a setting very near Ni'aj, but with substantially less utilization of tree and orchard wood, and perhaps greater reliance on dung fuel for their manufacturing needs.

The seed identifications and densities for ZAD document cultivation of cereals, limited legumes, orchard taxa (notably lacking *Olea*) and substantial amounts of wild species, with lower overall taxonomic diversity than seen at Hayyat or Ni'aj. Greater proportional reliance on fuel wood, rather than animal dung, emerges from low seed:charcoal ratios and the highest percentage of charcoal from tree taxa found at any of the four settlements. The highest *Hordeum*:*Triticum* ratio and pronounced densities of *Tamarix* and *Acacia* suggest that the occupants of ZAD utilized the limited fuel resources of an arid landscape unsuitable for olive cultivation but populated by desert tree species. Modeling of ancient potential vegetation around Ni'aj (4200 cal BP), Hayyat (3900 cal BP) and ZAD

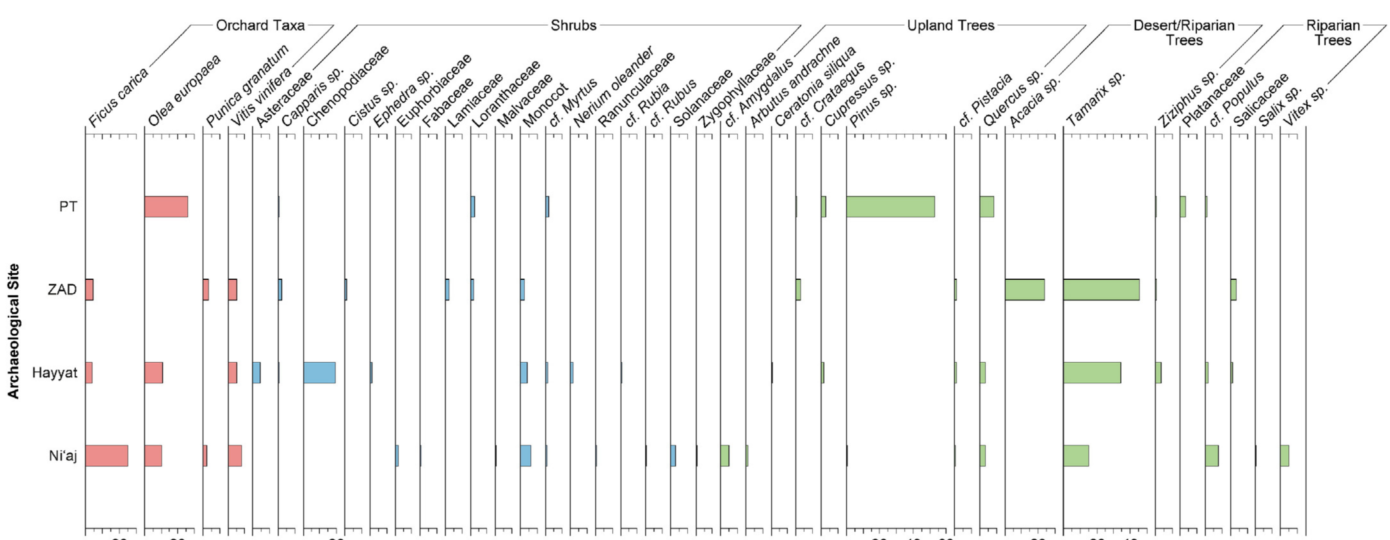

Fig. 5. Relative charcoal frequencies (%) for woody plant taxa at Politiko-*Troullia* (PT), Zahrat adh-Dhra'1 (ZAD), Tell el-Hayyat (Hayyat) and Tell Abu en-Ni'aj (Ni'aj).

Table 6
Seed and charcoal diversity indices for Politiko-*Troullia*, Zahrat adh-Dhra'1, Tell el-Hayyat and Tell Abu en-Ni'aj.

	Politiko-*Troullia*	Zahrat adh-Dhra'	Tell el-Hayyat	Tell Abu en-Ni'aj
Seeds				
Shannon*	1.531	1.799	2.205	1.891
Gini-Simpson**	0.694	0.780	0.871	0.800
Wood				
Shannon	1.399	1.778	2.208	2.474
Gini-Simpson	0.644	0.725	0.823	0.880

Calculations performed using template created by Klaus D. Goepel at http://bpmsg.com/. To view diversity data, see Appendix S2.
* $I_{Shannon} = H = -\sum p_i \ln(p_i)$.
** $I_{GiniSimp} = 1 - \sum n_i(n_i - 1)/N(N-1)$.

(3900 cal BP) suggests approximately 200 mm higher mean annual precipitation during the occupations of Hayyat and Ni 'aj in the northern Jordan Valley than at ZAD in the Dead Sea Basin (Soto-Berelov et al., 2015). This insight suggests that contrasts in seed and charcoal evidence between these sites reflect differing local vegetation and fuel availability. In particular, Bronze Age fuel use at ZAD is distinguished by considerable burning of trees despite much lower local rainfall.

Fuel use at *Troullia* reveals a very different landscape in which wood fuel use figured prominently. In this case, seed evidence suggests an agricultural regime incorporating arboriculture, modest cereal cultivation favoring wheat over barley and little or no cultivation of legumes. Modest seed densities and seed:charcoal ratios suggest low intensity dung combustion coupled with relatively greater wood fuel use based on pine and, to a lesser extent, oak. In combination with *Troullia*'s distinctive evidence for hunting and consumption of Mesopotamian fallow deer (*Dama dama mesopotamica*; Falconer and Fall, 2013a), patterns of fuel use portray a forest-oriented landscape around *Troullia* incorporating better watered but limited cereals incorporated into dung, and orchard cultivation on surrounding hillsides near pine/oak forests and their plant and animal resources. As an integral aspect of this setting, the villagers of *Troullia* fueled their copper metallurgy by harvesting wood from these immediately available woodlands and orchards.

5.3.1. Early Bronze Ni'aj vs. Middle Bronze Hayyat in the northern Jordan Valley

Comparisons between the evidence for fuel consumption at individual settlements reveal several specific contrasts with implications for inferring Bronze Age agrarian economies and anthropogenic landscapes. For example, while Ni'aj and Hayyat produce comparable seed densities and seed frequencies by vegetation categories, the relative importance of orchard crops and cereals shifts from emphasis on *Vitis* and *Hordeum* at Ni'aj to *Olea* and *Triticum* at subsequently inhabited Hayyat (Fall et al., 2002). A similar distinction is apparent between the emphasis on grape and barley cultivation at Bab edh-Dhra', Wadi Fidan 4 and Ras an-Numayra (McCreery, 1980, 2003; Meadows, 2001; Cartwright, 2003; White et al., 2014) in comparison to greater evidence for olive, wheat and legumes at the better watered Bronze Age towns of Megiddo, Beth Shean and Tell Abu al-Kharaz (Borojevic, 2006; Fischer and Holden, 2008; Mazar and Rotem, 2009). Collectively, these results document a transition from more arid adapted farming at Early Bronze Age settlements (especially those like Ni'aj dating to the Early Bronze IV collapse) to a preference for less drought tolerant cultigens by Middle Bronze Age communities (including Hayyat).

Charcoal profiles show a shift from burning of more riparian and orchard wood (with higher frequencies of *Populus*, *Vitex*, *Ficus* and *Punica*, as well as *Vitis*) and fewer shrubs at Ni'aj to more shrub wood and desert/riparian trees (e.g., *Tamarix*, *Ziziphus*) at Hayyat. While these two settlements utilized similarly diverse fuel sources from landscapes with minimal access to upland forests, the charcoal evidence points again to more arid-land adapted agriculture at Ni'aj. Interestingly, *Punica* wood was found at both ZAD and at Ni'aj. Since *Punica* does not grow wild in the Levant (Zohary and Spiegel-Roy, 1975), we infer that this charcoal comes from domesticated trees. *Punica* was first domesticated in the Levant during the Early Bronze Age, as demonstrated by seeds found at Jericho, Arad (Hopf, 1978, 1983; Zohary et al., 2012: 135) and Bab edh-Dhra' (McCreery, 1980, 2003).

5.3.2. Along the Rift: Middle Bronze Hayyat vs. ZAD

The roughly contemporaneous settlements at Hayyat and ZAD lie at similar elevations but with substantial differences in latitude and modern rainfall. These communities utilized dung fuel indicative of more grazing and cereal cultivation at Hayyat in contrast to animal browsing on wild species around ZAD. Tree charcoal at both sites includes substantial amounts of *Tamarix*, which is accompanied by *Acacia* at ZAD. Both the charcoal and seed evidence indicates greater importance of *Olea* than *Vitis* at Hayyat, with a contrasting pattern of more *Vitis* and a striking absence of *Olea* at ZAD, reflecting more arid adapted land use in the Dead Sea basin. Thus, the occupants of ZAD relied on wood fuel from desert trees, complemented with dung fuel from animals browsing on wild plants, whereas Hayyat's villagers managed a more intensively cultivated landscape with a more diverse array of fuel sources, including greater use of dung from grazing animals and wood from riparian trees.

5.3.3. Mainland Hayyat & ZAD vs. Troullia, Cyprus

Politiko-*Troullia* generates a much lower seed density than any of the other three sites, both overall and for each of the vegetation categories (including an absence of pulses). Several aspects of the seed and charcoal assemblages distinguish *Troullia* from its Levantine contemporaries, Hayyat and ZAD. The largest components of *Troullia*'s seed assemblage include orchard species (*Ficus*, *Olea* and *Vitis*) and wild taxa. Charcoal density is higher than at ZAD or Hayyat, and includes substantial evidence of upland tree species largely absent at the Levantine sites, especially pine and oak. Agriculture at Politiko-*Troullia* may have incorporated olive, grape and fruit cultivation on adjacent terraced hillsides (Fall et al., 2012), but carbonized cereal grains are very limited and pulses are absent from the seed assemblage, suggesting possible reliance on meat as a protein source for local villagers. This likelihood is reinforced by substantial evidence for consumption of venison (Falconer and Fall, 2013a). In overview, the evidence from *Troullia* suggests that its surrounding landscape was the least impacted and provided the least diverse array of fuel sources, with pronounced dependence on forest fuel wood and minimal remains of dung fuel from grazing animals. This portrait of forest oriented fuel use at Politiko-*Troullia* dovetails with extensive evidence of deer hunting, feasting and community identity at this preurban community on Cyprus (Falconer and Fall, 2013a; Falconer et al., 2014).

6. Conclusions

Comparative analysis of seed and charcoal assemblages from four Bronze Age communities reveals interrelated aspects of crop management and fuel use on a variety of ancient anthropogenic landscapes in the eastern Mediterranean. Patterns of carbonized seed deposition reveal pronounced and widespread utilization of dung fuel at Tell Abu en-Ni'aj and Tell el-Hayyat on a landscape of cultivated and grazed agricultural fields, with use of wood fuel from riparian trees but apparently only very limited access to upland forest resources. Pyrotechnic industry is clearly documented at Hayyat and implied strongly at Ni'aj. Charcoal evidence suggests burning of wood fuel from desert trees at Zahrat adh-Dhra'1, olive pruning at Politiko-*Troullia* and the exploitation of upland pine and oak forests to fuel copper metallurgy at this Cypriot village. These results draw a sharp contrast between the intensely populated and cultivated northern Jordan Valley, the more sparsely inhabited deserts of the southern Jordan Rift, and settlement on the upland forest margins of central Cyprus.

The fuel profile for Tell Abu en-Ni‘aj implicates utilization of more arid landscape resources during the Levantine urban collapse of the late third millennium B.C. in comparison to those utilized subsequently at nearby Tell el-Hayyat. These two settlements used the most diverse arrays of wood sources (Ni‘aj) and grazed crops (Hayyat), and revealed the most intense charcoal burning (Ni‘aj) in this study. In contrast, the evidence from ZAD and *Troullia* reflects fuel use on less intensely cultivated landscapes geographically distant from or prior to the influences of urbanism. In these cases, greater access to woodland resources was coupled with common use but less diverse arrays of fuel sources at ZAD and especially *Troullia*. Thus, comparative analysis of carbonized seed and charcoal evidence reveals fuel exploitation strategies as a means of inferring crop cultivation practices and the availability of woody vegetation as formative aspects of the development of Bronze Age anthropogenic landscapes in the eastern Mediterranean.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.jasrep.2015.09.004.

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