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Environment and horticulture in the Byzantine Negev Desert, Israel: sustainability, prosperity and enigmatic decline

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ABSTRACT

This study presents a comprehensive paleoenvironmental reconstruction of the Byzantine and Early Islamic western Negev Desert communities during the 4th-8th centuries CE. The study is based on 33 pollen samples and hundreds of charcoal remains that were recovered from the villages of Shivta and Nitzana. The results demonstrate that during the 5–6th centuries CE flourishing desert agricultural communities existed on the periphery of the Byzantine Empire (Eastern Roman Empire). The presence of diverse fruit-tree horticulture is revealed by both pollen and charcoal remains (grape, fig, olive, carob, almond/apricot, pomegranate, date palm and the exotic hazelnut). The rich botanical assemblages also provide evidence of the cultivation by irrigation of conifers and other Mediterranean trees common to the more humid Mediterranean vegetation zone, including the prestigious cedar of Lebanon. The palynological reconstruction of an ornamental garden at Shivta indicates the ability to invest water and labor, not only for horticultural and construction purposes, but also for ornamental greenery. We therefore suggest that the Byzantine Negev Desert community was a luxury society in contrast to societies living in a mode of survival in challenging desert environments. During the Early Islamic period (since the second half of the 7th century CE), our data show a dramatic decline in fruit-tree horticulture coupled with indicators signifying overexploitation for fuel of the nearby natural woody desert environment. Hence, we claim that in addition to previous possible explanations for the demise of the Negev Byzantine communities (plague pandemic, climate change, the Muslim conquest), overexploitation of the natural vegetation should also be taken into account. This study therefore helps address historical questions that are also pertinent to the modern era, regarding the existence of flourishing societies in challenging environments, overexploitation of the natural environment, and neglect of sustainability.

1. Introduction

During the first millennium CE, the Negev Desert communities witnessed the impact of several dramatic historical events, which included the weakening of the Roman Empire (2–4th centuries CE), the growth of the Byzantine (Eastern Roman) Empire and its enigmatic decline (4–7th centuries CE; Fig. 1a–b), and the Muslim conquest (beginning at the second half of the 7th century CE). The Negev Desert societies also withstood the rise of two of the monotheist religions, Christianity and Islam.

Settlement activity, population density and agricultural productivity reached their zenith in the Negev Desert during the 5–6th centuries CE under the hegemony of the Byzantine Empire (Fig. 1a). This exceptional prosperity, in such a harsh arid environment (Figs. 1c and 2c), was never seen again until the modern era. Many of the ancient agricultural installations are still visible today, including widespread construction of artificially built stone mounds on slopes to enhance floodwater runoff to the agricultural fields in the wadis (streambeds) and impoundment dams to catch alluvial soil and flood water in the fields (e.g., Evenari et al., 1989; Tepper et al., 2020a). Additional agricultural installations

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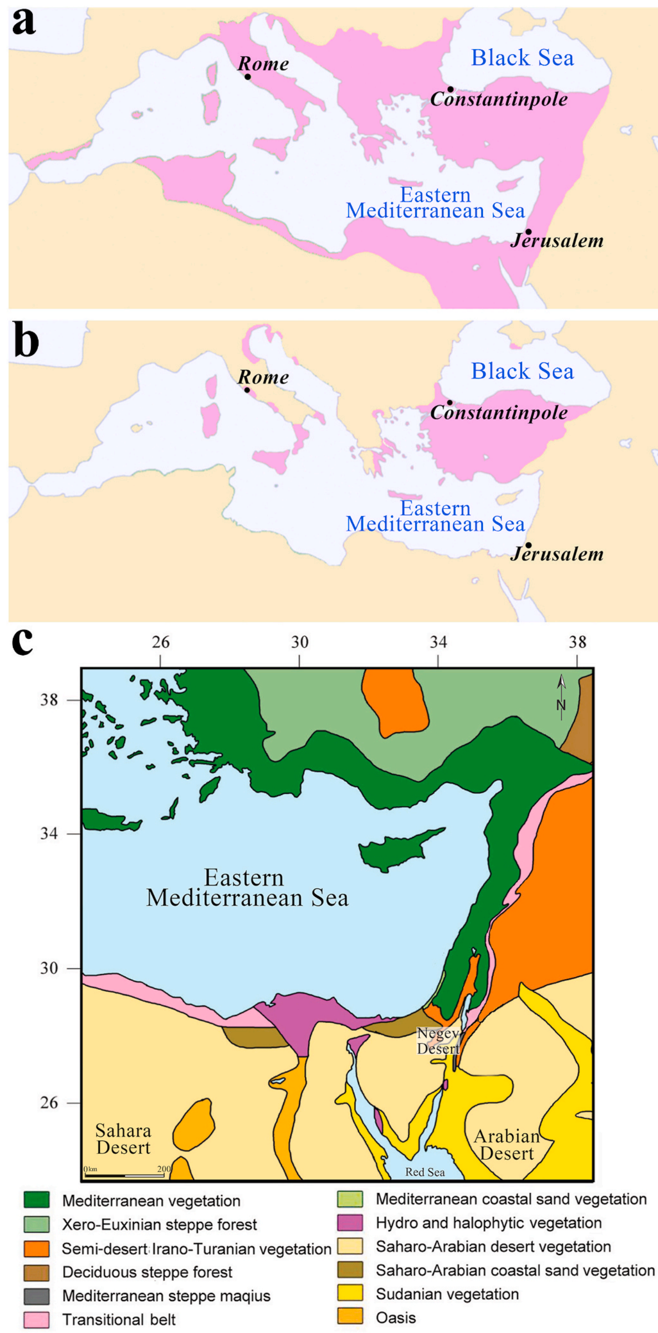

Fig. 1. (a) and (b) Maps of the Byzantine Empire* in the early 6th century CE and early 8th century CE, respectively. (c) Eastern Mediterranean vegetation map (modified after Zohary, 1973).
*The Byzantine period refers to that spanning the rise of Christian rule under Constantine to its downfall during the Islamic conquests, during the 4th to mid-7th centuries CE, in line with Levantine archaeological convention. The Byzantine Empire refers to the eastern Roman Empire throughout this time span.

scattered across the landscape are water cisterns and dovecotes, which were built near the fields in order to produce fertilizers, enriching the nutrient-poor desert soil (Tepper, 2007; Tepper et al., 2017). These agro-technological elements imply an ingenious and sophisticated water-harvest and management technology that enabled the Byzantine desert agricultural communities to flourish. Thousands of macro-botanical remains (charred wood) and micro-botanical remains (fossil pollen), which were identified in this study, provide for the first time direct evidence of the fruit trees that constituted this successful unique desert horticultural enterprise. The botanical remains were recovered from two large Byzantine villages: Shivta and Nitzana (Fig. 2). This new rich botanical database is the focus of this study.

Throughout the Byzantine period, events in the Negev Desert were tied to external geopolitical developments. Historians have argued that the flourishing of an agricultural society in the relatively dry and resource-limited environment of the Negev depended on the mobilization of external economic and human capital backed by the infrastructure of the Byzantine Empire and Christianity as the state religion beginning in the 4th century CE (Fig. 1; Rubin, 1996, 1997).

While the prosperity of Byzantine agriculture and trade in the southern Levant is well documented by the archaeological and historical

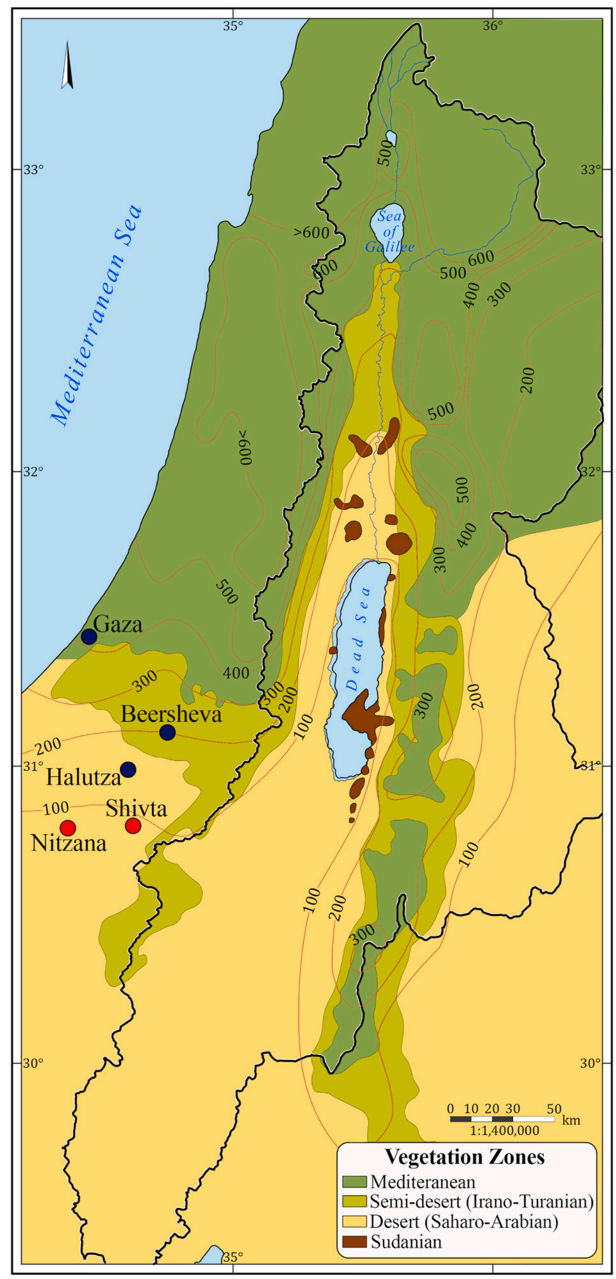

Fig. 2. The position of the two Byzantine villages – Shivta and Nitzana, studied in this research, together with other sites mentioned in the text. The watershed of the southern Levant is marked by the bold black line. Base map: Phytogeographic and precipitation map of the southern Levant (after Zohary, 1962; Srebro and Soffer, 2011, respectively).

records, the reasons for its weakening are still a subject of scholarly debate. Drier climatic conditions were observed in central Europe from the mid-6th to mid-7th centuries CE (e.g., Büntgen et al., 2016). In ca. 541 CE the Justinianic Plague (bubonic plague) broke out, spread rapidly via marine and overland trade throughout the empire and persisted until 750 CE (Stathakopoulos, 2004; Harbeck et al., 2013). Local natural catastrophes such as the strong seismic events in 634 and 659 CE (Agnon, 2014), which severely damaged Levantine sites such as Scythopolis (Beth She'an), Gerasa (Jerash), Heshbon and Pella, may have also contributed to some extent (e.g., Langgut et al., 2015a: 147 and references therein). Another explanation for the decline is related to the Persian and Arab invasions during the 7th century CE (Avni, 2008: 1–26, 2014: 344–348; Magness, 2012).

Here we shed new light on the prosperity of the Byzantine settlements on the desert periphery of the Byzantine Empire, as well as on their enigmatic weakening, by a meticulous examination of changes through time in the botanical assemblages. The new knowledge of this local sequence will be integrated into the broader historical dynamics of this crucial period. Furthermore, by providing new evidence regarding the centuries of successful sustainable horticulture in the Byzantine Negev, important useful insights may emerge. These perceptions can be applied to marginal environments around the globe and are especially relevant today as global warming and desertification intensify. Learning from the experience of past successful desert agricultural communities may lead to an increase of yields and may also promote biodiversity on the fringe areas of the Mediterranean Basin.

1.1. *The Negev Desert: environment and excavated sites*

The Negev Desert occupies the southernmost part of the Levantine region and continues into the Sinai Desert. This arid region is part of the global desert belt of 20–30° N latitude and is situated between the Sahara in the west and the Arabian Desert in the east (Fig. 1c). Conditions in the Negev move gradually from semi-arid in the north and west to arid in the south and the east. The excavated sites of Shivta and Nitzana are situated west of the regional watershed in a region that today receives an average of about 50–100 mm of annual precipitation (Fig. 2). Within this area, the natural vegetation is typically desert Saharo-Arabian with minor intrusions of certain semi-arid steppe Irano-Turanian elements (Zohary, 1962, 1973). Due to the arid conditions in the region, the preservation of wood materials, both charred and desiccated, is extremely good as demonstrated by the sites under study here (Colt, 1962: 57–59; Liphschitz, 2004, 2007: 60, 63; Sitry and Langgut, 2019). Similarly, arid conditions tend to also be conducive for the preservation of pollen (for recent pollen results from Shivta see Dunseth et al., 2019).

1.1.1. *Shivta*

The ruins of the ancient village of Shivta (Arabic: Subeita) are located at an altitude of ca. 350 m asl (above sea level). In antiquity, the site was established in remote spot ca.15 km southeast of the main route that crossed the Negev to Sinai. Even today, the site appears isolated as it is situated 40 km southwest of the nearest city, Beersheva (Fig. 2). This remoteness accounts for the fact that it is one of the best-preserved Late Antique sites in the region. Many of its domestic walls have survived to heights of 2–4 m, and the ruins of three churches stand as high as 8–10 m. The lines of most streets are still discernible, as are the two public water reservoirs (Negev, 1993: 1404–1410; Hirschfeld, 2003; Hirschfeld and Tepper, 2006; Tepper et al., 2018a). In 2005, UNESCO inscribed Shivta as a World Heritage Site.

The settlement was apparently first established just prior to the Roman annexation of the region (105/106 CE), although finds from that period are few (Hirschfeld, 2003; Tepper et al., 2018a). Shivta reached its zenith during the Byzantine period (5–6th centuries CE) and was abandoned following a significant decline during the Early Islamic period (after the 7th century CE; Rubin, 1990, 1996; Negev, 1993; Hirschfeld, 2003, 2006; Magness, 2003, 2012: 185–187; Avni, 2014: 263, 265–267; Tepper et al., 2015, 2018a; Tchekhanovets et al., 2017).

Shivta represents a major achievement in the establishment of flourishing farming communities in an arid desert environment. Despite the lack of permanent natural water sources in the immediate vicinity of the village (including aquifers that would allow the digging of wells), the surrounding areas were cultivated to a great extent. The remains of this initiative include widespread agricultural walls, dams and water channels, cisterns and a dense network of farms with numerous agricultural installations (Kedar, 1957; Evenari et al., 1989; Hirschfeld, 2003; Segal, 1983; Tsuk, 2003; Hirschfeld and Tepper, 2006; Ramsay et al., 2016; Tepper et al., 2018a).

1.1.2. *Nitzana*

The ancient village of Nitzana (Nessana), ca. 270 m asl, is situated in the western part of the Negev Desert, ca. 52 km southwest of Beersheva (Fig. 2). Colt's excavation at the site from 1935 to 1937 revealed that it was first established during the Hellenistic period, and continued to be occupied through the Roman, Byzantine and Early Islamic periods (Colt, 1962; Shereshevski, 1991: 49–52; Magness, 2003: 90–92, 180–185; Avni, 2014: 261–267). Colt's excavation exposed domestic quarters, two churches, a fortress and an archive of papyri from the 6–7th centuries CE, written in Greek and Arabic. This important finds bring to light a wealth of information about the day-to-day life of a desert community between the last phase of Christian administration in the Late Byzantine period and the earliest phase of the Islamic era. The papyri make Nitzana the best-documented community of all the Byzantine-Early Islamic sites in the Negev (Kraemer, 1958). A later excavation conducted by Urman from 1987 to 1995, exposed, in addition to domestic contexts, another church and a convent (Urman, 2007).

The villages of Shivta and Nitzana together with the city of Halutza are the focal point in our ongoing project "Crisis on the Margins of the Byzantine Empire: A bio-archaeological project in the Negev Desert". As will be demonstrated in this study, the botanical remains collected from Shivta and Nitzana during the 2015–2019 renewed excavations (directed by YT and GBO), are shedding new light on the forces and processes that enabled the Byzantine agricultural communities to flourish in that arid region of the Negev, as well as to better understand their decline. The botanical remains from Halutza have already been reported in Bar-Oz et al. (2019) but will also be discussed here in light of the new results.

2. Material and methods

2.1. *Anthracology (carbonized wood remains)*

In this study, most of the charred samples from Shivta and Nitzana were collected from a specific archaeological context – domestic trash mounds. The underlying assumption in anthracological studies is that such deposits are more likely to represent the accumulated remains not only of wood collected as fuel, but also "secondary" fuels, deriving from worked wood, defunct timber, horticultural refuse and wooden crafts. Hence, potential biases in taxon representation introduced by context-related variation are, to some extent at least, minimized (Asouti and Hather, 2001). At Shivta and Nitzana, waste from the Byzantine period was discarded in trash mounds that are situated outside the peripheral wall of the sites. We believe that these landfills reflect the massive collection and dumping of fuel and construction waste over time, as part of organized garbage management (Tepper et al., 2018a, 2020b; Bar-Oz et al., 2019; Marom et al., 2019). Garbage from the Early Islamic period was dumped inside the precincts of the old town walls, which were already out of use, and inside abandoned Byzantine buildings (e.g., Marom et al., 2019). In other cases, samples were also collected from domestic contexts such as accumulations above floors inside houses, fills below them, and from the accumulation of loess in an abandoned water reservoir and water installations. Charcoal remains were recovered using a variety of procedures to assure good recovery. These included handpicking of individual samples during excavation, floatation and dry and wet sieving. All of the excavated sediments went through dry sifting in 5-mm sieve mesh for hand sorting and 'rough' picking. Finds retrieved by flotation were sifted using stacked sieves and all the charcoal fragments from the 2-mm sieve mesh size were collected. A total of 508 samples were identified from Shivta and 344 from Nitzana.

The remains were microscopically analyzed in order to determine their taxonomic identification at the highest possible taxonomic level. Each fragment was cut and examined along three observational axes (transverse, tangential and radial) using a stereoscopic Carl Zeiss SteREO Discovery. V20 microscope with magnifications of up to 360 × under oblique-angled top-lighting. A Scanning Electron Microscope (SEM: JOEL JSM-6300) was used when a higher magnification was required. The abundance, arrangement and size of the wood's anatomical structures (e.g., annual growth rings, vessels, rays, fibers), along with a number of other diagnostic characteristics of the Eastern Mediterranean arboreal flora, were noted and compared with the modern reference collection of charred wood and tissue structure of the southern Levant (provided by the Steinhardt Museum of Natural History, Tel Aviv University) and with specialized literature on plant anatomy (among others, Fahn et al., 1986; Wheeler et al., 1989; Schweingruber, 1990; Akkemik and Yaman, 2012; Crivellaro and Schweingruber, 2013).

2.2. Palynology

Sediment samples for palynological investigation were collected with sterile equipment from various archaeological contexts such as garden soils, public reservoirs (pools) and floors of domestic and public structures. We also collected plaster samples from several installations which were facing the open air (in parallel to the interior of a structure). The assumption was that air-borne pollen could be trapped in wet plaster during its application.

Pollen extraction from sediments followed the physical-chemical standard methods in the archaeopalynology of desert environments (Horowitz, 1992; Langgut and Gleason, in press). One *Lycopodium* spore tablet was added to each sample in order to calculate pollen concentrations (e.g., Stockmarr, 1971; Weinstein-Evron et al., 2015). Samples were then immersed in HCl to remove the calcium carbonates, after which a density separation was carried out using a $ZnBr_2$ solution (with a specific gravity of 1.95) in order to float the organic material, together with 5 min of sonication. After sieving (150 μm mesh screen), the unstained residues were homogenized and mounted onto microscope slides using glycerin. Acetolysis was not carried out to allow the identification of any non-pollen palynomorph (NPP). Pollen was extracted from plaster layers following the technique suggested by Langgut et al. (2013). In all samples, all the pollen grains within the residue were counted.

Pollen grains were identified under a light microscope, at magnifications of 200 × , 400 × and 1000 × (oil immersion), to the most detailed possible systematic level. For pollen identification, a comparative reference collection of the Israeli pollen flora of Tel Aviv University (Steinhardt Museum of Natural History) was used, in addition to pollen atlases (e.g., Beug, 2004; Reille, 1995, 1998, 1999). For the preparation of the palynological diagram and calculation of principal component analysis (PCA), PolPal software was used (Walanus and Nalepka, 1999). In total, 33 samples were palynologically analyzed.

3. Results

3.1. The charcoal assemblages

A total of 852 individual charred wood samples from Shivta and Nitzana were processed for taxonomic identification. The results of the two assemblages show great resemblance (Table 1 and Appendix 1). Altogether, the combined results for the two sites demonstrated 35 different taxa. We decided to divide the assemblages into four categories: (i) Trees or shrubs typical to the desert environment including (in declining order): *Tamarix* spp. (tamarix), *Lycium* spp. (boxthorn), *Retama raetam* (white broom), *Salsola* spp. (saltwort), *Calotropis procera* (apple of Sodom), *Juniperus phoenicea* (Phoenician juniper), *Ziziphus/Paliurus* (jujube/Jerusalem thorn), *Populus/Salix* (poplar/willow), *Capparis spinosa* (caper bush), *Pistacia atlantica* (Persian turpentine), *Zygophyllum dumosum* (bushy bean caper), *Rhamnus* spp. (buckthorn), *Fagonia mollis* (fagonia) and *Moringa peregrina* (ben tree; a relatively rare Sudanian tropical tree that currently grows mainly in the Dead Sea region). (ii) Fruit trees (in declining order): *Vitis vinifera* (grapevine), *Hyphane thebaica* (doum palm), *Ficus carica* (common fig), *Prunus* spp. (dulcis/armenica), *Olea europaea* (olive), *Ficus sycomorus* (sycamore fig), *Punica granatum* (pomegranate) and *Phoenix dactylifera* (date palm).

A significant presence of non-desert species was noted at the assemblages. Trees and shrubs that are native to the Mediterranean parts of Israel were grouped in the third category: (iii) Mediterranean trees, which include (in declining order): *Pinus halepensis* (Aleppo pine), *Cupressus sempervirens* (Italian cypress), *Platanus orientalis* (oriental plane), *Pistacia palaestina* (terebinth), *Crataegus* spp. (hawthorn group/Maloideae), *Quercus calliprinos*, (Kermes oak), *Myrtus communis* (true myrtle) and *Vitex agnus-castus* (chaste tree). The last category is composed of trees that typically grow in northern Mediterranean regions: (iv) Exotic trees. In the latter group, three tree species were observed (in declining order): *Cedrus libani* (cedar of Lebanon), *Fraxinus excelsior* (European ash) and, *Buxus sempervirens* (boxwood).

3.2. The palynological spectra

At Shivta pollen was preserved in three contexts (Fig. 3): the northern reservoir (sample nos. 1–19; Fig. 4), the southern reservoir (nos. 20–25; Table 2) and the garden adjacent to the northern church (nos. 26–32; Table 2). A sample of recent sediments was also analyzed for comparison and control purposes. That sample was taken from nearby Wadi Zeitan, 5 cm below the surface (no. 33; Table 2). Unfortunately, at Nitzana all the samples we checked (mainly collected from floors of excavated houses), were pollen barren.

3.2.1. The northern reservoir

Nineteen sediment samples were collected from this water reservoir and analyzed. The pollen results are shown in Fig. 4. The samples, taken at 10-cm intervals, represent a section from the top sediments to the floor of the reservoir (Fig. 5). While the lower sediment unit (zone 1, sample nos. 10–19, ca. 85–180 cm) represents an *in situ* deposition, the upper unit (zone 2, sample nos. 9–1, ca. 0–85 cm) is composed of mixed sediments in an oblique deposition (Tepper et al., 2018a). These fills probably derived from Baly's excavations of the southern reservoir (Baly, 1935; Tepper et al., 2018a). The lower section of zone 1 (130–180 cm) is comprised of laminated, light brown fine-grained silt sediments covered by a thin layer of silt sediments and pebbles (120–130 cm). On top of this layer, homogenous, off-white fine silt sediments had accumulated (85–120 cm). According to Tepper et al. (2018a), the top of zone 1 (ca. 85–100 cm) represents the last days of the use of the pool, toward the end of the Byzantine period and the beginning of Early Islamic period. The PCA (in particular PCA 1 and PCA 2; Fig. 4), supports this palynological and sedimentological division into pollen zone 1 and pollen zone 2. The dominant taxon in the assemblages, Chenopodiaceae, was excluded from the pollen diagram due to its tendency for over-representation (for a full diagram with Chenopodiaceae see Supplementary Material 3).

The palynological spectra of zone 1 and zone 2 are composed of almost the same taxa, and therefore support the assumption that the fill sediments that comprise zone 2 derive from the adjacent southern pool. Furthermore, the pollen columns of the two zones appear in similar ratios with the exception of *Pinus halepensis*, which exhibits higher frequencies in zone 2, and Asteraceae Asteroideae pollen type (aster-like)

Table 1
Identified charred material in absolute numbers[a] and percentages in Shivta and Nessana.

Category	Taxon	Shivta		Nessana	
		Absolute number	%	Absolute number	%
Desert trees and shrubs	*Tamarix* spp. (tamarisk)	305	60.0%	213	61.7%
	Lycium spp. (boxthorn)	31	6.1%	35	10.1%
	Retama raetam (white broom)	7	1.4%	16	4.6%
	Salsola vermiculata (Mediterranean saltwort)	5	1.0%	4	1.2%
	Calotropis procera (apple of Sodom)	4	0.8%	1	0.3%
	Juniperus phoenicea (Phoenician juniper)	1	0.2%	3	0.9%
	Ziziphus/Paliurus (jujube/Jerusalem thorn)	2	0.4%	2	0.6%
	Populus/Salix (poplar/willow)	–	–	3	0.9%
	Capparis spinosa (caper bush)	4	0.8%	–	–
	Pistacia atlantica (Persian turpentine)	1	0.2%	1	0.3%
	Zygophyllum dumosum (bushy bean caper)	1	0.2%	1	0.3%
	Salsola tetandra (saltwort [tetandra])	2	0.4%	–	–
	Rhamnus spp. (buckthorn)	1	0.2%	1	0.3%
	Fagonia mollis (fagonia)	–	–	1	0.3%
	Moringa peregrina (Ben tree)	1	0.2%	–	–
Fruit trees	*Vitis vinifera* (grapevine)	28	5.5%	4	1.2%
	Ficus carica (common fig)	21	4.1%	6	1.7%
	Hyphane thebaica (doum palm)	15	3.0%	1	0.3%
	Prunus spp. (dulcis/armenica)	2	0.4%	6	1.7%
	Olea europaea (olive)	10	2.0%	–	–
	Ficus sycomorus (Sycamore fig)	–	–	1	0.3%
	Punica granatum (pomegranate)	–	–	1	0.3%
	Phoenix dactylifera (date palm)	1	0.2%	–	–
Mediterranean trees and shrubs	*Pinus halepensis* (Aleppo pine)	20	3.9%	10	2.9%
	Cupressus sempervirens (Italian cypress)	9	1.8%	5	1.4%
	Platanus orientalis (oriental plane)	–	–	3	0.9%
	Pistacia palaestina (terebinth)	2	0.4%	1	0.3%
	Crataegus spp. (hawthorn group/Maloideae)	1	0.2%	2	0.6%
	Quercus calliprinos (Kermes oak)	2	0.4%	–	–
	Myrtus communis (true myrtle)	–	–	1	0.3%
	Vitex agnus-castus (chaste tree)	–	–	1	0.3%
Exotic trees	*Cedrus libani* (cedar of Lebanon)	20	3.9%	7	2.0%
	Fraxinus excelsior (European ash)	–	–	2	0.6%
	Buxus sempervirens (boxwood)	1	0.2%	1	0.3%
	Undetectable	10	2.0%	11	3.2%
TOTAL		508	100%	344	100%

[a] For the exact context of each specimen see Supplementary Material 1 and 2.

which appears in reduced ratios in comparison to zone 1. Among the non-local desert trees *Pinus halepensis*, Cupressaceae (cypress/juniper), *Fraxinus* (ash), *Ulmus* (elm) and *Salix* (willow) were recorded. *Cedrus* is the only taxon in this assemblage that is not native to Israeli flora. *Cedrus* pollen is indistinguishable to the species level, however, based on the occurrence at Shivta of both charcoal remains (Table 1) and wooden implements made of the cedar of Lebanon (*Cedrus libani*; Hirschfeld and Tepper, 2006; Sitry and Langgut, 2019), it is suggested that the cedar pollen came from the cedar of Lebanon (Fig. 6a–c). Among the fruit trees, *Vitis* (grapevine), *Olea europaea* (olive) and *Phoenix dactylifera* (date palm), were documented. Pollen of small shrubs and herbs that may have been related to cultivation includes Cerealia pollen type (cereals), Apiaceae (umbels) and Fabaceae (legumes).

3.2.2. The southern reservoir

This reservoir is located only a few meters south of the northern one (Fig. 3). Six sediment samples were collected and analyzed from different contexts, all derived from the bottom of the reservoir. Three samples were recovered from sediments that lay on the pool's floor (nos. 20–22), one sample from the sediments that lay on the bottom of the inner depositional basin (no. 23) and two plaster samples – one was taken from the floor (no. 24) and another from plaster in a water tunnel (no. 25). The pollen results are presented in Table 2. The components of the palynological spectrum of the southern reservoir were almost identical to its adjacent northern reservoir. However, two additional taxa were detected: *Corylus* (hazelnut), which is not native to Israeli flora, and *Ceratonia siliqua* (carob), which grows as a wild and domesticated tree in Israel in northern areas of the Mediterranean environment. While most of the pollen taxa identified in this study bloom during late winter and spring, carob blooms in autumn.

3.2.3. The garden of the northern church

Adjacent to the northern church (Fig. 3) a garden soil and an irrigation system was found (Tepper, 2019a). Five samples were collected from the garden's soil (nos. 26–30) and two additional samples were taken from the plaster of a water tunnel (nos. 31–32). Among the wind-pollinated trees, the assemblages include the following taxa: *Pinus halepensis*, Cupressaceae (cypress/juniper), *Fraxinus*, *Salix*, *Cedrus*, *Olea europaea*, *Phoenix dactylifera*, *Tamarix* and *Corylus*. Pollen grains of the small trees/shrubs of *Myrtus* (true myrtle) and *Vitis*, both taxa characterized by low pollen-dispersal efficiency, were also detected in these assemblages. While the pollen of the wind-pollinated taxa may originate from the garden and/or from distant locations at the site and its hinterland, it is suggested, based on their pollen-dispersal mechanism, that myrtle and grapes were cultivated in the church's garden. Pollen of small shrubs and herbs that may be related to human cultivation includes Cerealia pollen type, Fabaceae and *Bunium* type, which belong to the umbel family. This pollen type includes *Petroselinum crispum* (garden parsley) and *Anethum graveolens* (dill).

Table 2
Pollen results in absolute numbers from the southern pool and the garden of the northern church, Shivta.

Field ID	Southern pool						The garden of the Northern church							Modern sediment control - Wadi Zeitan # 51, 5 cm below surface
	Area x #1 sediments accumulated on the pool's floor	Area HS #2 sediments accumulated on the pool's floor	Area HS #5 sediments accumulated on the pool's floor	Area HS #4 sediments which accumulated on the bottom of the inner depositional basin	Area HS #3 plaster of the pool's floor	Area HS #8 plaster of a tunnel southern wall	Area E #5 brownish sediments	Area E #6 brownish sediments	Area E #2 light brown sediments	Area E #4 light brown sediments	Area E #6 light brown sediments	Area E #7a plaster of a water tunnel	Area E #7 b plaster of a water tunnel	
Lab ID	20	21	22	23	24	25	26	27	28	29	30	31	32	33
Pinus (pine)	5	2	8	13	2	10	98	58	2	9	2	17	10	
Pinaceae (pine family)									1			1		
Cedrus (cedar)		2		2			5	2	1					
Juniperus/ Cupressus (juniper/ cypress)	105	96	4	13	2	16	21	30			1	2	1	64
Olea europaea (olive)	2					1		1	2	6		17	2	
Ceratonia siliqua (carob)	2		5	2									2	
Fraxinus (ash)			6			2						1		
Myrtus communis (true myrtle)												2	3	
Salix (willow)						2				8		2	7	
Vitis vinifera (grapevine)		18				2	11	24	8	11		8	12	
Phoenix dactylifera (date palm)	3													
Zygophyllum (bean-caper)									13					
Tamarix (tamarisk)												2		
Corylus (hazel)				2		2				13		13	3	
Carthamus (distaff thistle)	1						1		2			1		
Cardus (plumeless thistles)														
Asphodelus (asphodels)												1		
Geranium (cranesbill)	1						4		4				1	
Calendula (marigold)			1											
Artemisia (sagebrush)	1	1	14	1		1		1	62	61		14	18	
Asteraceae Asteroideae type (aster-like)	131	46	26	57	6	12	47	52	45	36	12	10	9	125
Asteraceae Cichorioideae type (dandelion-like)	47	44	12	8	1	6	8	19	8	8		1	4	

(*continued on next page*)

Table 2 (*continued*)

Field ID	Southern pool						The garden of the Northern church							Modern sediment control - Wadi Zeitan # 51, 5 cm below surface
	Area x #1 sediments accumulated on the pool's floor	Area HS #2 sediments accumulated on the pool's floor	Area HS #5 sediments accumulated on the pool's floor	Area HS #4 sediments which accumulated on the bottom of the inner depositional basin	Area HS #3 plaster of the pool's floor	Area HS #8 plaster of a tunnel southern wall	Area E #5 brownish sediments	Area E #6 brownish sediments	Area E #2 light brown sediments	Area E #4 light brown sediments	Area E #6 light brown sediments	Area E #7a plaster of a water tunnel	Area E #7 b plaster of a water tunnel	
Poaceae (grasses)	1				1				1	4	1	1		
Cereals			4							1	4	11	8	
Caryophyllaceae (pinks)							1		1					
Liliaceae (lilies)			2		1	1				1		1		
Chenopodiaceae (chenopods)	1027	201	539	351	4	33	149	289	301	272	1	95	47	22
Rumex (docks)										1				
Plantaginaceae (plantains)		1		1	1	4			3			1	1	
Bunium type	2	4	6			6		1	8			22	1	1
Ferula type													1	
Ephedra (Mormon-tea)	1		1	5		1	6		1			4		9
Brassicaceae (mustards)	1							4	4	5		10	1	2
Fabaceae (legumes)					1	1			1			6		
Centaurea (knapweeds)													1	
Polygonaceae (buckwheat)	1			1				1				3		
Malvaceae (mallows)									1			1		
Thymelaeaceae	1											11		
Cistus (rock rose)				1										
Total counted	1332	415	628	457	19	100	351	482	469	436	21	258	132	34
Unidentifiable	23	22	38	37	3	15	9	30	29		1	10	5	
Spores	5	49		12	6	1	10	10	2			3	5	79
Cyperaceae (sedges)					1		1					1		
Nimphaea (water lilies)					1									4
Sparganium (bur-reeds)										1		1		
Lycopodium	56	374	73	204	130	281	383	182	20	26	213	92	548	835

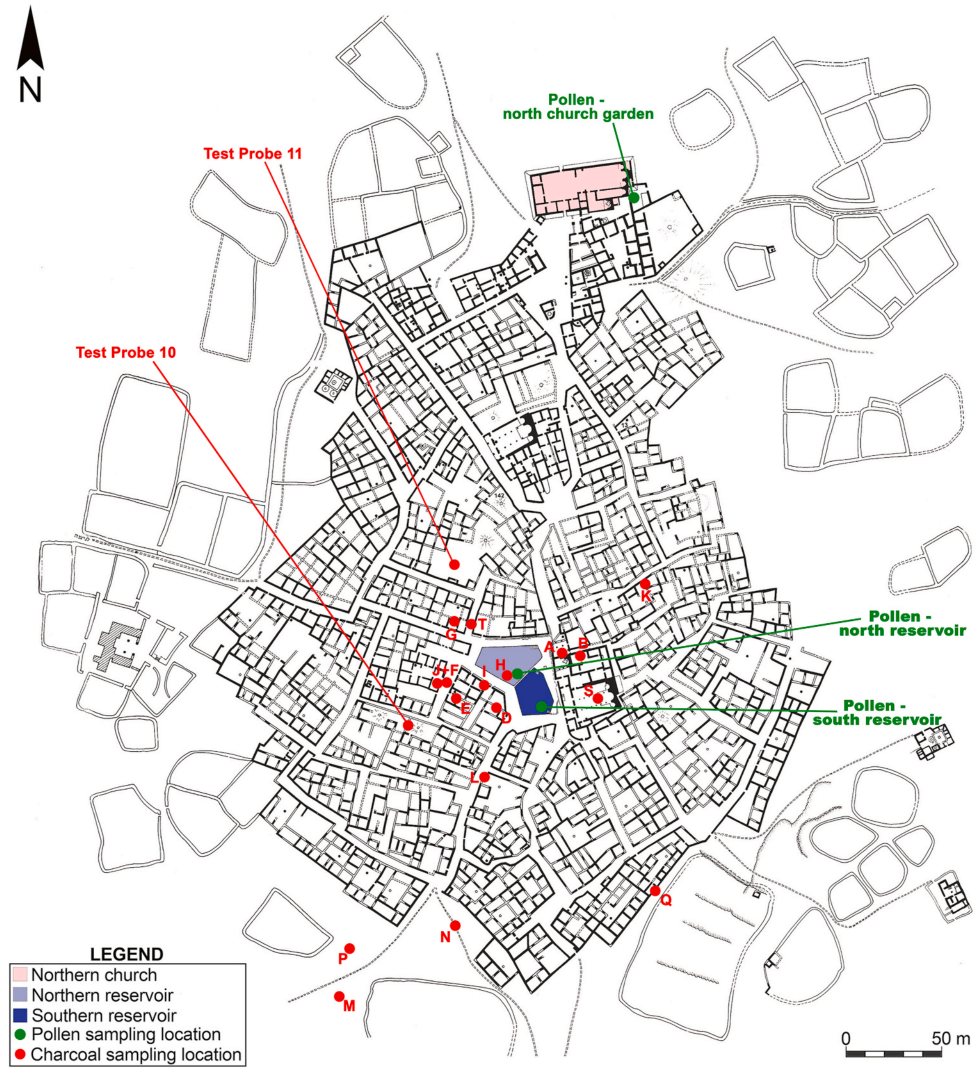

Fig. 3. Site plan of Shivta with the locations from which charcoal remains and pollen samples were collected (modified after Hirschfeld, 2003: fig. 3).

4. Discussion

4.1. *Wood remains in the Byzantine Negev settlements: identification, origin and uses*

Timber for everyday use was usually collected from areas close to the site. Therefore wood-charcoal remains found in certain archaeological contexts often reflect the natural and cultivated arboreal environment (e.g., Deckers et al., 2007). Only rarely was precious wood imported from afar and it was mainly used for the construction of prestige buildings or the manufacture of delicately crafted objects. It is therefore suggested that most of the charcoal remains identified in this study (Table 1), reflect the immediate environment of the Byzantine villages of Shivta and Nitzana.

Additionally, we assume that the non-desert arboreal pollen identified at Shivta (Fig. 4 and Table 2), mainly reflects the cultivated and irrigated environment near and within the site. This assumption is based on several principal reasons: The total lack of pollen of other wind-pollinated trees common to the southern Levant Mediterranean maquis/forest, such as oaks and terebinth, clearly indicates that the pollen of the non-desert trees did not originate from their natural habitats in the more humid north and were not transported by prevailing winds, but that they were cultivated in the area studied. We also ruled out the possibility of long-distance arboreal pollen transportation based on the absence of most Mediterranean tree components from the recent pollen sample (Table 2, sample no. 33). The presence of taxa characterized by low pollen-dispersal efficiency such as *Vitis vinifera*, *Ceratonia siliqua* and *Myrtus communis* also points to nearby cultivation. Furthermore, the relatively high ratios of exotic pollen support the assumption that the desert settlers of the Byzantine Negev were engaged in a significant enterprise of tree cultivation for diverse utilizations such as fruit consumption, construction, crafts and for ornamental prestigious gardening purposes as well.

4.1.1. *Fuel*

Charred wood remains recovered from archaeological excavations are often assumed to be remnants of fuel material, since eventually most wood, regardless of its original intended use, would have been burned (Asouti and Hather, 2001; Thery-Parisot et al., 2010; Picornell Gelabert et al., 2011). The scarcity of woody plants was a limiting factor in desert environments. We assume that during the Byzantine era, settlers in the Negev used fuel from two main sources: gathering of local desert wood from the surroundings of the sites, and horticultural refuse, which derived primarily from regular maintenance activities such as branch pruning, which was and still is a common practice in fruit-tree horticulture (e.g., Langgut et al., 2014). It is worth mentioning that the use of agricultural waste for fuel is common today among many traditional societies, such as the Bedouin in Sinai and rural societies in central

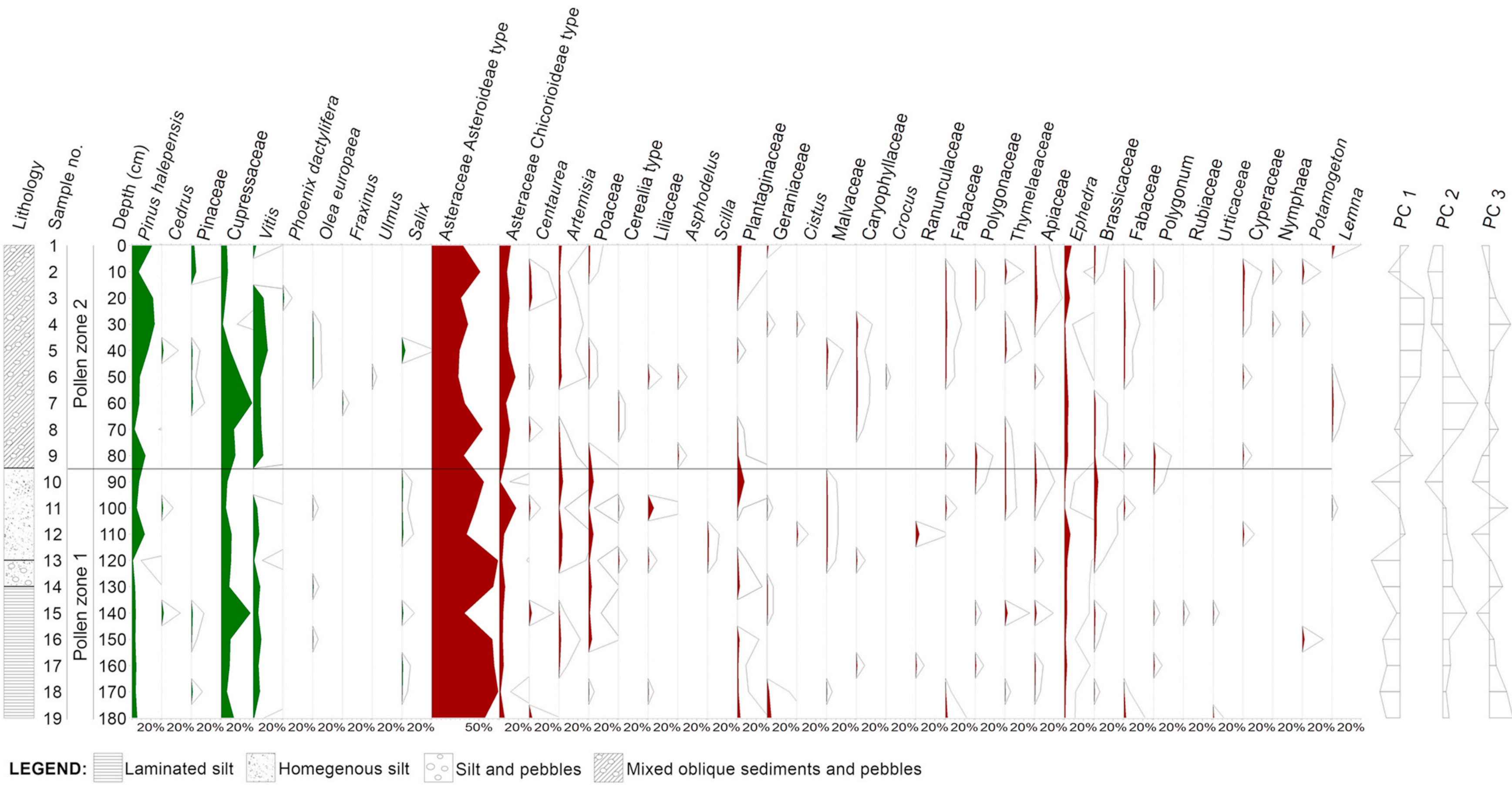

Fig. 4. Palynological diagram of the sediment outcrop recovered from the northern pool at Shivta, together with PCA results for patterns clarification. A tenfold exaggeration curve is used to show changes in low taxa percentages.

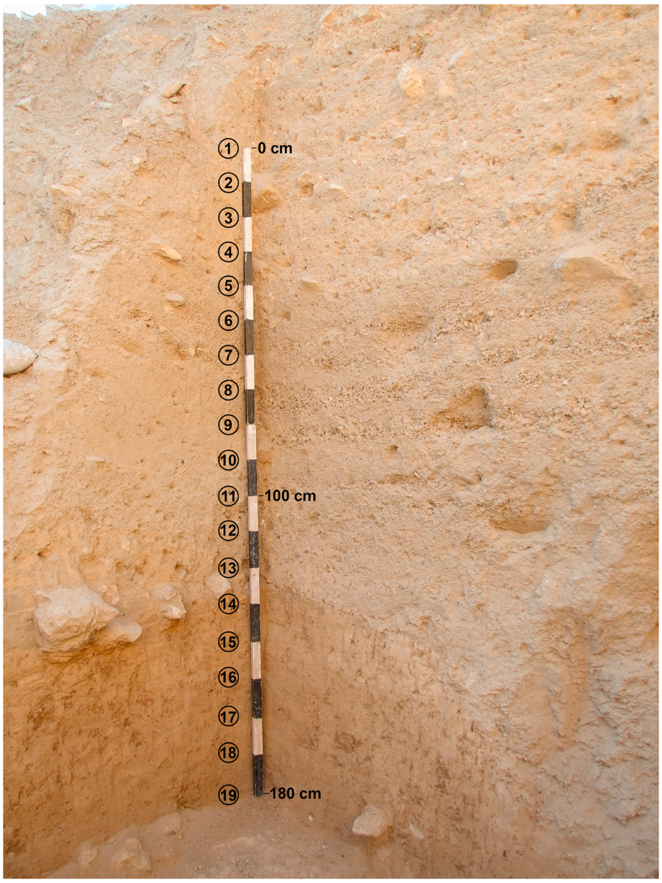

Fig. 5. Sediment outcrop at the northern pool, Shivta with the location of samples collected for the palynological investigation. For the exact location of the sediment section see Fig. 3.

Africa (e.g., Hobbs, 1989: 53; Picornell Gelabert et al., 2011; Andersen et al., 2014). Surprisingly, *Vitis* carbonized wood stands out for its relatively high ratio. Usually this species is under-represented in wood-charcoal assemblages since it possesses a low density of 0.40 g/cm^3 (Crivellaro and Schweingruber, 2013: 569) and therefore the weak constitution of lianas deteriorates easily. The samples encountered in this study hint at intense viticulture around the Byzantine villages in the Negev (Fuks et al., 2020) and the use of their agricultural refuse as a common source of energy.

Yet since the charcoal assemblages from Shivta and Nitzana are both dominated by tamarisk and boxthorn (with the former constituting more than 60% of the total identified charcoals), it seems that the first source – the nearby surroundings was the primary source exploited for fuel at the Negev Byzantine sites. The same observation was noted at Halutza (Bar-Oz et al., 2019: table S8). White broom was also present in relatively high frequencies in the three assemblages. Tamarisk is considered a mediocre energy source whereas boxthorn and white broom, with their high wood density, are considered superior (Bailey and Danin, 1981), especially the latter with a density of 0.88 g/cm3 (Engel and Frey, 1996).

While diachronically analyzing the assemblages recovered from the middens, an interesting observation emerged (Figs. 7 and 8 for Shivta and Nitzana; Bar-Oz et al., 2019: table S8 for Halutza). A decrease of boxthorn and white broom together with an increase in tamarisk ratios was documented during the Early Islamic period, in comparison to the Byzantine period at all three sites. Furthermore, at Shivta, a total disappearance of white broom was recorded during the Early Islamic period. These results may signify a possible depletion of quality firewood between the two periods. Higher frequencies of conifer charcoals in the Early Islamic period may suggest that craft items and/or beams, possibly from abandoned houses and farms were being burned to compensate for the deficiency of natural fuel sources (Fig. 8). We therefore propose that over-exploitation of natural vegetation may have been a contributing factor in the demise of the Byzantine Negev settlements.

4.1.2. Construction and crafts

Since many coniferous species produce relatively long and resilient logs, it is suggested that the three non-desert conifer species identified in this study – Aleppo pine, Italian cypress and cedar of Lebanon – were used as the main large-scale construction materials in the Byzantine villages. The long logs could have been used for roofing, beams, posts and frames (Gale and Cutler, 2000). Cedar wood, in addition to its straight long trunks, is also characterized by a pleasant odor. This tree was often imported from the northern Levant and used in monumental and luxury construction in the southern Levant (Lev-Yadun, 1992; Lev-Yadun et al., 1996: 122; Liphschitz, 2007: 122–129; Benzaquen et al., 2019; Roth et al., 2019). At one of Shivta's dovecotes, Hirschfeld and Tepper (2006) identified worked beams produced from Aleppo pine and cedar of Lebanon. Construction using the wood of coniferous species is also described in Greco-Roman textual sources, which report on their high value (e.g., Theophrastus, *Historia Plantarum* 5.7.1, 5, 8; Vitruvius, *De architectura* 1.2.8 (Rowland and Howe, 1999), Pliny the Elder, *Natural History* 16.76.197–198 (Rackham, 1952)). Although the integration of conifer-wood materials in buildings was common in the southern Levant as early as the Early Bronze Age, a dramatic increase in their presence in local assemblages was documented from the Hellenistic to the Byzantine period (Liphschitz, 2007: 34–46, 120–124, and references therein; Roth et al., 2019). It was recently suggested that Aleppo pine and Italian cypress were cultivated in the Judean Highlands for their wood during the classical periods (Roth et al., 2019). This stands in contrast to previous claims that pines and cypress species were imported into the southern Levant (e.g., Liphschitz and Biger, 1989, 2001). The occurrence of pollen from the drought-resistant conifer taxa *Pinus* and *Cupressus* (Lev-Yadun, 1987; Lev-Yadun and Weinstein-Evron, 2002), which are planted today in runoff water-collecting habitats in the Negev at Shivta, combined with their documented planting in Roman culture support the assumption of local cultivation rather than full dependence on long-distance wood importation.

When it comes to minor construction endeavors, local nearby desert species were probably used (e.g., Liphschitz, 2007; Sitry, 2014; Langgut et al., 2016a). Indeed, recently at Shivta, part of a door frame and a piece of unworked wood were both identified as *Tamarix* spp. The latter item, with a diameter of at least 150 cm, has clear traces of saw cuts on all sides and has been suggested as a raw material (Sitry and Langgut, 2019: figs. 4.1 and 6.4). The presence of wood as a raw material at Shivta may indicate the existence of a local carpenter's workshop at the site (Sitry and Langgut, 2019). Tamarisk is a common desert tree in the vicinity of Shivta and, as noted, dominates the charcoal assemblages from Nitzana and Shivta (Table 1), as well as Halutza's charcoal assemblage (Bar-Oz et al., 2019: table S8).

Unfortunately, none of the charcoal specimens hinted at their original shape. Therefore, the suggestions regarding the timber used for preparation of the wooden objects relied mainly on previous studies. A recently identified wooden artifact (and artifact-fragment) assemblage from Shivta, composed of 21 items, indicated that one third of the assemblage consisted of desert trees such as tamarisk, ben tree, jujube and *Capparis decidua* (karira). Another third was made up of one of the two conifers – Italian cypress or cedar of Lebanon (Fig. 6 d-e). The rest of the items, artifacts such as a reel (spool of yarn) and a button, were produced from the exotic boxwood tree, and one round frame was prepared from *Fagus* sp. (beech) (Sitry and Langgut, 2019). Since the latter two exotic taxa were not identified in the palynological spectra, it is possible that the artifacts may have been brought to Shivta from northern Mediterranean regions. In antiquity, boxwood was considered

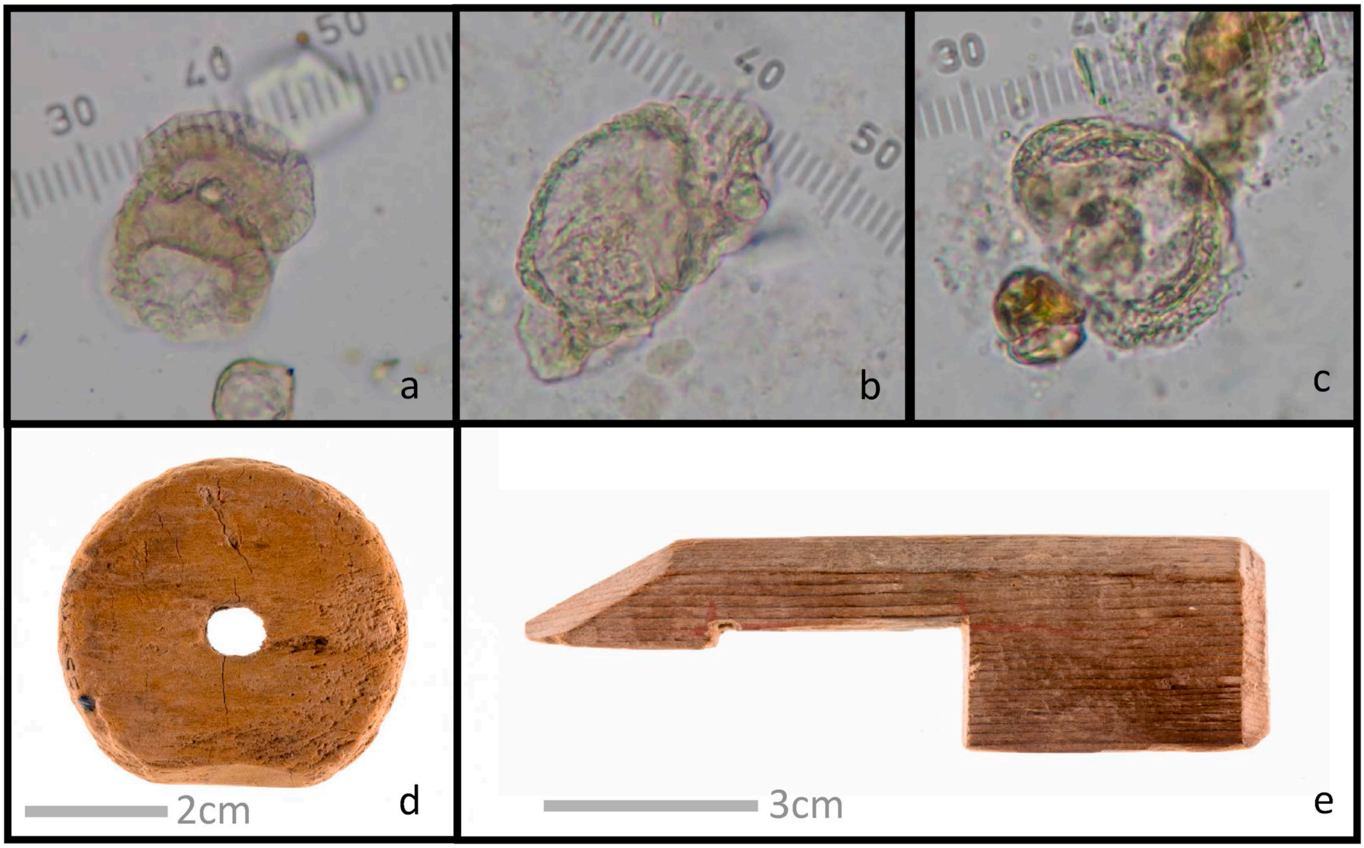

Fig. 6. (a–c). Fossil pollen grains of *Cedrus* (cedar) recovered from the soil of the garden adjacent to the northern church at Shivta (Area E, sample nos. 26–27). Images were taken at 400 × magnification; (d). A spindle whorl and (e). A bolt case made of cedar of Lebanon found at Shivta (taken from Sitry and Langgut, 2019: figs. 1.3 and 6.1).

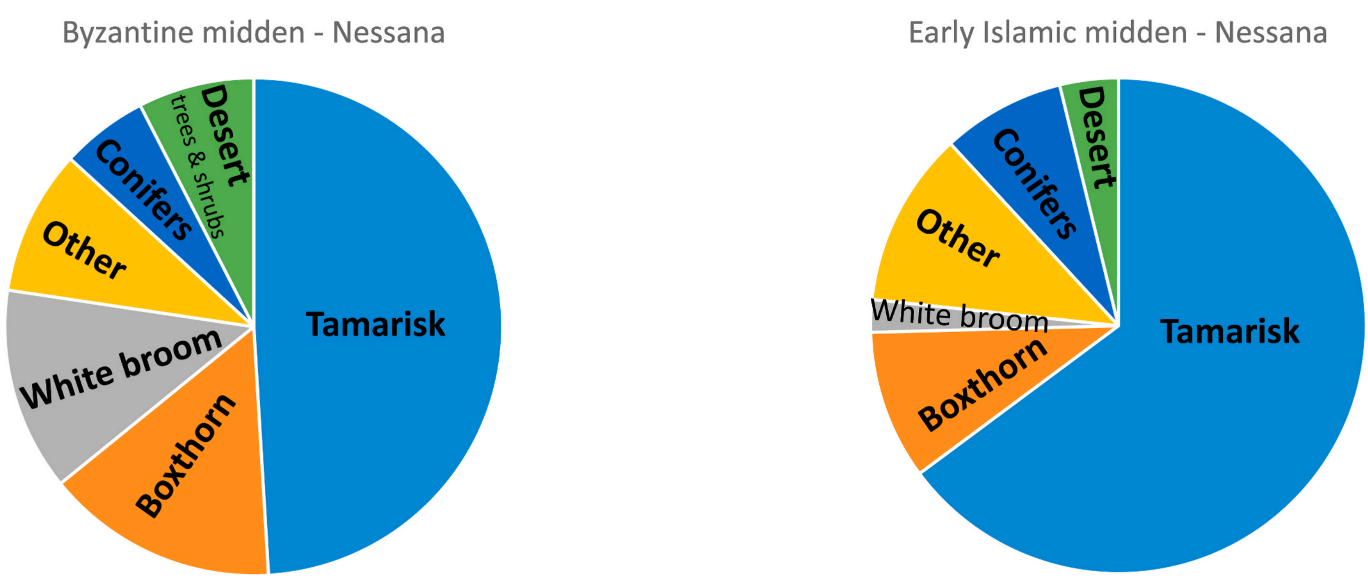

Fig. 7. Diachronic comparison of the charcoal assemblages recovered from trash mounds at Nitzana: the Byzantine period versus the Early Islamic period.

to be high-quality wood, mostly used for small and delicate objects that needed to be strong (*Buxus sempervirens* is characterized by a basic density of 0.82 g/cm^3; Crivellaro and Schweingruber, 2013: 189), or for items requiring fine workmanship. Wooden objects made of boxwood were also identified at Nitzana (Colt, 1962: 57–59; Liphschitz, 2007: 136–137). In any case, the presence of the wood as well as charcoal remains of imported luxury boxwood and beech may point to long-distance trade connections and to the presence of inhabitants of relatively high socioeconomic status at both Shivta and Nitzana.

4.1.3. *Horticulture*

The general assumption in anthracological studies is that the presence of wood-charcoal remains from fruit trees at a site indicate their cultivation in the vicinity (Lev-Yadun, 2007; Liphschitz, 2007: 103–104,

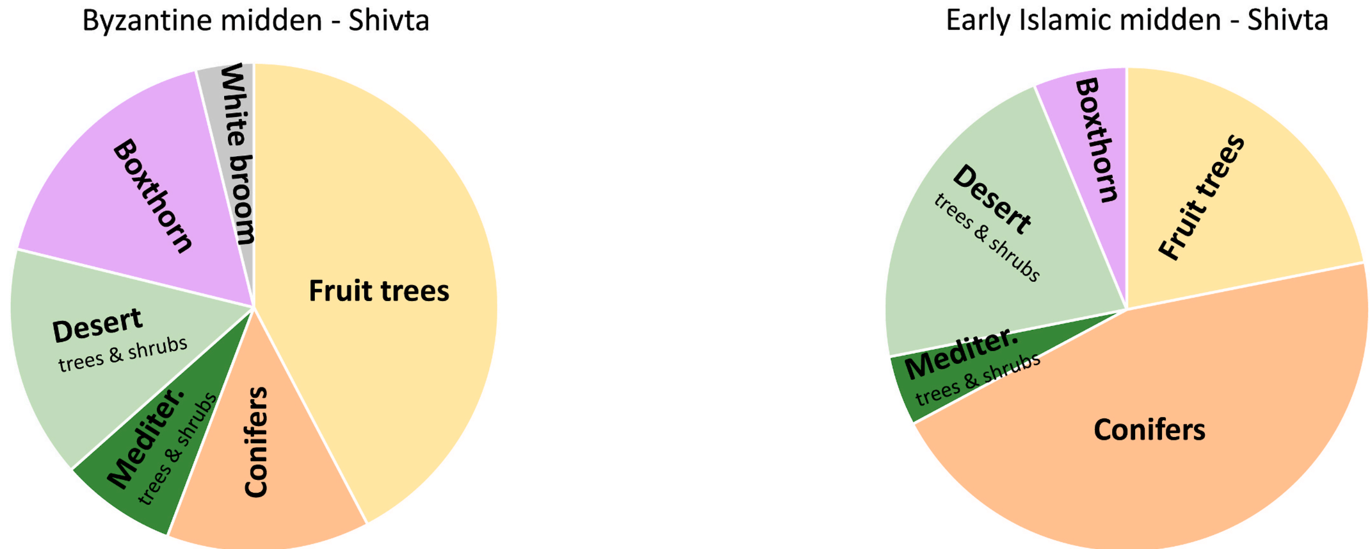

Fig. 8. Diachronic comparison of the charcoal assemblages recovered from trash mounds at Shivta: the Byzantine period versus the Early Islamic period. Tamarisk was excluded for a better representation of the fruit trees. Complete data are reported in Supplementary Material 1.

108). The pollen of fruit-tree taxa that was recovered from Shivta provides direct evidence of fruit-tree cultivation in the environs of the site. This assumption is chiefly supported by the pollen occurrence of fruit-tree taxa characterized by low pollen-dispersal efficiency (e.g., grapevine and carob) and by the presence of pollen of the non-local hazelnut.

Ten taxa of fruit trees were found within the charcoal assemblages and/or palynological spectra. Aside from doum palm and date palm (the latter with much tastier fruit than the former), both of which are typical desert species, most of the fruit-tree taxa encountered were characteristic of the southern Levant Mediterranean flora, with the exception of the exotic hazelnut. Evidence of the diverse horticulture of the Byzantine Negev villages is attested by the remains of the following common Levantine fruit trees: grapevine, fig, olive, carob, almond/apricot, sycamore fig and pomegranate.

Among the fruit-tree remains, there is no doubt that the presence of both the pollen and the charred wood of *Vitis* is especially interesting. Both proxies are usually underrepresented in archaeobotanical records (e.g., Fuks et al., 2020). Previous excavations revealed the presence of three large winepresses at Shivta (Mazor, 2009). *Vitis* is also well-represented at Shivta in the form of large quantities of grape pips, including some peduncle and epidermis remains (Fuks et al., 2016, in press). *Vitis* botanical remains were also recovered from dovecotes near Shivta (Ramsay and Tepper, 2010; Ramsay et al., 2016). The Nitzana papyri (6–7th centuries CE) provide information about the existence of vineyards around Nitzana (Kraemer, 1958). Other monastic references (4–6th centuries CE) mention the vineyards of the Negev in direct connection with winemaking, illustrating that grapevine cultivation was a preferred agricultural activity (Mayerson, 1962, 1985; Lantos et al., 2020), most probably related to the exportation of the famous "Gaza wine" (Mayerson, 1985; Safrai, 1994: 131; Fuks et al., 2020). *Vitis* pollen is totally absent from the sediment section that was assumed to represent the last phase of use of the northern reservoir (ca. 85–100 cm; Fig. 4). According to Tepper et al. (2018a), these sediments were embedded in the water reservoir toward the end of the Byzantine–beginning of the Early Islamic periods. We therefore suggest that the main viticulture activity at Shivta took place during the 5–6th centuries CE. At the beginning of the 7th century CE viticulture probably diminished dramatically and may have even disappeared, as is also evident by the total lack of *Vitis* charcoals from Shivta's Early Islamic assemblages. Recently published datasets of grape pips and ceramics from Byzantine-Early Islamic Negev settlements, also illuminate the rise and fall of local viticulture in the 4–6th centuries CE (Fuks et al., 2020).

The charcoal remains and pollen of fruit-tree taxa, such as olive, fig, carob, date, almond/apricot, hazelnut and pomegranate, most probably represent cultivation for local consumption. Indeed, no olive oil presses were clearly identified at Shivta and Nitzana and olive charcoal remains are totally absent from the latter site. In addition to pollen and charcoal remains of fruit trees, the following fruit remains were recovered from Shivta and its environs: fig, olive and date (Ramsay and Tepper, 2010; Fuks et al., 2016; Ramsay et al., 2016). At Nitzana, Liphschitz (2004: 115) identified fruit remains of almond, olive, date, peach and walnut.

4.1.4. Ornamental gardening

We propose that several trees and shrubs may have been associated with ornamental gardening in addition to the use of some of them for construction and horticulture. As previously suggested, in the southern Levant (and beyond) ornamental trees that were recovered from gardening contexts and whose remains were identified in this study include cypress, pine and olive (Langgut et al., 2015b; Langgut and Gleason, in press), willow, fig and poplar (Langgut et al., 2013), date palm (Kisilevitz et al., 2017; Langgut and Gleason, in press), grapevine (Langgut et al., 2013) and the exotic trees cedar of Lebanon (Benzaquen et al., 2019; Langgut and Gleason, in press) and hazelnut (Langgut et al., 2015b). The use of non-indigenous trees in prestigious ornamental gardening has a long tradition in the region (e.g., Langgut, 2017).

Recently at Shivta, adjacent to the northern church, an interesting gardening context that includes garden soil, several terraces and a sophisticated irrigation system was exposed (Tepper, 2019a). The palynological spectra recovered from the garden soil and from plaster layers of a water tunnel (Table 2) were composed of wind-pollinated species such as cypress, olive, pine, date palm, willow, ash and hazelnut. The spectra also included taxa characterized by relatively low pollen-dispersal efficiency such as grapevine, carob, true myrtle and *Bunium* pollen type. This observation may indicate the actual cultivation of these taxa in the garden. *Bunium* pollen type includes species such as garden parsley and dill. The pollen assemblage may therefore suggest that this garden was not only ornamental, but also incorporates fruit trees and some edible herbs and condiments for local consumption.

There is no doubt that the presence of true myrtle is one of the most interesting observations that emerged from this garden. Because of its deep evergreen color, fragrant white flowers and amenity to clipping to form a hedge, since ancient times, the myrtle has been (and still is) a key feature in ornamented gardens in the southern Levant (Langgut et al., 2013; Kisilevitz et al., 2017; Benzaquen et al., 2019; Langgut and Gleason, in press) and throughout the Mediterranean sphere (for instance, in the western Classical world; Langgut and Gleason, in press and references therein). The plant was also known for its medicinal properties (Zilkah and Goldschmidt, 2014; Dafni, 2016; Langgut et al., 2016b). Yet, its use as a ritual plant in Christianity (Dafni, 2016), may be the most relevant role of this plant in the current archaeological context – a domestic ornamental garden adjacent to a church, probably within a monastery (for further discussion about the identity of that complex, see: Tepper, 2019a).

The establishment and maintenance of ornamental plants in this remote desert landscape required specialized gardeners who took care of the necessary drainage, irrigation and probably fertilization systems in addition to ensuring that the right soil would be used as garden soil. The gardeners also had to be acquainted with the conditions essential for the non-local trees and shrubs to thrive in the desert environment. Therefore, it seems that both great knowledge was required and major investments were required for sustaining plants outside their natural habitat, especially in the case of demanding exotic plants such as the cedar of Lebanon (Fig. 6a–c). But the most important conclusion that emerges from the presence of this domestic-ornamental garden is that the inhabitants of Shivta were able to maintain a flourishing ornamental garden in such a harsh arid environment (Fig. 9). The inhabitants were not only engaged in successful sustainable agriculture enterprises but also, they were able to devote some water to sustaining a luxurious garden.

4.1.5. *Summary of the suggested wood uses*

As was demonstrated above, the tree taxa that were recorded in this study were usually utilized for more than one purpose (Table 3). The integration of the two different archaeobotanical methods, palynology and anthracology, enables us to draw a more detailed and accurate picture of the natural and cultivated arboreal environment of sites (e.g., Asouti and Austin, 2005; Langgut et al., 2019). For example, it was previously suggested that the remains of wood and charcoal of cedar of Lebanon at Shivta are an indicator of the importation of prestige beams and/or luxury wooden objects from northern regions (e.g., Hirschfeld and Tepper, 2006; Sitry and Langgut, 2019). However, the identification of *Cedrus* pollen from various contexts at Shivta in this study clearly points to the actual cultivation of the tree at the site (Fig. 6a–c). Pollen of cedar is totally absent from the recent pollen rain (Table 2, sample no. 33) and from slightly later pollen assemblages (Early Islamic, Dunseth et al., 2019). We therefore ruled out the possibility of long-distance pollen transportation. Still, it seems to us, based on the physiology of the cedar of Lebanon, that the trees were grown in small numbers as ornamentals for prestige and not to supply timber for construction. In addition, anthracology, compared to palynology, has the advantage that it can detect insect-pollinated species (e.g. Rosaceae taxa) that are underrepresented in palynological studies (Deckers et al., 2009), as demonstrated also in this study.

Fig. 9. Suggested reconstruction of the prestigious garden adjacent to the northern church at Shivta. Drawn by Y. Korman.

Table 3
A summarization of the possible use/uses of the identified tree taxa recovered from Shivta and Nitzana.

	Taxon	Presence			Suggested uses					
		Pollen	Charcoal	Wood[1]	Construction	Fuel	Fruit consumption	ornamentation	Wooden objects	others
1	*Buxus sempervirens* (boxwood)[2]		*	*					*(reel, button, slat, combs, coil, box)	
2	*Calotropis procera* (apple of Sodom)		*			*				
3	*Capparis spinosa* (caper bush)		*			*				
4	*Cedrus libani* (cedar of Lebanon)	*	*	*	*			*	*(board, bolt case, spindle whorl, ladder)	
5	*Ceratonia siliqua* (carob)	*					*	*		
6	*Corylus* spp. (hazelnut)	*					*	*		
7	*Crataegus* spp. (hawthorn group/Maloideae)		*							
8	*Cupressus sempervirens* (Italian cypress)	*[3]	*	*	*			*	*(boards)	
9	*Fagonia mollis* (fagonia)		*			*				
10	*Ficus carica* (common fig)		*				*	*		
11	*Ficus sycomorus* (Sycamore fig)		*		*		*			
12	*Fraxinus excelsior* (European ash)	*[4]	*					*	*	
13	*Juniperus phoenicea* (Phoenician juniper)		*		*					
14	*Hyphane thebaica* (doum palm)		*				*		*	
15	*Lycium* spp. (boxthorn)		*			*				
16	*Moringa peregrina* (Ben tree)		*	*					*(cylindrical Boxes)	
17	*Myrtus communis* (true myrtle)	*	*					*		rituals?
18	*Olea europaea* (olive)	*	*		*	*	*	*		
19	*Phoenix dactylifera* (date palm)	*	*		*		*	*		
20	*Pinus halepensis* (Aleppo pine)	*	*		*			*		
21	*Pistacia atlantica* (Persian turpentine)		*			*				
22	*Pistacia palaestina* (terebinth)		*						*	
23	*Platanus orientalis* (oriental plane)		*					*		
24	*Populus euphratica* (Euphrates poplar)		*	*	*			*	*(handle)	
25	*Prunus* spp. (dulcis/armenica)		*				*			
26	*Punica granatum* (pomegranate)		*				*			
27	*Quercus calliprinos* (Kermes oak)		*		*					
28	*Retama raetam* (white broom)		*			*				
29	*Rhamnus* spp. (buckthorn)		*			*				
30	*Salix* spp. (willow)	*	*					*		
31	*Salsola tetandra* (saltwort [tetandra])		*			*				
32	*Salsola vermiculata* (Mediterranean saltwort)		*			*				
33	*Tamarix* spp. (tamarisk)	*	*	*		*			*(doorframe, joint, box's cover, stopper)	
34	*Vitex agnus-castus* (chaste tree)		*			*				
35	*Vitis vinifera* (grapevine)	*	*				*	*		
36	*Ziziphus/Paliurus* (jujube/ Jerusalem thorn)	*	*	*		*			*(board)	
37	*Zygophyllum dumosum* (bushy bean caper)	*	*			*				

Remarks: (1) All samples identified in this study were carbonized; wood within this table relates to wooden objects and fragments of wooden objects that were previously studied (Shivta: Hirschfeld and Tepper, 2006; and Sitry and Langgut, 2019; Nitzana: Liphschitz, 2007: 136–37). (2) On this tree list, *Buxus sempervirens* is the only element that we suggest did not grow in the vicinity of the villages of Shivta and Nitzana; its presence in the wood and charcoal assemblages relates to the importation of luxuries and/or delicate wooden artifacts. (3) Palynologically, *Cupressus* and *Juniperus* pollen cannot be distinguished from each other. Yet we believe that this pollen taxon is more likely to derive from *Cupressus*, mainly because of its intensive use during the Classical periods for construction, crafts and ornamentation (Liphschitz, 2007: 34–46, 120–24, and references therein; Langgut et al., 2015b; Roth et al., 2019). (4) Pollen of *Fraxinus* cannot be identified to the specie level. Two charcoal samples of the exotic *Fraxinus excelsior* were recovered from Nitzana.

4.2. The prosperity and demise of the Byzantine Negev villages as reflected by their tree and shrub environment

Several components within the wood and pollen assemblages clearly reflect the flourishing of the Byzantine Negev villages of Shivta and Nitzana: (1) The evidence of diverse fruit-tree horticulture mainly for local consumption; (2) The successful viticulture for local consumption and for export ("Gaza wine"); (3) The cultivation of conifer trees as well as other southern Mediterranean trees common to the more humid Mediterranean vegetation zone that require significant irrigation in the Negev Desert environs; (4) The importation of luxury wooden artifacts that point to long-distance trade connections, and above all; (5) The ability to allocate water and labor, not only for horticultural and construction purposes, but also for ornamentation (Fig. 9). The exotic cedar of Lebanon is a case in point since the cultivation of this prestige northern Levantine tree in a desert landscape indicates that the inhabitants of the Byzantine settlements had the ability and knowledge to sustain trees dramatically outside their natural habitats and ecology (Fig. 6a–c).

Based on several lines of evidence, the demise of the Byzantine Negev society is also reflected in the arboreal remains. We identified in this study, for the first time, indicators pointing to overexploitation of the woody natural nearby desert environment for fuel. This is particularly noticeable with taxa such as white broom, which provides high-quality fuel material, and which became depleted during the Early Islamic period (Figs. 7 and 8). We therefore claim that in addition to previous suggestions regarding the possible explanations for the demise of these desert communities, overexploitation of the natural vegetation should also be taken into account as one of several factors that operated simultaneously. The higher ratios of conifer charcoals in the Early Islamic period at Shivta and Nitzana may suggest that craft items and architectural elements from abandoned houses and installations were being burned as a means to compensate for the over-exploitation of natural fuel sources.

Another line of evidence regarding the decline of the Byzantine Negev agricultural communities derives from the sedimentological and palynological indicators identified at the northern reservoir in Shivta. Laminated silt sediments had accumulated on the floor of that reservoir (130–180 cm; Fig. 5), indicating a lack of cleaning. Cleaning was a common practice in the maintenance of Byzantine water cisterns as indicated by the textual evidence (Youtie, 1936; Segal, 1983; for further discussion see: Tepper, 2019b). The absence of organized reservoir cleaning may represent a change in the social-administrative organization of the site. The same change was identified at Halutza regarding the cessation of organized garbage disposal, though it was dated to several decades earlier, as early as the mid-sixth century CE (Bar-Oz et al., 2019). The upper part of the homogenous sediment section, which covers the laminated interval (85–100 cm) represents the last days of the use of the reservoir (Tepper et al., 2018a; Tepper, 2019b), and is characterized by a total absence of grapevine pollen (Fig. 4). We therefore suggest that toward the last years of the Byzantine occupation at Shivta, the flourishing viticulture enterprise reached its end. This suggestion is corroborated by the lack of grapevine charcoals from the Early Islamic assemblage at the site. This decline can also be seen from the abandonment of houses within the sites (Tepper et al., 2015, 2018a) and of the dovecotes around the sites (Hirschfeld and Tepper, 2006; Tepper et al., 2018b).

The cessation of the successful viticulture industry in the periphery of the Byzantine Empire may be linked to events that occurred in other areas of the empire. The Justinian Plague pandemic, which began in ca. 541 CE and continued until 750 CE (Stathakopoulos, 2004; Harbeck et al., 2013) was responsible for a dramatic demographic decline (although mortality rates have been greatly debated; e.g., Whittow, 1990; Mordechai et al., 2019), coupled with crop failure as a result of drier and cooler climate conditions (Büntgen et al., 2016), led to a decrease in the purchasing power of the imperial centers of Byzantium, among them “Gaza wine”. Another natural catastrophe that may have been linked to the decline in purchasing power were the major volcanic eruptions that took place in the 530s and 540s CE (Sigl et al., 2015; Büntgen et al., 2016; Dull et al., 2019). The outcome of the intense volcanic activity was anomalously cold summer temperatures that persisted in much of the Northern Hemisphere throughout the 540s (Sigl et al., 2015; Büntgen et al., 2016; Helama et al., 2018; Dull et al., 2019). These indirect factors contributed to the weakening of the international ties of the Negev with trade networks of the Byzantine Empire (Bar-Oz et al., 2019; Fuks et al., 2020).

During the Early Islamic period, the arboreal economy of Shivta and Nitzana reflected a different pattern: In addition to the decrease of high-quality wood fuel sources such as white broom and boxthorn (Fig. 7), the charcoal assemblages point to declining frequencies of fruit trees (in addition to grapevine), indicating the diminishing horticultural component of the economy (Fig. 8). A profound change in the subsistence economy of these agricultural communities is also evident from the zooarchaeological record. The new findings of Marom et al. (2019), recovered from the same middens, indicate an increase in sedentary herding activities and exploitation of wildlife resources. Evidence that dung pellets were burned in Early Islamic Nitzana’s trash mounds, also confirms that the inhabitants were increasingly involved in herding and that dung was no longer used (or at least to a much lesser extent) to fertilize agricultural fields, but probably as fuel (Butler et al., in press). The large assemblage of rodent remains accumulated just above the destruction layers of dovecotes in the hinterland of sites further demonstrates the reduced anthropogenic impact of the post-Byzantine inhabitants (Fried et al., 2018). These studies show decreased economic viability of agriculture and to overexploitation of the nearby environment.

The change in the subsistence economy is also palynologically evident in other regions of the southern Levant (Palmisano et al., 2019). For example, pollen diagrams from the Dead Sea indicates a dramatic decline in olive pollen ratios between the Byzantine and the Early Islamic period, reflecting the abandonment of olive orchards in the Judean Highlands (Neumann et al., 2010: Fig. 2).

4.3. Paleoenvironment and sustainability

Discussion of the prosperity of the Byzantine agricultural communities in the Negev Desert always leads to the question of whether to attribute this anomaly to human ingenuity – the innovation of extremely efficient water-harvesting technologies – or to the prevalence of more humid conditions in the area. Although we cannot provide a direct answer, the results of this study suggest that a society that could sustain not only flourishing agriculture but could also manage to devote water for ornamental purposes, was a luxury society rather than one that was living in a mode of struggle for survival in a challenging environment. Yet since we found the remains of typical desert plants in this study, especially shrubs such as *Zygophyllum*, it is clear that even if there had been a somewhat less arid phase, the region was still a typical desert. The reconstructed rainfall amounts, based on the Soreq Cave (Judean Highlands) speleothem isotopic record, show some increase in precipitation between ca. the beginning of the 4th century CE and the mid-6th century CE (Orland et al., 2009: Fig. 6). The source of the precipitation at the Soreq Cave area is the Mediterranean climate system, which also partially influences the region studied in this research. Almost at the same time, slightly higher reconstructed Dead Sea Levels are manifested, representing a rise in precipitation at the Dead Sea drainage basin (Bookman [Ken-Tor] et al., 2004; Migowski et al., 2006; for the borders of the basin see Fig. 2). Towards the beginning of the 7th century CE, these local paleoclimate records indicate that a shift to somewhat more arid conditions occurred, most probably similar to present climate conditions. This arid trend is also textually evident from the historical correspondences from the Nessana archives indicating episodes of drought (Mayerson, 1983: 252, 1994: 197–203).

The comparison between the charcoal assemblages of the Byzantine and the Early Islamic periods (Figs. 7 and 8) demonstrates how the Negev Desert serves as an ideal environmental recorder due to its enhanced sensitivity and delicate ecological balance. This led to better visibility of changes in natural and cultured arboreal vegetation. The ability to sustain flourishing agricultural communities in the desert, as is so vividly expressed by the botanical remains identified in this study, bears important implications for present-day concerns about sustainability. This is significant especially on the fringe areas of the Mediterranean Basin, with predictions of profound global warming within the next decades contributing to the expansion of arid regions. The results of this study demonstrate that the desert can be quite productive if the land is sympathetically managed. Indeed, modern experiments in the Negev have also confirmed the ability of this desert to sustain agriculture. For example, stone removal from hillsides increases water run-off by almost 250 percent (Evenari et al., 1989; Lavee et al., 1997).

5. Conclusions

The comprehensive vegetation and paleoenvironmental reconstruction that has emerged from this study has helped address historical questions that are also pertinent to the 'Anthropocene' 21st century. These questions relate to the existence of flourishing societies in challenging environments, overexploitation of the natural environment, and unsustainable practices. The charcoal assemblages and the palynological spectra recovered from the Negev Desert villages of Shivta and Nitzana, which were inhabited during the Byzantine and Early Islamic periods and that were the focus of this study, enabled us to conclude as following:

1. During the 5–6th centuries CE flourishing agricultural communities existed on the periphery of the Byzantine Empire, in the Negev Desert, though distant from the imperial centers of power in the north. The exceptional success of these desert villages is richly expressed by the abundant botanical assemblages: (i) The diverse fruit-tree horticulture mainly for local consumption included trees such as fig, olive, carob, almond/apricot, pomegranate, date palm and the exotic hazelnut; (ii) Successful viticulture industry which was part of the exportation of the famous southern Levant "Gaza wine"; (iii) Cultivation by irrigation of conifer trees as well as other south Mediterranean trees common to the more humid Mediterranean vegetation zone, including the non-local prestige tree – cedar of Lebanon; (iv) The importation of luxurious wooden artifacts (made of boxwood for example), which point to long-distance trade connections; (v) The ability to invest both water and labor, not only for horticultural and construction purposes, but also for ornamentation initiatives. We therefore suggest that the Byzantine Negev Desert community was a luxurious society in contrast to societies living in a mode of survival in challenging desert environments. Growing cedar of Lebanon and hazel in the arid Negev Desert seems to indicate a cultural influence of the western and northern regions of the Byzantine Empire, where these trees are natural. Possibly some of the clergy arrived from there.
2. During the beginning of the Early Islamic period, a profound change in the botanical assemblages was documented. One of the most important observations that emerged from this study is the identification of indicators signifying overexploitation for fuel of the woody natural nearby desert environment. This is particularly noticeable with natural vegetation that provided high quality fuel material, such as boxthorn and white broom, which were depleted at the beginning of the Early Islamic period. We therefore claim that in addition to previous possible explanations for the demise of the Negev Desert Byzantine communities, overexploitation of natural vegetation should also be taken into account. Other changes between the Byzantine and the Early Islamic botanical assemblages point to a major transformation in the subsistence economy between the two periods, specifically a dramatic decrease in horticulture, coupled with the cessation of the successful Byzantine viticulture.
3. This study demonstrates how the combination of data originating from two different archaeobotanical proxies (anthracology and palynology), has enabled us to arrive at a more detailed and accurate reconstruction of vegetation. This reconstruction, which integrates wood-charcoal rich assemblages and well-preserved pollen spectra, provides independent evidence of the rise and fall of the prosperous Byzantine sustainable agricultural communities that for centuries occupied a marginal and challenging arid area of the empire.
4. The Negev Desert serves as an ideal research area not only because botanical remains and wooden objects are well preserved in this dry region. It also functions as an ideal environmental recorder due to its enhanced sensitivity and delicate ecological balance, which led to better visibility of even small changes in the natural and cultured vegetation.

Declaration of competing interest

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

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.quaint.2020.08.056.

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