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Landscape use and fruit cultivation in Petra (Jordan) from Early Nabataean to Byzantine times (2nd century BC - 5th century AD)

CHARLENE BOUCHAUD¹, CHRISTIANE JACQUAT², DANIELE MARTINOLI³

¹ AASSP, UMR 7209, CNRS/MNHN, Sorbonne Universités, CP56, 55 rue Buffon, 75005 Paris, France, e-mail: charlene.bouchaud@gmail.com

² Department of Plant and Microbial Biology, University of Zürich, Zollikerstrasse 107, 8008 Zürich, Switzerland

³ IPNA, University of Basel, Spalenring 145, 4055 Basel, Switzerland

Abstract Archaeobotanical analyses of charred seeds, fruit and wood charcoal from the residential part of the ez-Zantur area at Petra, Jordan, provide new data on the agricultural economy and use of the landscape in this famous merchant Nabataean city from the middle of the 2nd century BC to the beginning of the 5th century AD. The study is based on analyses of 7,499 whole and fragmented seeds, pips and fruit stones and 624 charcoal fragments sampled from household deposits. The results show that the food supply was based on common Mediterranean cultivated taxa such as cereals (*Hordeum vulgare*, *Triticum aestivum/durum*), pulses (*Lens culinaris*) and fruit (*Olea europaea*, *Ficus carica*, *Vitis vinifera*), which were probably cultivated both in the city and its hinterland. The by-products from the processing of cereals and fruit trees played a significant role in fuel supply, supplementing woody wild plants obtained from rocky slopes and the desert valley. The variety of fuel resources shows a major capacity to manage complex supply networks and perhaps the rarity of natural woodland cover. The existence of orchards within the city centre and notably olive groves is indicated in the Early Nabataean period

(mid 2nd century to mid 1st century BC) but they expanded during the Classical Nabataean period (mid 1st century BC to 1st century AD), probably reflecting specialised fruit growing. Unusual plant remains such as *Prunus armeniaca* (apricot), *P. persica* (peach) and *Juglans regia* (walnut) are considered to be social indicators of prosperity. These archaeobotanical results fit with others from this region and match with the urbanization and social dynamics of the city of Petra.

Keywords *Seed and fruit analysis · Wood charcoal analysis · Petra · Antiquity and Late Antiquity · Fruit growing · Fuel management*

Introduction

One of the most complete descriptions of Petra, Jordan, is attributed to Strabo who reports the Athenodorus of Tarsus' account at the end of the 1st century BC: "*The metropolis of the Nabataeans is Petra, as it is called; for it lies on a site which is otherwise smooth and level, but it is fortified all round by a rock, the outside parts of the site being precipitous and sheer, and the inside parts having springs in abundance, both for domestic purposes and for watering gardens.*" (*Geographia* XVI.4.21, Jones 1961) (Fig. 1). This sentence introduces two important aspects about Petra and its ancient inhabitants: the hilly character of the place due to the successions of sandstone and limestone rocks (Besançon 2010; Beckers et al. 2013) and the ability of the Nabataean tribes to manage their territory. However, while Petra is especially known for its role as a trading centre and its impressive architecture (Netzer 2003; McKenzie 2005), the daily life and relationships of the occupants with their environment remain poorly understood. More specifically, the role of crop growing within the city itself has rarely been examined, especially given the lack of material evidence and analyses. Issues relating to agricultural economy and landscape management have mainly been addressed through archaeological surveys and the study of the water management systems (Oleson 1995; Lavento et al. 2004, 2007; Al-Salameen 2005; Bellwald 2006; Kouki 2009, 2012, 2013; Knodell and Alcock 2011; Tholbecq 2013) or geographical approaches (Gentelle 2009; Besançon 2010). Bioarchaeological studies remain limited (Studer 2002, 2007; Studer and Schneider 2008; Tholbecq et al. 2008; Ramsay and Bedal 2015). Our study aims to understand new economic and territorial aspects of Petra by focusing on charred plant remains (fruits, seeds and wood) found in the ez-Zantur area. Ez-Zantur was a residential

quarter located in the city centre, which consisted of several buildings and domestic facilities that were occupied from at least the mid 2nd century BC to the beginning of the 5th century AD (Fig. 1). The excavations were conducted from 1988 to 2001 by the Classical Archaeology Department of the University of Basel and directed by R. A. Stucky and B. Kolb under the authority of the Swiss-Liechtenstein Foundation for Archaeological Research Abroad (Bignasca et al. 1996; Schmid and Kolb 2000; Grawehr and Keller 2006). The ez-Zantur excavation has provided the most important discoveries on the domestic and residential lifestyles in Petra to date. Archaeobotanical analyses conducted in this area provide new data on farming and use of the landscape in and around the city from the mid 2nd century BC to the early 5th century AD and offer new insights about how the Petra inhabitants supplied themselves with food and fuel in such a craggy and arid landscape.

Regional setting, vegetation and chronology of Petra

Geographical setting

The Petra region, Ma'an Governorate, Jordan, is located between the arid plains of wadi Arabah and the desert steppes of the Transjordanian plateau, in the mountainous region of Edom. The very large site of Petra is composed of a succession of granites and metamorphic bedrock, Palaeozoic sandstone formations dissected by deep gorges and canyons between about 600 - 1,100 m a.s.l. and Cretaceous limestone above 1,100 m a.s.l. (Fig. 2; Beckers et al. 2013). Climatic conditions of the southern Levant have generally remained unchanged since the mid Holocene (Rambeau 2010; Finné et al. 2011). Rainfall is irregular and mainly occurs during winter. Eastern summits such as jabal Shara have the highest precipitation, 350 to 400 mm/year. At the altitude of the centre of Petra, 860-940 m a.s.l., annual rainfall reaches 150-200 mm and the mean annual temperature is about 15 °C. Arid conditions, with very low rainfall (50 mm/year) and high mean annual temperature (25 °C) prevail over the lowlands of the wadi Arabah. As a result, the region is characterized by heterogeneous landscapes, and the transition from the semi-arid zone with wooded Mediterranean steppes to arid desert occurs over less than 40 km east to west, offering large plant diversity,

although the modern landscape has been considerably affected by human activity and climatic erosion processes (Lücke 2008). Sporadic *Quercus ithaburensis* and *Q. calliprinos* (deciduous and evergreen oaks), together with *Pistacia atlantica* and *P. palaestina* (pistachios) are evidence of a more widespread Mediterranean woodland above 1,200 m in the past. The lower levels have scattered *Juniperus phoenicea* (Phoenician juniper) and shrubby plants, mainly *Retama raetam* and *Thymelaea hirsuta*. Sudanian and Sahara-Arabian vegetation, characterized by desert bush vegetation and scattered *Acacia tortilis* ssp. *tortilis*, *A. tortilis* ssp. *raddiana* (acacias) and *Tamarix aphylla*, *T. negevensis* and *T. palaestina* (tamarisks), occur in the lowlands (Ruben 2006; Hunt et al. 2007; Besançon 2010; Beckers et al. 2013).

Agricultural potential

The hilly and dry conditions around Petra made farming quite difficult. The soils are mostly shallow and poor in nutrients. Red Mediterranean soils, terra rossa, on limestone bedrocks are sporadically present on the highest summits, as seen on jabal ash-Shara, but torrential rains are frequent and slope run-off leaves no time for slow absorption into the soil, making it a major form of erosion. The lower exposures of the median sandstone plateau have some sandy alluvium deposits favourable to agriculture in spite of the relatively limited usable area and lower precipitation. There are also larger flat areas outside the centre of Petra, towards jebel Haroun and Beidha (Gentelle 2009; Besançon 2010). The mean annual rainfall is barely sufficient for the dry farming of cereals, but the cultivation of more demanding plants would require manuring and sometimes irrigation. Today, the rocky outcrop, now mostly dedicated to tourist activities, is used for sporadic dry cultivation of *Hordeum vulgare* (barley) and *Lens culinaris* (lentil) and a few irrigated fruit groves are found along the seasonal streams (Simms and Russell 1997; Besançon 2010; Kouki 2012, pp 103-104).

Occupation chronology in Petra and ez-Zantur

The first Nabataean occupations (4th - mid 1st century BC)

Mainly known for its Nabataean inhabitants, the prehistory of the Petra region is however much older, principally known from Pre-pottery Neolithic (Byrd 2005),

Neolithic (Gebel et al. 1997; Gebel and Hermansen 2004) and Iron Age settlements (Bienkowski 1990, 2013). The first known reference to the Nabataeans was made by Diodorus Siculus referring to the Greek expedition to Petra in 312-311 BC (*Bibliotheca Historica* XIX.94.100, Geer 1947). At this time, Petra began to play an important role in trade relationships in the southern Near East and became the major Nabataean centre (Wenning 2007). The Arab tribes living there are described as nomadic sheep and camel herders, forbidden to cultivate land or build under penalty of death (Diodorus Siculus, *B.H.* XIX.94.2-3). This account most probably follows the literary tradition of the depiction of nomads in antiquity (Graf 1990). Indeed, there is corresponding archaeological evidence of semi-permanent and permanent occupations, especially those corresponding to small structures dated to the 4th-3rd century BC found below the area of the later Qasr al-Bint in the centre of Petra (Renel et al. 2012; Graf 2013; Renel and Mouton 2013), and then during the mid 2nd to mid 1st century BC at ez-Zantur (Stucky 1995) and to the east of Jabal Numayr at the so-called Obodas Chapel (Tholbecq and Durand 2013). Distinctive Nabataean coins and pottery types were developed in the late 2nd to early 1st century BC (Schmid 2000, 2001, pp 368, 371-373). It is now accepted that while Nabataeans were largely involved in trade, part of the population was responsible for farming to provide food for the community (Fiema 1996; Kouki 2013; Tholbecq 2013). The oldest archaeological evidence of agricultural activities linked with Nabataean occupation recognized to date are a crusher structure discovered in a late 2nd - early 1st century BC layer in the ez-Zantur area, probably linked with oil extraction (Kolb and Keller 2001) and small and isolated contemporary farmsteads in the surroundings of Petra (Kouki 2012, p 110).

Classical Nabataean (mid 1st century BC to 1st century AD)

According to the classical writers, Petra was considered a royal city by the mid-1st century BC by Flavius Josephus in *Jewish Antiquities* XIV.5.1 and *The Jewish War* I.2 [125] (Marcus 1966; Thackeray 1967; Fiema and Schmid 2016). The city grew during the second half of the 1st century BC and the 1st century AD. Temples, market places, private houses, pavements and luxurious facilities such as gardens and pools were built in the city centre, while rock-built tombs and places for worship developed in and around it (Schmid 2001; McKenzie 2005;

Graf 2007; Bedal 2013, Fiema and Schmid 2016). Cisterns and subterranean channels 6-8 km long carried water from the nearest springs to the city centre and a series of holding dams was built in order to manage the flash floods which occur in winter (Al-Muheisen 1990, 2009; Oleson 1995; Bellwald 2006). Nabataean houses of various sizes and qualities, supplied with fresh water via an aqueduct system, were erected on the ez-Zantur terraces (Bignasca et al. 1996; Kolb 2007). In the surroundings of Petra, rural settlements and run-off terrace systems came into existence, as well as olive and wine presses (Lavento et al. 2007; Gentelle 2009; Kouki 2009; Beckers et al. 2013; Tholbecq 2013). The faunal data in Petra are currently available mostly for the 1st century AD and later. They show an economy similar to that of other contemporary Near Eastern settlements, based on sheep and goat herding supplemented by other domestic animals, notably camel and pig, very few hunted animals, as well as fish (Studer 2007).

Roman, Late Roman and Byzantine occupations (2nd to 7th century AD)

The annexation of the Nabataean kingdom by Rome took place in AD 106. Petra remained an urban centre until the major trade routes moved to the east and south in the 4th century AD (Fiema 2002, 2003). Wealthy houses are recognized at ez-Zantur (Kolb and Keller 2001; Kolb 2003). The severe regional earthquake of AD 363 caused a decline in the occupation of the city centre (Fiema 2002, 2003; Fiema and Schmid 2016). Some domestic rooms at ez-Zantur were destroyed and then re-built and used again during the Byzantine period until there was another earthquake that may have taken place in AD 419 (Bignasca et al. 1996). During the 5th and 6th centuries, the Byzantine city was a Christian religious centre and both carbonized Petra papyri (Frösen et al. 2002; Arjava et al. 2007; Arjava et al. 2011; Nasarat et al. 2012; Koenen et al. 2013) and survey studies (Kouki 2009; Knodell and Alcock 2011; Tholbecq 2013) underline the importance of agricultural production. A probably gradual urban decay into rural settlements happened from the 7th century until the rediscovery of the city in the 19th century (Fiema 2002).

Materials and methods

The present study is based on the plant material collected during the various excavation campaigns carried out in the ez-Zantur area between 1991 and 2002. It compiles data by various scholars from unpublished theses and dissertations (Martinoli 1997; Bouchaud 2011) and partially published works (Bouchaud 2015; Karg 1996; Jacquat and Martinoli 1999).

Sampling and identification processes

The soil samples came from four different excavation sectors corresponding to the three natural terraces of ez-Zantur (Ez I, III and IV) and one deep sounding (Ez II) (Fig. 1), dated to the Early Nabataean (mid 2nd to mid 1st century BC), Classical Nabataean (mid 1st century BC to 1st century AD), Roman (2nd to 3rd century AD), Late Roman (1st half of the 4th century) and Byzantine (early 5th century). Although the Early Nabataean period runs through the 4th century to the mid 1st century BC, the ez-Zantur samples only contain material dated to the mid 2nd to mid 1st century BC. Likewise, the Byzantine period, from the mid 4th century to the 6th century AD, is only represented here by samples from the early 5th century AD.

The archaeological layers provided 80 samples from household sediment accumulations representing dumps, pit fills, soil layers, oven fills or ashy layers, where charred material was more likely to be found. The samples all corresponded to a mixture of primary and secondary deposits; no strict primary deposit was found. The preserved plant remains are thus very meaningful for archaeoethnobotanical interpretation (d'Alpoim Guedes and Spengler 2015). The selection process of the archaeological samples was initially planned for plant macro-remain (carpological) studies and no dispersed contexts suitable for archaeoenvironmental reconstruction through charcoal analyses were sampled (Théry-Parisot et al. 2010). The sediment samples were processed by wet sieving using 6, 2 and 0.5 mm mesh sieves. When necessary, the 0.5 mm sieve residues were processed by flotation if there was a significant amount of carbonized material. The heavy fraction (6 mm) was sorted by eye to extract the wood charcoal fragments. The light fractions (2 and 0.5 mm) were sorted under a stereoscopic microscope at 10× to 40× magnification to extract small wood

charcoal fragments (only in the 2 mm fraction) and carpological remains consisting of seeds, fruits, chaff and other non-woody elements as well as non-plant remains such as dung fragments and micro-fauna. Of these, 62 samples, corresponding to 742.8 litres of sediment, contained carpological remains and 34 samples, corresponding to 275.1 litres of sediment, contained wood charcoal fragments (Table 1).

Fruits, seeds and other non-woody plant remains were identified under a stereoscopic microscope using up to 60× magnification. They were compared to illustrations in reference seed atlases (Berggren 1969, 1981; Anderberg 1994; Cappers et al. 2012) and to modern reference collections in the archaeobotanical laboratories at the Universities of Basel and Zürich and at the Museum National d'Histoire Naturelle in Paris.

Wood charcoal fragments were identified using a reflected-light microscope at 50× to 500× magnification. Archaeological specimens were compared to charcoal reference atlases (Fahn et al. 1986; Schweingruber 1990; Neumann et al. 2001) and to the modern reference collection at the Museum National d'Histoire Naturelle, Paris.

Quantification methods

The carpological analysis is based on the total number of remains, comprising whole and fragmented elements (Table 2), and the minimum number of items (MNI, Table 3) (Jones 1991; Marston 2015). For the latter, according to the fragmentation profiles from one sample to another, we consider that four fragments of *Olea europaea* (olive) endocarps, *Phoenix dactylifera* (date palm) fruit stones or *Vitis vinifera* (grape) pips represent one whole item. Although this method does not take into account the reality of each sample, it has the advantage of being easy to calculate and repeatable from one sample to another. Moreover, the remains of rachis fragments were converted into the equivalent number of caryopses; for a rachis segment of *Hordeum vulgare* able to bear one to three caryopses depending on sub-species (2 row, *H. vulgare* ssp. *distichon* or 6 row, *H. vulgare* ssp. *vulgare*), the number of remains is multiplied by two. For a segment of free-threshing wheat rachis (*Triticum aestivum* ssp. *aestivum*, bread wheat, or *T. turgidum* ssp. *durum*, hard wheat) having on average three caryopses, the number of segments is multiplied by three. A rachis segment of *T. turgidum* ssp.

dicoccon (emmer) is multiplied by two (Cappers and Neef 2012, p 388). The caryopses of *Triticum* sp. are proportionally distributed among the free-threshing wheat and the emmer caryopses. Unidentified cereal rachis fragments are arbitrarily multiplied by two. Cereal bracts, culm node and root culm fragments are excluded, since these elements would provide redundant quantitative information with respect to caryopses and rachis remains. Finally, the minimum number of items (MNI) per sample is weighted by the sample volume collected (Table 3, Figs. 3, 4). Relative abundance (NR/total number of remains or NMI/total minimum number of remains) and ubiquity proportion (number of samples where the taxa is present/total number of samples) are used to discuss the results. Furthermore, the significance of the association between the contemporary terraces or between the different periods and the cultivated groups (sum of the MNI of cereals, pulses, fruits) was tested with Fisher's exact test of independence, which is the most suitable statistical test for non-parametrical small samples. The tests were computed with the software R (R Core Team 2015).

The charcoal analysis is based on the number of remains, which corresponds to the number of identified fragments of each taxon. It appears from the number of samples and remains that the different phases and terraces are not comparable across time (see below, Table 1). In order to reduce the effect of methodological bias, only the largest assemblage, from the late Roman period, is quantitatively described with relative proportion and frequency computations, whereas the smallest ones are only discussed qualitatively.

Results

The carpological remains

The carpological assemblage consists of 7,640 items, including a mix of fragmented and whole remains. All of them are charred, except the mineralized nutlets of the Boraginaceae. 141 items (1.8 %) were not identifiable. The discrepancies in the numbers of plant macro-remains between periods and terraces are mainly explained by the differences in preservation of organic material according to excavation area and archaeological context, as well as the representativeness of the different cultural layers at ez-Zantur (Table 1). As a result, the Nabataean (number of samples, n=19; number of remains, NR=3,121)

and late Roman (n=23; NR=3,405) periods are better represented than the Early Nabataean (n=11; NR=496), Roman (n=5; NR=345) and Byzantine (n=4; NR=273) periods.

The carpological remains are represented by a minimum of 62 taxa, which have been separated into groups according to economic and/or ecological criteria. The cultivated plants group includes cereals, pulses and fruits; the wild plants group consists of weeds associated with fields and gardens, ruderals, plants from steppe, desert or woodland plant communities and other unspecific wild plants (Table 2). In order to highlight change with time, cultivated and wild plants are presented separately in the results.

Cereals

The cereals group consists of at least three different species preserved in the form of grains or by-products, *Hordeum vulgare* (hulled barley), *Triticum aestivum/durum* (bread/hard wheat) and *T. turgidum* ssp. *dicoccon* (emmer wheat). Around 65 % of the total number of remains of the grains and by-products could not be identified to species level because of poor preservation or the absence of diagnostic elements (Table 2). Cereal by-products such as rachis fragments, bracts, culm nodes and root fragments are present in small quantities through time and do not exceed 8 % of the total number of cereal remains (Ez II, Nabataean period, Table 2). They are absent from the Roman and Byzantine layers. The few badly preserved barley rachis fragments do not allow identification of *Hordeum vulgare* ssp. *distichon/vulgare* (2 row or 6 row barley). Similarly, rachis fragments of free-threshing wheat cannot be clearly attributed to *T. turgidum* ssp. *durum* or *T. aestivum* ssp. *aestivum*.

Barley and free-threshing wheat are present in each terrace and period, except in Ez I during the Roman period. The relative abundance (MNI) and ubiquity proportion of barley are more important than those of free-threshing wheat from the Early Nabataean to the late Roman period (Fig. 3). All wheat caryopses seem to belong to free-threshing wheat, but some emmer rachis nodes were recognized among the samples of the Early Nabataean and Late Roman periods.

Pulses

The pulses were quite damaged and many are identified as indeterminate Fabaceae, around 50 % of the total number of pulses remains per terrace (Table 2). Nevertheless, six species are recognized, all belonging to well-known pulses domesticated in the Near East during the Neolithic period (Zohary et al. 2012, pp 77-95). *Lens culinaris* ssp. *culinaris* (lentil) is present in all terraces and periods, except in Ez II during the Early Nabataean period and Ez I during the late Roman period. *Vicia ervilia* (bitter vetch), *Cicer arietinum* ssp. *arietinum* (chickpea), *Pisum sativum* (pea), *Vicia* cf. *faba* (fava bean) and *Vicia sativa* (common vetch) are sporadically present in smaller quantity (<2 %). All the pulses are present in Ez IV during the late Roman period.

Fruit and nuts

Potentially domesticated fruit and nuts are *Ficus* cf. *carica* (fig), *Juglans regia*, *Olea europaea*, *Phoenix dactylifera*, *Prunus armeniaca* (apricot), *P. persica* (peach) and *Vitis vinifera*. *Ficus*, *Olea* and *Vitis*, the three kinds of fruit that were the most cultivated throughout the Mediterranean basin since the Chalcolithic/Bronze Age (Tengberg 2012), are continuously present in all areas and periods at ez-Zantur (Table 2). Each of them reaches different high records of relative abundance and ubiquity proportion in the various terraces and periods. For instance, fig achenes are present in 40 % of the samples during the Early Nabataean period in Ez II and reach 35 % of the MNI of cultivated plants in Ez IV during the Late Roman period (Fig. 3). Olive, which is mainly found in the form of broken stones (98 % of the total number of olive stones, Table 2), is present in more than 60 % of the samples from the Nabataean to the Byzantine period and reaches 77 % of the MNI of cultivated plants in Ez III during Roman period (Fig. 3). Grape pips are well represented during the Nabataean period in Ez III, in which they are present in 73 % of the samples and constitute 58 % of the MNI of cultivated plants (Fig. 3). Beside these three important Mediterranean fruits, one characteristic Middle Eastern species, *Phoenix dactylifera* (date palm), is less abundant, but it is regularly found in the form of fruit stones from the Early Nabataean period. Its ubiquity proportion fluctuates from 25 to 36 % until the Byzantine period (Fig. 3). Finally, two fruit stones of *Prunus persica* and one of *P. armeniaca* as well as three *Juglans regia* (walnut) fragments were found in

domestic sediment layers associated with the Late Roman mansion in the Ez IV terrace.

The wild taxa

At least 46 taxa are potentially wild plants that are likely to have grown naturally in Petra. The majority of the plant list cannot be safely attributed to a specific ecological group because of the low identification level of most of the taxa.

Indeed, only four species are identified, whereas 32 taxa are identified to genus level, with five doubtful identifications (cf.), and ten taxa are identified to family level (Table 2). Nevertheless, some of the taxa are clearly wild plants from natural habitats and others are plants that are potential indicators of areas of human activity. Moreover, we cannot exclude that some of these wild plants might have been processed and maybe cultivated for specific purposes, such as for medicinal uses.

Two Mediterranean woody taxa (*Crataegus* sp., *Pistacia* sp.) are recognized from the Early Nabataean and Nabataean periods. Shrubby plants characteristic of desert or steppe habitats, such as *Capparis* sp. (caper) and Amaranthaceae only appear during the Nabataean and Late Roman period. Amaranthaceae seed accumulations (NR=639) are observed in four samples from the household area of Ez IV (Table 2).

Other wild plants are irregularly distributed through time and between terraces and these are only quite well represented in Ez III during the Nabataean period and in Ez IV during the Late Roman period (Table 4). The comparison of these two assemblages shows that the most frequent seeds, present in both terraces, are *Silene* sp., *Asperula/Galium*, *Melilotus/Trifolium*, *Fumaria* sp. and *Medicago* sp. These genera include common Near Eastern weeds which grow in non-irrigated winter crop fields and belong to the Secalinetea class (Zohary 1973, pp 636-643). Other less frequent taxa probably correspond to weeds, although most could also have been ruderals, growing on disturbed ground such as abandoned fields and roadsides or even coming from other habitats, as it is known that the segetal flora becomes less specific and different from the surrounding non-segetal flora as it gets closer to desert conditions (Zohary 1973). Several strictly annual or perennial ruderals are recognized (*Erodium* sp, *Malva* cf. *parviflora*, *Plantago* sp.). No specific weeds of irrigation crops were identified, apart from three genera,

Amaranthus sp., *Setaria (verticillata)* and *Heliotropium* sp., that contain species which correspond to the Panicetea hydro-segetalis class of plant communities of irrigated summer crops (Zohary 1973). The attempt to classify taxa according to phytosociological criteria (Zohary 1973, pp 636-643) appears unconvincing, mainly because of the low resolution of the dataset. After all, the most conclusive result is the change of the taxonomic spectra between the Nabataean and the Late Roman period. Indeed, 11 taxa are only represented in Nabataean layers whereas six taxa and two doubtful identifications are present only in Late Roman contexts (Table 4).

Wood charcoal analysis

The total number of wood charcoal fragments in the archaeological samples is very small, probably because of the selection process of the archaeological samples that was initially planned for seeds and fruit studies only. All the wood charcoal elements that could be collected (Number of remains, NR=624) were examined and 617 of them identified (98.9 %). Most of the fragments correspond to Late Roman layers (n=15 samples, NR=439) in Ez IV. Early Nabataean (n=10, NR=43) and Nabataean (n=9, NR=142) layers are very poorly represented and no charcoal was found in the samples from the Roman and Byzantine periods (Table 1). As wood charcoal fragments were found in the various household areas of ez-Zantur (Table 5) where no traces of fires were observed, they must be considered as fuel residues (Théry-Parisot et al. 2010). They are composed of 19 taxa classified into four large ecological communities: cultivated fruits, desert plants, open woodland and riverside woodland. The small number of charcoals analysed from the Early Nabataean and the Nabataean periods does not constitute a representative dataset for examining fuel use, and so a mainly qualitative description is given. On the other hand, the data for the Late Roman period with 15 samples and 439 fragments are described quantitatively.

Cultivated fruits

Fruit growing is represented by olive, grapevine and fig. Olive is the only one found from the Early Nabataean to the Late Roman period. It constitutes 41 % of the total number of charcoal fragments during this last period. Although no precise measurement of the wood diameters was made, it was noted that very

small pieces, less than 5 mm, were common in the assemblages. Fig wood only appears in the Nabataean period in Ez I and grapevine in the Late Roman period in Ez IV (3 % of the total number of remains).

Desert plants

Amaranthaceae shrubs and *Acacia* are two typical desert woody plants growing in sandy plains in the Near East. Charcoal fragments of these two taxa are present in all periods. *Acacia* charcoal constitutes the second dominant taxon of the Late Roman assemblage with 17 % of the total number of remains. It is also particularly present in Ez I during the Nabataean period, where it constitutes half of the total charcoal.

Open woodlands

Eleven taxa are shrubs or trees characteristic of the Mediterranean open woodland vegetation formations commonly found on Jordanian mountain slopes (Zohary 1973). Among them, four taxa are ubiquitous, *Pistacia* sp. (pistachio), *Quercus calliprinos*-type (an evergreen oak), *Juniperus* sp. (juniper) and Fabaceae (legumes). All the Fabaceae fragments have a similar anatomy characterised by the presence of vessels in an oblique to dendritic pattern together with the paratracheal parenchyma in transversal section. Furthermore, in longitudinal tangential section, vessels are weakly storied with axial parenchyma. These criteria fit well with some of the species of the subfamily of shrubby brooms (Faboideae) (Fahn et al. 1986, pp 119-125), like *Retama raetam* (white broom), which grows both in the desert areas and on rocky slopes at Petra today (Ruben 2006). Although Fabaceae fragments are ubiquitous, they constitute a small fraction (7 % of the total number of remains) during the Late Roman period, similar to juniper (2 %) and evergreen oak (0.5 %). Only *Pistacia* reaches 11 % of the total number of remains. Charcoal fragments of *Cistus* sp. (cistus), *Cupressus sempervirens* (cypress), *Pinus* sp. (pine.), cf. *Prunus* sp. and *Quercus ithaburensis*-type (a deciduous oak) are only noted during the Late Roman period and in small percentages (<3%).

Riverside woodland

Platanus orientalis (oriental plane), *Salix* sp. (willow) and *Tamarix* sp. (tamarisk) are typical trees of riverside woods which grow beside the seasonal rivers in the southern Near East. They can also be planted in irrigated gardens. Tamarisk charcoal fragments are continuously present, whereas plane and willow only reach small percentages during the Late Roman period (<2 %).

Comparison of carpological and charcoal remains

Several taxa are found both in carpological and wood charcoal assemblages (Table 6). They mainly correspond to potentially cultivated fruit, *Olea*, *Ficus* and *Vitis* and, to a lesser extent, trees and shrubs growing in their natural habitats, such as *Acacia*, *Pistacia* and *Amaranthaceae*. No other fruits of the wild trees recognized through the wood charcoal analyses have been identified in the carpological study, such as conifer cones or acorns. The woody taxa identified in the carpological study but absent from the charcoal results are *Crataegus*, *Capparis*, *Phoenix dactylifera*, *Prunus persica* and *P. armeniaca*, although the doubtful identification of ring-porous cf. *Prunus* sp. charcoal might correspond to one of the latter two fruit trees.

Discussion

Limits and meaning of the archaeobotanical assemblage from ez-Zantur

The rich and diverse plant remain assemblage from ez-Zantur gives us a unique opportunity to understand the farming and environment at Petra. However, the dataset presents several methodological biases that should be addressed in order to rule them out of the discussion.

First, a Fisher's exact test was done on the carpological results to analyse the significance of the association of the contemporary terraces according to the three groups of cultivated plants, cereals, pulses and fruit. The results show that there is no significant difference between Ez I and Ez II during the Early Nabataean period ($p=0.163$), little significant difference between Ez I and Ez III during the Nabataean period ($p=0.002$) and strong significant difference between Ez I and Ez

IV ($p < 0.05$) during the Late Roman period. However, the irregular distributions of the number of samples and remains obviously affect these results. Moreover, we assume that the stochastic effect (random process) is very high, resulting from the plant accumulation rates, sampling strategies and use practices. The same Fisher's exact test was done by adding the MNI of each category (cereals, pulses, fruits) for contemporary terraces in order to evaluate the significance of the association between the different periods. This showed that the Early Nabataean period is significantly different from the Nabataean period ($p < 0.05$) and from the Late Roman period ($p < 0.05$). Similar results were obtained by taking into account the MNI weight according to the sampled volume. These results allow us to assume that the distribution of the relative abundance and ubiquity proportion of the cultivated plants between the Early Nabataean period, on the one hand, and Classical Nabataean and Late Roman periods on the other, show two main tendencies (Fig. 6) characterized by differences in records of cereals and fruit. Cereal percentages decrease from the Early Nabataean period (64-80 % of the cumulative MNI, 80 % of ubiquity) to the Late Roman period (4-23 % of the cumulative MNI, 50-90 % of ubiquity). The fruit, especially olive, fig and grape, generally increases from the Early Nabataean period (9-16 % of the cumulative MNI, 20-40 % of ubiquity according to the species) to the Late Roman period (53-96 % of the cumulative MNI, 50-100 % of ubiquity according to the species). In parallel, detailed examination of changes in fruit values shows important species differences between terraces, independent of the chronology (Fig. 5). For instance, during the Nabataean period, olive is dominant in Ez I (36 % of MNI, 100 % of ubiquity), whereas grape dominates in Ez III (58 % of MNI, 73 % of ubiquity). We assume that this reflects differences of fruit plant use and diversity of practices, as discussed below.

Secondly, several taxa commonly found in the carpological assemblage are absent from one period or one terrace, for example free-threshing wheat and lentil are absent from Ez II during the Nabataean period and Ez I during the Late Roman period, or free-threshing wheat and barley during the Roman period. It is certain that these absences are the result of preservation and sampling effects rather than actual spatial or chronological differences. Likewise, the weak representativeness of the wild taxa during the Early Nabataean and Roman periods should probably be considered to be due to these methodological factors, even other explanations,

such as the rarity of dung use as fuel in these specific contexts, might also be involved; see below, on fuel management).

Finally, as already noted, the wood charcoal spectra are very poor, especially for the Early Nabataean and Classical Nabataean periods, and the quantitative results cannot be compared for the discussion of change over time. Only the results from the Late Roman period are discussed quantitatively to provide some insights into the sources of fuel.

The presence of a Mediterranean farming system in the Early Nabataean period

Regional inheritance and continuity

The most frequent species present at ez-Zantur are cultivated plants that are continuously present through the various occupation periods. Cereals (hulled barley and naked wheat), pulses (lentil, pea, bitter vetch) and fruit trees (olive, grape, fig, date palm) are found from the early Nabataean period and the qualitative spectra remain nearly the same during the following periods. These plants represented a common food supply for both humans and animals in the ancient Near East. The slight presence of emmer rachis could show that it was sometimes grown or it could be considered as a contaminant in the fields of free-threshing wheat (Cappers 2006, p 131). The other archaeobotanical studies conducted in ancient Petra and its hinterland show very similar plant spectra, despite the specific nature of the contexts, whether religious (Tholbecq et al. 2008), funerary (Sachet et al. 2013) or garden spaces (Ramsay and Bedal 2015), and the small number of samples in some cases (Table 7; Neef 1987, 1990). The results are very similar to those from other archaeobotanical analyses conducted in the southern Near East (Gilliland 1986; Crawford 1987, 2006; Willcox 1992, 2003; Hoppé 2012; Ramsay 2013). All of these help us to understand which crop plants were grown in this semi-arid region characterised by the growing of free-threshing wheats, hulled barley and Mediterranean fruit (Bouchaud 2015), a triad inherited from at least the Bronze Age (Tengberg 2012). It is however difficult to know whether the inhabitants of ez-Zantur cultivated the various crops themselves, and if they did, the location of the irrigated or rain-fed fields. Otherwise they might have obtained their food from another farming community.

Local farming within and outside the city centre

Several results support the idea that farming was well developed in the centre of Petra from the early beginning of the Nabataean occupation. The strong presence of fruit by-products in the form of seeds, stones and wood charcoal reveals the regular use of edible products as food and inedible by-products as fuel (see below), probably coming from neighbouring plots. This is particularly well demonstrated for the olive, from which all the different plant elements were found from each period of occupation. With the discovery of a round rotary olive crusher in the substructure of the Nabataean house of Ez IV dated to the late 2nd or early 1st century BC (Kolb and Keller 2001), these archaeobotanical data give direct evidence of farming under Nabataean and then Roman rule, contrary to Strabo's claim that no olive trees grew in the Nabataean territory (*Geography*, XVI.4.26, Jones 1961). The presence of vineyards and fig groves is also clearly shown by the regular presence of pips and wood. The rarity of the date palm fruit stones and the complete absence of trunk or leaf remains in the charcoal assemblage probably together demonstrate that dates were rarely cultivated and consumed in Petra. Perhaps date palm only grew in some specific gardens, as in the Petra garden and pool complex, where phytolith analyses have revealed its presence (Ramsay and Bedal 2015).

Secondly, the small but consistent amounts of cereal chaff, straw remains and weeds resulting from post-harvesting processing probably indicate local farming, as is the case for the regional ancient farming sites in the southern Near East, for instance at Bir Madhkur (Ramsay and Smith II 2013), or other more distant contemporary archaeological sites (Gilliland 1986; Crawford 1987, 2006; Willcox 1992, 2003; Hoppé 2012; Ramsay 2013). Nevertheless, the proportions of cereal by-products at ez-Zantur are much lower than at other farming sites, like Dharrah in the north (Bouchaud 2015) or Humayma in the south (Ramsay 2013), where charred chaff and straw constitute more than 50 % of the cereal remains. As it is highly unlikely that these by-products were not used as fuel, fodder or temper in such a semi-arid environment (van der Veen 1999), one can assume that the cereal spikes were processed elsewhere, whereas only the grains, or florets together with accidental by-products and weeds, reached ez-Zantur. One of the last stages of cereal processing, grinding, is directly demonstrated at ez-Zantur by the presence

of milling installations dated from the last few centuries BC (Grawehr 2010, pp 209-211).

Although the interpretation of the cereal assemblage is not completely conclusive, the presence of charred fruit tree and vine remains, indicates without doubt that the cultivation plots were located not far from ez-Zantur. It is highly probable that some of the inhabitants were involved in the cultivation of small fields in the neighbouring area, for instance along the various seasonal watercourses, or on the terraces in the direction of jabal Harun (Fig. 1), as is the case today, from the Early Nabataean period and during all periods of occupation. In parallel, archaeological surveys show the increasing presence of farming structures in the area around Petra during the Nabataean period that suggest that some of the foodstuffs for the inhabitants of the city centre would have been provided from there (Kouki 2012; Tholbecq 2013). It is worth considering that this was partially the case for the inhabitants of ez-Zantur, notably for the cereals, which could explain why the proportions of by-products are so low. Nevertheless, it is likely that small-scale growing of cereals and/or pulses was done under the fruit trees and vines inside the city, following the traditional examples of a Mediterranean farming system where annual and perennial plants are mixed in order to benefit each other (Eichhorn et al. 2006).

The apparent uniformity of farming, mainly based on Mediterranean fruit, free-threshing wheat and hulled barley, should be qualified by a more realistic view of its adaptation to ecological and cultural aspects that probably led to the existence of many varieties of each crop, as was always observed in the 20th century (Russell 1995, p 696). A good illustration of this view concerns the results of the morphometric study previously conducted on some of the grape pips found in the Nabataean levels of Ez III, which showed the presence of various morphotypes, some of which are wild (Jacquat and Martinoli 1999). As demonstrated in the western Mediterranean, this probably indicates the cultivation of a mixture of grape vine types, ranging from morphologically wild to domesticated, rather than harvesting practices (Bouby et al. 2013). Indeed, harvesting methods for food are almost invisible in the results from ez-Zantur, as in the other regional archaeobotanical results. For instance, pistachio fruit remains are only represented by some endocarp fragments, whereas pistachio wood seems to have been largely

used for fuel, as shown by the continuous presence of charcoal fragments (Table 5).

Fuel management: wood gathering and use of the by-products from farming and herding

The use of wild trees and shrubs was mainly for firewood rather than for food. The analysis of the wood charcoal assemblages shows the use of various vegetation types (Table 5). Woods possibly growing on rocky slopes, with pistachio, juniper and evergreen oak above 1,200 m and Fabaceae and pistachio between 800 and 1,200 m, sandy plains with acacia and Amaranthaceae and tamarisk probably growing on the banks of wadis are represented during the Early Nabataean, Nabataean and Late Roman periods, demonstrating use of various types of woody vegetation around Petra. The quantitative data from the Late Roman period show that pistachio and acacia were the main trees used and each was likely to have grown in the vicinity, the first just above the ez-Zantur terraces, such as around jabal Umm al-Biyarah, and the second on the sandy plains, such as along the wadis al-Farasah and al-Matahah (Fig. 1). The many other taxa found from the Late Roman period provide new indices of the richness of the local biodiversity of the open woodland and riverside woods, and highlight the ability of the inhabitants to manage a large variety of fuel resources. This practice is also particularly expressed through the dominant presence of agricultural waste resulting from fruit tree cultivation. The systematic discoveries of olive stone fragments and wood charcoal, among which small diameter pieces were present, result from the common practice in the Near East of the use of prunings and pressed fruitstones as fuel (Neef 1990; Warnock 2007; Marinova et al. 2011). Olive residues are still considered a high quality fuel in most of the Mediterranean countries (Nefzaoui 1988; Zabaniotou et al. 2000, Braadbaart et al. 2016) and their ubiquity at ez-Zantur perhaps suggests that they were stored to provide a permanent fuel supply. The use of grapevine remains is shown by the presence of abundant charred seed and pedicel remains in the Nabataean layers of Ez III, probably corresponding to the direct use of grapevine waste after pressing (Jacquat and Martinoli 1999; Margaritis and Jones 2006), as well as wood charcoal during the Late Roman period resulting from prunings. During the Nabataean period, the strong presence of grapevine residues in Ez III, while olive

residues dominate in Ez I, shows that there were probably various supply networks from the places of cultivation and processing according to the availability of resources. In addition to wild woody plants and by-products from cultivated plants, the presence of charred sheep or goat droppings (Table 2) would show their use as fuel. Livestock were probably kept in Petra centre since the Nabataean population began living inside the city, and so sheep and goat dung would have been continuously available (Studer 2002). Although no strict correlation is observed between the distribution of wild plants and weeds and sheep/goat dung remains, it is likely that some of the wild plants, especially the ruderal ones, reveal the original presence of dung in the samples that disappeared with carbonization (Miller and Smart 1984; Charles 1998).

The archaeobotanical results from ez-Zantur cannot be used for palaeoenvironmental reconstruction due to methodological bias. However, such studies have been conducted in wadi Faynan south of Petra and they indicate loss of woodland due to increased human activities related to copper extraction, between the Bronze Age and the Byzantine period (Barker et al. 1998; Hunt et al. 2007). In Petra, the single pollen study, made on fossil *Procapra capensis* (hyrax) middens, leads to a similar conclusion, although the small assemblage prevents generalization of the conclusion and the chronology should be revised in the light of recent research (Fall 1990). Considering the intense urbanisation process in Petra from the Early Nabataean period, and the development after the 1st century BC of specialised craft activities, like making pottery (Schmid 2000) or metalworking (Ryzewski et al. 2011), the collection of firewood would have been important. On the one hand, our results show a great diversity of plants during the Late Roman period, perhaps underlying a modest human impact on biodiversity. On the other hand, the multiplicity of the fuel resources for household consumption, notably the presence of crop by-products and dung, probably shows a certain shortage of natural woody vegetation, while demonstrating a great ability to manage collection and redistribution of fuel.

Chronology of Ez-Zantur as a reflection of the farming and economy of Petra

Toward specialization in fruit growing

The quantitative data of the plant macro-remains (Fig. 4) suggest an increase in fruit growing, especially olives and grapes, between the Early Nabataean period later in the Nabataean, Roman and Late Roman periods. The decrease in fruit remains during the Byzantine period is difficult to consider since the sampling effect is probably important; results for this period are therefore excluded from the discussion. The hypothesis of specialization in fruit growing in Petra from the Nabataean period, after the middle of the 1st century BC, must be considered, especially as other lines of evidence show the same tendencies. First, the pollen record from Petra contains its highest value of *Olea* pollen between the 2nd and 4th century AD (Fall 1990). Secondly, archaeological structures linked with oil or wine production in and around Petra developed from the 1st century AD (Al-Muheisen 1990; Zeitler 1990, 1991, 1993; 'Amr et al. 2000; 'Amr and al-Momani 2001; Al-Salameen 2005). Third, the development of complex water management systems at the end of the 1st century BC throughout the entire city (Ortloff 2005; Al-Muheisen 2009; Beckers et al. 2013) may be partly linked with the needs of farming, as this would make the cultivation of some plants easier. None of the weeds directly confirms the presence of irrigation practices, except three potential taxa (see results) that cannot be linked with precise crops, but the presence of grape remains, from a plant which needs enough water, should indicate that these crops were irrigated. Similarly, willow and poplar during the Late Roman period could represent trees that were planted in irrigated gardens rather than those growing in natural riverside woods. Specific references to Nabataean irrigated gardens are found in the description by Strabo (*Geographia* XVI.4.21, Jones 1961), in the excavation of the Petra garden and pool complex (Bedal 2013; Ramsay and Bedal 2015) and the possible gardens of the Nabataean royal residence at the foot of al-Khubthah (Schmid et al. 2012, Fiema and Schmid 2016). However, these references more probably refer to pleasure gardens (*paradeisos* in Greek) rather than ones for growing crops for food. In the area around Petra, the archaeological surveys point to well-developed run-off systems as well as cisterns and water pipes (Kouki 2012; Tholbecq 2013). The Petra

papyri found in a storage room in a Byzantine church and dated to the 6th century AD, after the chronological interval represented by the archaeobotanical remains of ez-Zantur, provide useful data on land settlement in Petra and its surroundings which have many similarities to what is proposed for the preceding periods. They show the presence of irrigated orchards and *xerokēpia* (literally dry gardens) near the houses in and around the city, vineyards on the rocky soils and sown terraced fields near the slopes to take advantage of run-off (Frösen et al. 2002; Arjava et al. 2007; 2011; Nasarat et al. 2012; Koenen et al. 2013). The scroll contents do not provide detailed information on the cultivated crops, crop rotation or potential associations of annual and perennial plants, nor any mention of olives. As it is unlikely that olives disappeared from the Petra city centre between the 5th century, when they were recorded for the last time in the ez-Zantur area, and the 6th century, it should be considered that the so-called *xerokēpia* included these trees, as well as other drought-tolerant plants, such as barley and hard wheat, possibly in rotation with lentils, as is seen in the modern traditional methods of farming (Palmer 2001). As a result, the Petra papyri, like the archaeological and archaeobotanical studies, show the permanence of complex farming systems in Petra which took advantage of the contrasting topography by choosing adapted plants and improving both water management systems and run-off farming. In parallel to the continuity of the crop selection, several archaeological elements suggest some changes to the land plots used over time. For instance, the western and eastern hinterlands of Petra show intense agricultural activities during the Nabataean period (Kouki 2012; Tholbecq 2013), but the eastern part was apparently less used during the Late Roman period, probably because of soil erosion due to human impact (Tholbecq 2013). This would probably be true as well in other parts of Petra, although the current state of knowledge makes it difficult to detect such spatial and chronological changes (Besançon 2010). If we assume that most of the wild seeds and fruits found correspond to post-harvest processing and the burning of dung, their presence in relation to their ecological qualities may indicate from where they came and the different eco-systems exploited. Sadly, the low resolution of a large part of the identified material and the non-specific ecological requirements of various taxa prevent any spatial reconstruction of the different areas used and their changes through time. Only the

radical differences in weed composition between the Nabataean and Late Roman periods (Table 4) perhaps indicate the moving of the land plots.

It is thus worth considering that urban development in Petra during the second half of the 1st century BC goes along with pronounced changes in farming which are characterised, not on the selection of new crops, but on the development of farming structures and the growing of well-known perennial fruit. None of the written data provide any indication on potential cash crops from Petra. Even if the local use of the produce was clearly the priority, we should consider that some of it, especially that from grape and olive, may have been involved in a small regional trade, invisible in the literature (Bouchaud 2015).

Prosperity of the city during the Late Roman period: the evidence from Ez IV

From the archaeological studies, it is now clearly established that there were high quality residential complexes from the Nabataean to Late Roman periods on the Ez IV terrace, and that the inhabitants were wealthier than those on the Ez I and Ez III terraces. Indeed, numerous fine rooms have been found together with a residential part, a heating system, thin pottery and glass, and sophisticated wall paintings (Kolb and Keller 2000, 2001). Furthermore, the faunal spectra from Ez IV are characterized by greater wild and domestic bird consumption than in Ez I, pointing to particular food practices (Studer 2002, 2007). The archaeobotany results show that beside the common cultivated plants found in the various terraces, three new foodstuff remains were found only in Ez IV, apricot, peach and walnut. They represent regular but very rare discoveries in the semi-arid regions of the Near East during antiquity.

Apricot and peach were probably introduced during the second half of the 1st millennium BC to the Near East from Eastern or Central Asia (Zohary et al. 2012, p 144). To date, apricot and peach records in southwest Asia have been mostly reported from Egypt in Ptolemaic and Roman sites (Germer 1985, p 61; Thanheiser 2002; Cappers 2006, p 122; van der Veen 2011, p 155). In the southern Near East, peach and a few apricot stones were found in funeral, religious, military or harbour contexts dating to Roman and Byzantine times (Mayerson 1986; Crawford 1987; Ramsay 2010; Bouchaud et al. 2011; Hoppé 2012). For walnut, pollen records (Leroy 2010; Neumann et al. 2010) and macro-

remains analyses (Zaitschek 1962; Kislev 1992; Simchoni and Kislev 2009) around the Dead Sea show the increase of its cultivation from the 4th-3rd century BC. However, walnut evidence in other areas of the southern Near East are scarce and limited (Mayerson 1986; Ramsay 2010; Bouchaud et al. 2011). The rarity of these discoveries shows that apricot, peach and walnut were uncommon foodstuffs in the Petra region, as has been suggested for Egypt (Cappers 2006, p 122; van der Veen 2011, p 155). While these fruits were possibly sporadically cultivated in Petra, for instance in irrigated pleasure gardens, they may also have been brought to the city by merchant caravans, fresh or dried with the fruit stones still enclosed for apricot and peach (van der Veen 2011, p 155). Whether they were traded or locally cultivated, these fruits are likely to represent delicacies intended for a small part of society.

Conclusions

This integrative study of carpological and wood charcoal remains from the ez-Zantur terraces in Petra offers new insights on past agricultural systems and economies through time, from the Early Nabataean period to the Byzantine period. Staple food was largely, if not only, directly obtained from local fields both near the city centre and in the surroundings, and we assume that some of the inhabitants of ez-Zantur were involved in the production and processing of crops plants during all of the occupation phases. The results show that the inhabitants of Petra, characterised by their Nabataean culture as identified from archaeological and historical evidence, followed farming methods directly inherited from the preceding periods and based on irrigated and rain-fed cultivation of hulled barley, free-threshing wheats and Mediterranean fruit, offering an adapted and durable response to environmental constraints while ensuring economic autonomy. Fuel supplies were integrated with farming, allowing complete use of pruning and crop processing waste in addition to wood gathered from plant communities on the rocky slopes and sandy plains. In parallel, the archaeobotanical results reflect the economic dynamics of the city, showing the presence of specialised fruit growing from the Nabataean period, perhaps partly intended for trade. The rare food items in the richest houses of the ez-Zantur terraces may have been obtained from orchards or by trade, and these items can be interpreted as social indicators of prosperity.

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Figure Captions

Fig. 1 Geographical settings: Top left, Location of Petra and the main archaeological sites cited in the text, from Google Maps. Top right, Aerial photograph of the ez-Zantur area, Petra, with the four excavated terraces, from Swiss-Liechtenstein Archaeological Mission. Bottom, Schematic map of Petra, location of ez-Zantur, after a map drawing by I. Sachet

Fig. 2 Schematic profile of the modern relationships between geology, topography, vegetation and climate from the western wadi Arabah to the eastern Jordanian upland and the potential origin of the main identified archaeological taxa; adapted from Beckers et al. (2013), Besançon (2010), Hunt et al. (2007)

Fig. 3 Carpological diagram, ez-Zantur, Petra. Relative abundance of minimum number of items and ubiquity proportion of the potentially cultivated plants per area and period. Abbreviations, ENab, Early Nabataean; Nab, Nabataean; Rom, Roman; LRom, Late Roman; Byz, Byzantine. For quantitative details, see Tables 1, 2, 3

Fig. 4 Carpological diagram, ez-Zantur, Petra. Relative abundance of minimum number of items and ubiquity proportion of the various categories of cultivated plants per area and period. Abbreviations, ENab, Early Nabataean; Nab, Nabataean; Rom Roman; LRom Late Roman; Byz, Byzantine; n, Number of samples; MNI, Minimum number of items

Table 1 Quantitative data according to the different types of plant remains per period and terrace at ez-Zantur. Abbreviations, ENab, Early Nabataean; Nab, Classical Nabataean; Rom, Roman; LRom, Late Roman; Byz, Byzantine

Table 2 Carpological data from ez-Zantur, Petra, total number of remains (NR) and ubiquity (Ub, number of samples where the taxon is present); Abbreviations, ac, achene; end endocarp; fgt, fragment; gl, lemma/palea fragment; mer, mericarp; ped; pedicel; k, kernel; nut, nutlet; rac, rachis fragment; s, seed; sf, spikelet fork. For chronology and further abbreviations, see Table 1

Table 3 Carpological data from ez-Zantur, Petra, minimum number of items (MNI) and minimal number of items weighted by volume (MNIw) per period and terrace; for chronology and further abbreviations, see Table 1

Table 4 Distribution of the wild plants found in Ez III during the Nabataean period (Nab) and Ez IV during the Late Roman period (LRom) according to modern weed communities and life cycles (Zohary 1973). a, annual; b, biennial; p, perennial. The doubtful taxa (cf.) are excluded

Table 5 Charcoal results of ez-Zantur, Petra. ENab, Early Nabataean; Nab, Classical Nabataean; LRom, Late Roman; NR, Number of remains; Ub, Ubiquity; C.I., precision of the Confidence Interval (95%)

Table 6 Taxa identified through carpological and wood charcoal analyses. ENab, Early Nabataean; Nab, Nabataean; LRom, Late Roman; c, carpological results; a, anthracological results

Table 7 Distribution of the main cultivated plants from several archaeological sites in the Petra region, according to the estimation of the minimum number of plant macro-remains proportions recovered. x, present; xxx, abundant; +, no available quantitative data

Figure 1

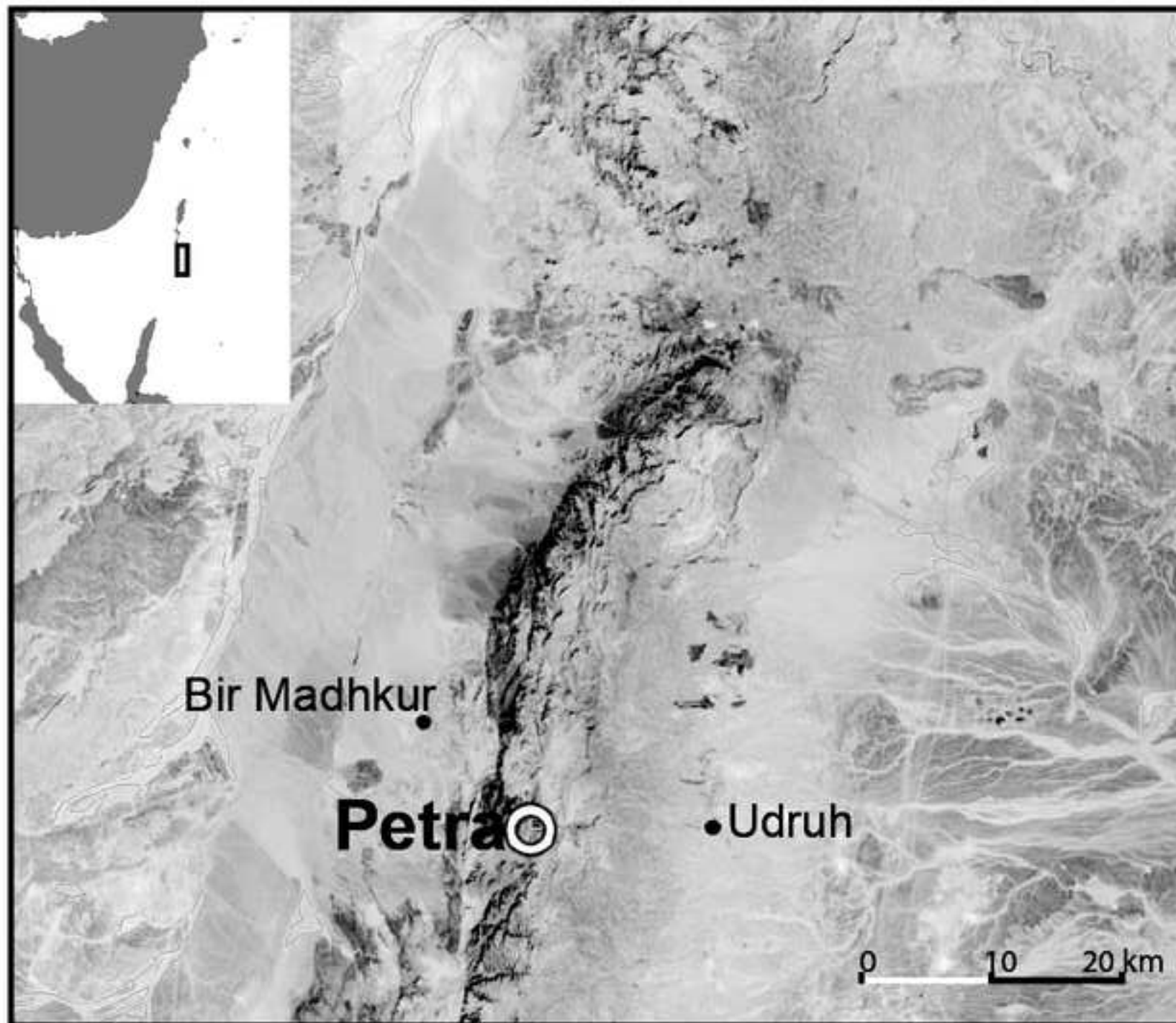


Figure2

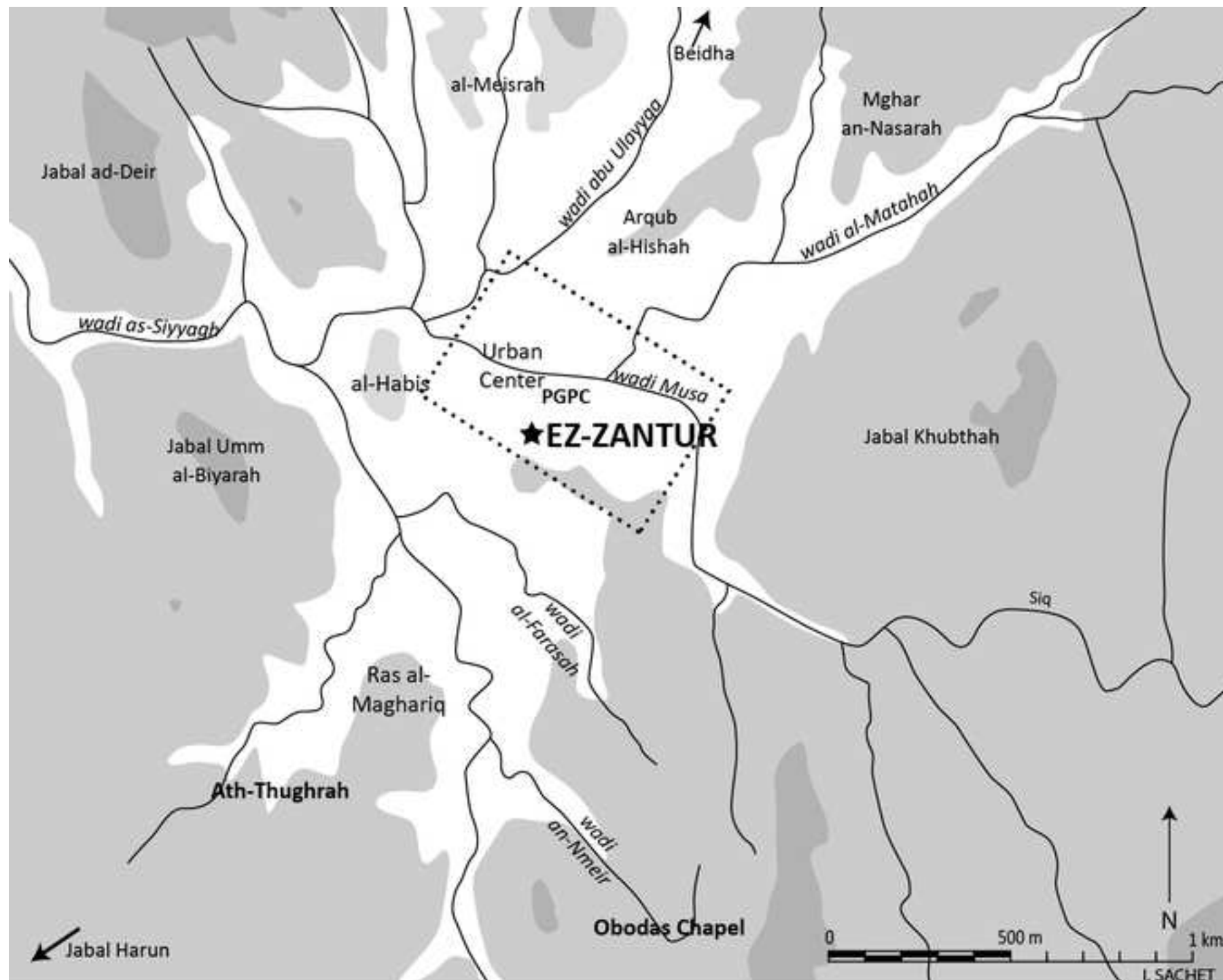


Figure3



Figure 4

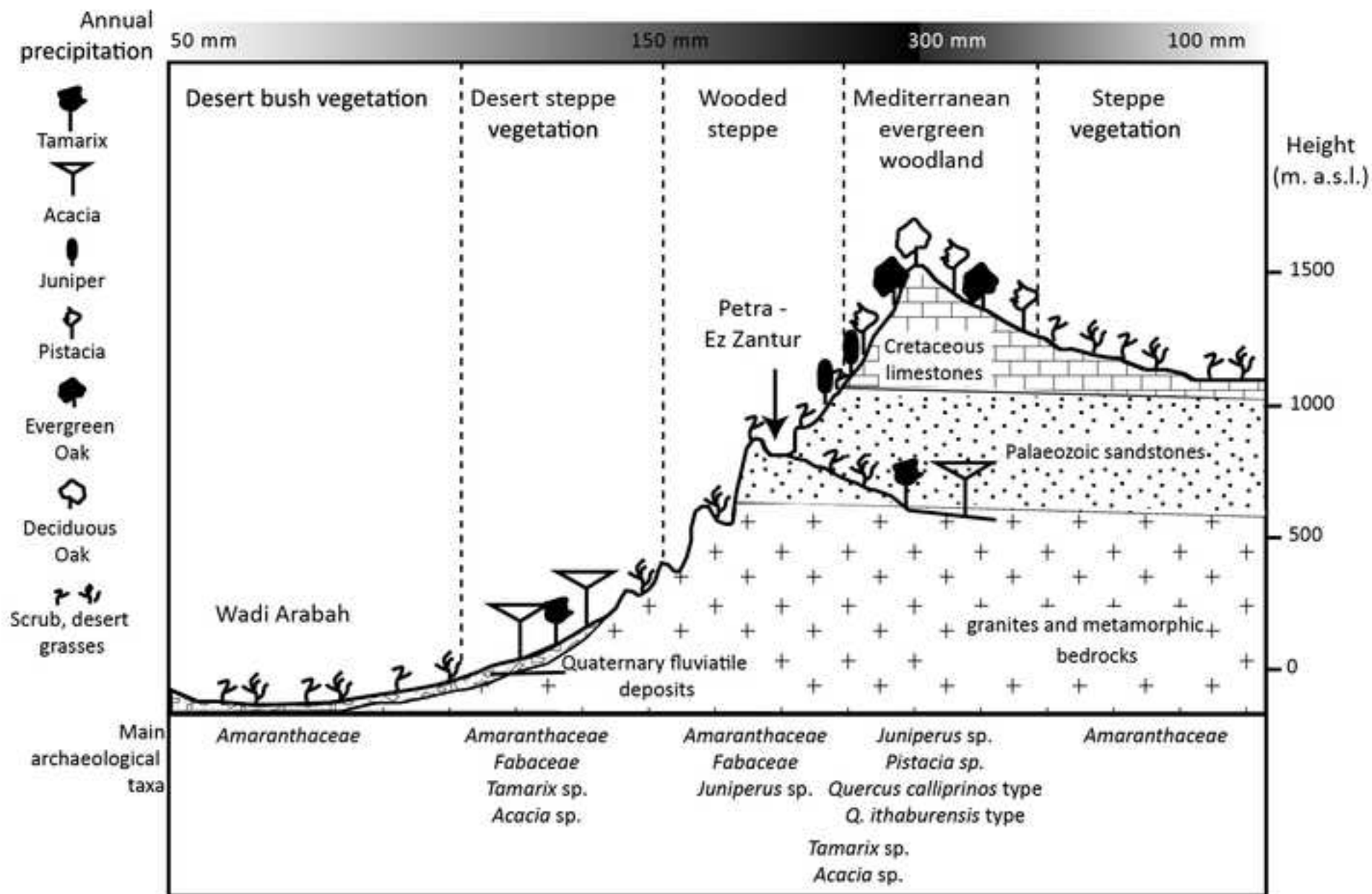


Figure 5

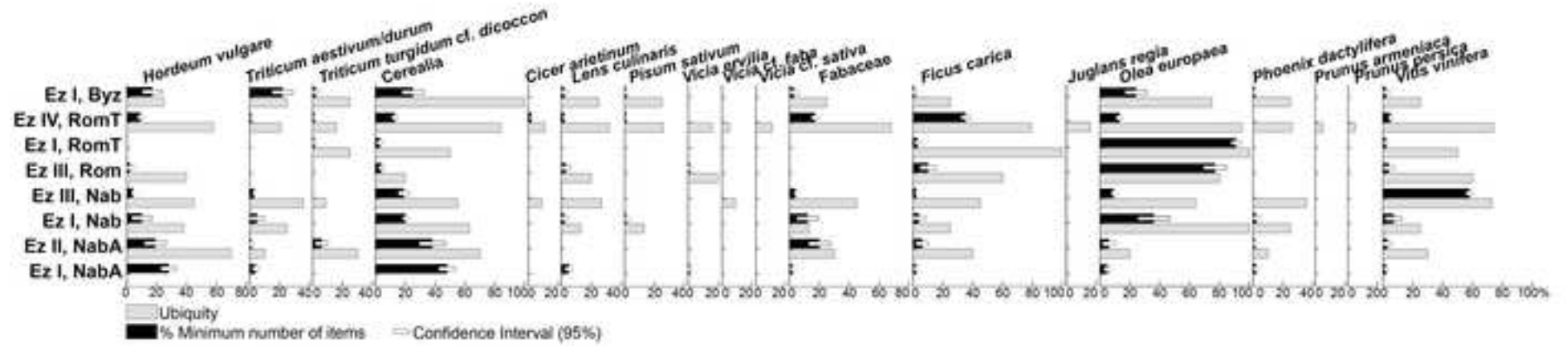


Figure 6

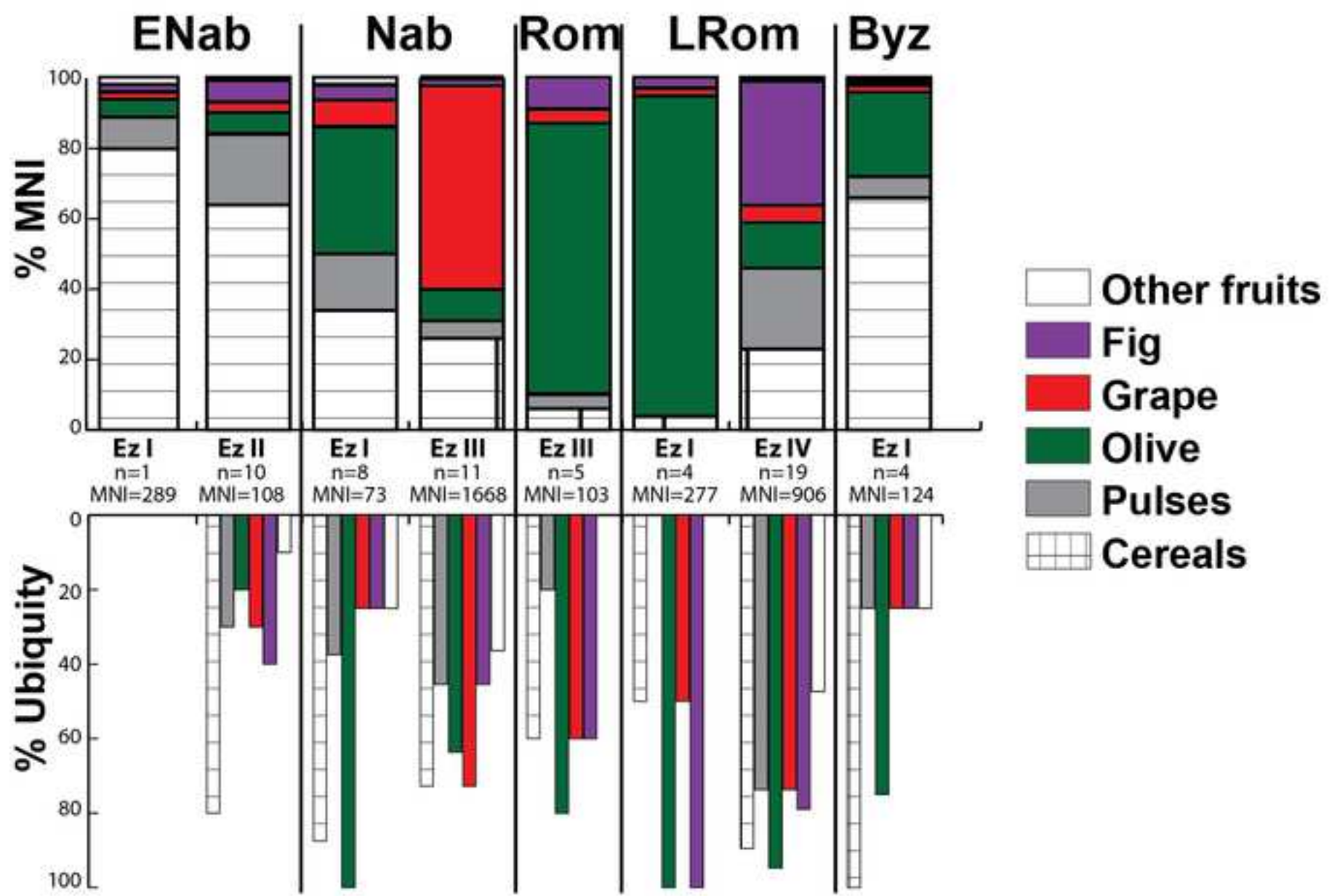


Table 1. Quantitative data according to the different types of plant remains per period and terrace at ez-Zantur. ENab= Early Nabataean, Nab=Classical Nabataean, Rom=Roman, LRom=Late Roman, Byz=Byzantine

	Phase	ENab		Nab		Rom	LRom		Byz
	Dating	mid 2 nd c.-mid 1 st c. BC		mid 1 st c. BC-1 st c. AD		2 nd -3 rd c.	1 st half 4 th c.		Early 5 th c.
	Terrace	Ez I	Ez II	Ez I	Ez III	Ez III	Ez I	Ez IV	Ez I
Carpological remains	Nb of samples	1	10	8	11	5	4	19	4
	Volume (l)	22	40.5	63	179.2	41.9	18.5	352.7	25
	Raw Nb of remains	352	144	160	2961	345	1001	2404	273
	Minimum number of items (MNI)	295	119	81	1883	114	283	1989	177
Charcoal	Nb of samples	5	5	6	3	-	-	15	-
	Volume (l)	22	21.6	23.4	5.4	-	-	208.1	-
	Nb of remains	21	22	101	41	-	-	439	-

Table 2. Carpological data from ez-Zantur, Petra, raw number of remains (NR) and ubiquity (Ub). ENab= Early Nabataean, Nab=Classical Nabataean, Rom=Roman, LRom=Late Roman, Byz=Byzantine, ac=achene, end=endocarp, fgt=fragment, gl=lemma/palea fragment, mer=mericarp, ped=pedicel, k=kernel, nut=nutlet, rac.=rachis fragment, s=seed, sf=spikelet fork

Phase	ENab			Nab				Rom		LRom				Byz	
Dating	mid 2 nd c.-mid 1 st c. BC			mid 1 st c. BC-1 st c. AD				2 nd -3 rd c.		1 st half 4 th c.				Early 5 th c.	
Terrace	Ez I	Ez II		Ez I		Ez III		Ez III		Ez I		Ez IV		Ez I	
Number of samples	1	10		8		11		5		4		19		4	
Volume (litres)	22	40.5		63		179.2		41.9		18.5		352.7		25	
	NR	NR	Ub	NR	Ub	NR	Ub	NR	Ub	NR	Ub	NR	Ub	NR	Ub
Cereals, grains															
<i>Hordeum vulgare</i>	80	24	8	8	3	51	8	2	2			82	11	21	2
<i>Triticum aestivum/durum</i>	11			4	2	26	1							23	1
<i>Triticum</i> sp.		2	1			4	2					9	4	7	1
Cerealia	140	44	7	16	5	291	6	4	1	7	2	134	16	31	4
Cereals, chaff and straw															
<i>Hordeum vulgare</i> , rac						5	1					4	3		
<i>Triticum aestivum/durum</i> , rac						9	2					1	1		
<i>Triticum turgidum</i> subsp. <i>dicoccon</i> , rac		3	2							1	1	1	1		
Cerealia, rac		2	2			17	1			1	1	3	1		
Cerealia, gl		1	1									2	1		
Cerealia, culm node		3	3	2	1	2	2					1	1		
Cerealia, root-culm	1														
Pulses, seeds															
<i>Cicer arietinum</i>						5	1					2	2		
<i>Lens culinaris</i>	15			2	1	4	3	3	1			23	6	2	1
<i>Pisum sativum</i>	1			1	1							8	5	1	1
<i>Vicia ervilia</i>	3							1	1			5	3		
<i>Vicia</i> cf. <i>faba</i>						1	1					1	1		
<i>Vicia</i> cf. <i>sativa</i>												3	2		
Fabaceae	6	7	3	1	1	13	5					56	13	4	1
Potential cultivated fruit trees															
<i>Ficus</i> cf. <i>carica</i> , ac	6	8	4	3	2	37	5	10	3	9	4	364	15	1	1
<i>Juglans regia</i> , end												3	3		
<i>Olea europaea</i> , end (whole)	3			4	2	2	2	2	1	12	2	4	4	2	1

<i>Olea europaea</i> , end (fgt)	48	29	2	102	7	599	6	308	4	955	4	524	18	112	3
<i>Olea europaea</i> , k	1			1	1	9	4					2	2	11	2
<i>Phoenix dactylifera</i> , s (fgt)	24	4	1	4	2	8	4					8	5	1	1
<i>Prunus armeniaca</i> , end												1	1		
<i>Prunus persica</i> , end												2	1		
<i>Vitis vinifera</i> , s	5	4	3	6	2	800	8	4	3	5	2	47	14	3	1
<i>Vitis vinifera</i> , s (fgt)	3	1	1			815	2			3	1	27	4		
<i>Vitis vinifera</i> , ped						5	1								
Wild plants															
<i>Acacia</i> sp., s														1	1
<i>Amaranthus/Chenopodium</i> , s						5	1								
<i>Amaranthaceae</i> s				1	1	13	2					639	6		
<i>Androsace</i> sp., s												1	1		
cf. <i>Anthemis</i> sp., ac												1	1		
<i>Apiaceae</i> , mer						1	1								
<i>Asperula/Galium</i> , ac				1	1	9	3			1	1	5	5		
<i>Asteraceae</i> , mer						2	1					2	2		
<i>Astragalus/Trigonella</i> , s						17	1								
<i>Boraginaceae</i> , nut		1	1			6	3	2	1	1	1	126	11		
<i>Brassicaceae</i> , s				1	1	3	2								
cf. <i>Bromus</i> , car												1	1		
<i>Buplerum</i> sp., ac						1	1								
<i>Capparis</i> type, s						1	1								
cf. <i>Caucalis</i> sp., s												1	1		
<i>Cerastium</i> sp., s						4	1								
<i>Coronilla</i> sp., s						1	1								
<i>Crataegus</i> sp. end	1														
<i>Cynodon dactylon</i> , s		2	1												
<i>Cyperaceae / Polygonaceae</i> , s						1	1					2	2		
<i>Erodium</i> sp., awn						5	1					1	1		
<i>Euphorbia</i> cf. <i>aleppica</i> , s												4	1		
<i>Fabaceae</i> , s						1	1					4	1		
<i>Fumaria</i> sp., s						2	1	1	1			7	4		
<i>Heliotropium</i> sp., nut												1	1	1	1
<i>Hordeum</i> cf. <i>spontaneum</i> , car						6	1								
<i>Hyoscyamus</i> sp., s										1	1				

<i>Labiatae</i> , s						3	2					2	2		
<i>Liliaceae</i> , s		3	1			1	1								
<i>Lolium temulentum</i> , car						1	1							1	1
<i>Lolium</i> sp., car						10	1								
<i>Malva</i> cf. <i>parviflora</i> , mer						55	1			1	1				
<i>Malva</i> sp., s						3	1					8	3		
<i>Medicago</i> sp., s						27	1					10	6		
<i>Melilotus/Trifolium</i> , s						1	1	1	1			11	6		
<i>Onopordum</i> sp., ach												1	1		
<i>Panicum / Setaria</i> , car						2	2					3	3		
<i>Papaver</i> sp., s						2	1								
<i>Phalaris</i> sp., car												52	2		
<i>Poaceae</i> , car						4	1					44	8		
<i>Poaceae</i> , sf												11	1		
<i>Pistacia</i> sp., end	4			1	1	1	1								
<i>Plantago</i> cf. <i>lanceolata</i> , s						3	1					2	2		
<i>Polygonum/Rumex</i> , s										1	1	3	1		
<i>Silene</i> sp., s		1	1	1	1	50	2	5	2			74	12		
cf. <i>Solanum</i> sp., s						2	1								
cf. <i>Stellaria</i> sp., s		4	1			1	1					1	1		
<i>Viola</i> sp., s						1	1								
Indeterminate		1	1	1	1	13	3	2	1	3	1	70	10	51	2
Sum	352	144		160		2961		345		1001		2404		273	
Sheep/goat faeces		25	2	9	2	1	1			4	1				

Table 3. Carpological data from ez-Zantur, Petra, Minimum number of items weighted by volume per period and terrace. ENab= Early Nabataean, Nab=Classical Nabataean, Rom=Roman, LRom=Late Roman, Byz=Byzantine

Phase	ENab		Nab		Rom	LRom		Byz
Dating	mid 2 nd c.-mid 1 st c. BC		mid 1 st c. BC-1 st c. AD		2 nd -3 rd c.	1 st half 4 th c.		Early 5 th c.
Terrace	Ez I	Ez II	Ez I	Ez III	Ez III	Ez I	Ez IV	Ez I
<i>Hordeum vulgare</i>	3.64	1.09	0.36	2.77	0.09		4.09	0.95
<i>Triticum aestivum/durum</i>	0.5	0.04	0.18	2.55			0.34	1.23
<i>Triticum turgidum</i> cf. <i>dicoccon</i>		0.32		0.05		0.09	0.30	0.14
Cerealia	6.36	2.18	0.73	14.77	0.18	0.41	6.36	1.41
<i>Cicer arietinum</i>				0.23			0.91	
<i>Lens culinaris</i>	0.68		0.09	0.18	0.14		1.05	0.09
<i>Pisum sativum</i>	0.04		0.05				0.36	0.05
<i>Vicia ervilia</i>	0.14				0.05		0.23	
<i>Vicia</i> cf. <i>faba</i>				0.05			0.05	
<i>Vicia</i> cf. <i>sativa</i>							0.14	
Fabaceae	0.27	1.14	0.45	3.23			8.14	0.18
<i>Ficus</i> cf. <i>carica</i>	0.27	0.36	0.14	1.68	0.45	0.41	16.55	0.05
<i>Juglans regia</i>							0.14	
<i>Olea europaea</i>	0.68	0.33	1.34	6.90	3.59	11.40	6.14	1.36
<i>Phoenix dactylifera</i>	0.27	0.04	0.09	0.18			0.23	0.05
<i>Prunus armeniaca</i>							0.05	
<i>Prunus persica</i>							0.09	
<i>Vitis vinifera</i>	0.26	0.19	0.27	45.86	0.18	0.26	2.44	0.14
Wild/weed plants	0.23	0.5	0.23	11.14	0.41	0.23	46.23	0.14

Table 4. Distribution of the wild species found in Ez III during the Nabataean period (Nab) and Ez IV during the Late Roman period (LRom) according to modern weed plant communities and lifecycle (Zohary, 1973). a=annual, b=biannual, p=perennial. The doubtful taxa (cf.) are excluded.

Taxa	Ez III Nab	Ez IV LRom	<i>Secalinetea orientalia</i>	<i>Panicetea hydro-segetalia</i>	Ruderals	Biological lifecycle
<i>Silene</i> sp.			+		+	a, p
<i>Asperula/Galium</i>			+		+	a, p
<i>Melilotus/Trifolium</i>			+		+	a, p
<i>Medicago</i> sp.			+		+	a, b, p
<i>Fumaria</i> sp.			+			a
<i>Panicum/Setaria</i>			+	+	+	a, p
<i>Erodium</i> sp.					+	a, p
<i>Malva</i> sp.					+	a, p
<i>Plantago</i> cf. <i>lanceolata</i>					+	p
<i>Astragalus/Trigonella</i>			+		+	a, b
<i>Buplerum</i> sp.			+		+	a
<i>Cerastium</i> sp.			+			a
<i>Coronilla</i> sp.			+			a
<i>Hordeum</i> cf. <i>spontaneum</i>			+		+	a
<i>Lolium temulentum</i>			+			a
<i>Papaver</i> sp.			+		+	a
<i>Viola</i> sp.			+			a
<i>Amaranthus/ Chenopodium</i>			+	+	+	a
<i>Lolium</i> sp.			+		+	a
<i>Malva</i> cf. <i>parviflora</i>					+	a
<i>Androsace</i> sp.			+			a
<i>Euphorbia</i> cf. <i>aleppica</i>			+			a
<i>Heliotropium</i> sp.			+	+	+	a, p
<i>Phalaris</i> sp.			+		+	a
<i>Polygonum/Rumex</i>			+		+	a, p
<i>Onopordum</i> sp.			+		+	p

Table 5. Anthracological results of ez-Zantur, Petra. ENab= Early Nabataean, Nab=Classical Nabataean, LRom=Late Roman. NR= Number of remains, Ub=Ubiquity, C.I.= precision of the Confidence Interval (95%)

	ENab				Nab				LRom			
	Ez I		Ez II		Ez I		Ez III		Ez IV			
Number of samples	5		5		6		3		15			
Volume (l)	22		21.6		23.4		5.4		208.1			
	NR	Ub	NR	Ub	NR	Ub	NR	Ub	NR	%	C.I.	Ub
Cultivated fruit trees												
<i>Ficus cf. carica</i>	-	-	-	-	10	1	-	-	-	-	-	-
<i>Olea europaea</i>	2	1	-	-	1	1	1	1	180	41%	4.6	10
<i>Vitis vinifera</i>	-	-	-	-	-	-	-	-	11	3%	1.6	2
Desert plants												
<i>Acacia</i> sp.	2	2	4	2	52	1	-	-	75	17%	3.5	5
<i>Amaranthaceae</i>	1	1	1	1	4	2	10	2	8	2%	1.3	2
Open forest												
<i>Cistus</i> sp.	-	-	-	-	-	-	-	-	6	1%	0.9	1
<i>Cupressus sempervirens</i>	-	-	-	-	-	-	-	-	10	2%	1.3	1
<i>Cupressus/Juniperus</i>	-	-	-	-	-	-	-	-	9	2%	1.3	2
<i>Fabaceae</i>	2	1	1	1	8	3	28	2	30	7%	2.4	3
<i>Juniperus</i> sp.	-	-	1	1	6	2	-	-	10	2%	1.3	5
<i>Pinus</i> sp.	-	-	-	-	-	-	-	-	5	1%	0.9	1
<i>Pistacia</i> sp.	12	5	11	4	8	2	-	-	48	11%	2.9	5
cf. <i>Prunus</i> sp. (ring-porous)	-	-	-	-	-	-	-	-	2	0.5%	0.7	2
<i>Quercus calliprinos</i> type	2	1	2	1	3	1	1	1	3	0.5%	0.7	1
<i>Quercus ithaburensis</i> type	-	-	-	-	-	-	-	-	5	1%	0.9	1
<i>Rhamnus</i> sp.	-	-	-	-	1	1	-	-	6	1%	0.9	2
Riparian gallery												
<i>Platanus orientalis</i>	-	-	-	-	-	-	-	-	5	1%	0.9	1
<i>Salix</i> sp.	-	-	-	-	-	-	-	-	10	2%	1.3	2
<i>Tamarix</i> sp.	-	-	2	1	8	1	1	1	9	2%	1.3	3
Indeterminate	-	-	-	-	-	-	-	-	7	2%	1.3	2
Sum	21		22		101		41		439			

Table 6. Taxa identified through carpological and wood charcoal analyses. ENab= Early Nabataean, Nab=Nabataean, LRom=Late Roman, c=carpological results, a=anthracological results.

Taxa	ENab		Nab		Rom	LRom		Byz
	c	a	c	a	c	c	a	c
Cultivated fruit trees								
<i>Ficus cf. carica</i>	+		+	+		+		+
<i>Olea europaea</i>	+	+	+	+		+	+	+
<i>Vitis vinifera</i>	+		+			+	+	+
Wild shrubs and trees								
<i>Acacia</i> sp.		+		+			+	+
<i>Amaranthaceae</i>		+	+	+		+	+	
<i>Pistacia</i> sp.	+	+	+	+			+	

Table 7. Distribution of the main cultivated species in several archaeological sites of the Southern Middle East according to the estimation of the minimum number of plant macro-remains proportions recovered (from x=present to xxx=abundant, +=no available quantitative data)

	Petra garden&Pool complex (PGPC)					Obodas Chapel		Ath-Thughrah	Udruh	Bir madkhur
	1 st c. BC-early 1 st c. AD	early 1 st c.-early 2 nd c.	2 nd -3 rd c.	1 st half 4 th c.	4 th -early 5 th c.	2 nd -1 st c. BC	1 st -2 nd c. AD	4 th c. BC-4 th c. AD	2 nd -3 rd c. AD	4 th -6 th c. AD
Cereals										xx
<i>Hordeum vulgare</i>		x	x	x	x	x		x	+	+
<i>Triticum aestivum/durum</i>			x	x	x					+
<i>T.aestivum</i> ssp. <i>compactum</i>										+
<i>T.turgidum</i> subsp. <i>durum</i>										+
<i>T.turgidum</i> ssp. <i>dicoccum</i>									+	+
<i>Cerealia</i>	xx	x	x	x	xx	xxx	xx	xx		+
Pulses										x
<i>Cicer arietinum</i>			x							
<i>Lathyrus</i> sp.		x	x							
<i>Lens culinaris</i>	x	x	x					xx		+
<i>Pisum sativum</i>						x				+
<i>Vicia ervilia</i>			x							
<i>Vicia</i> cf. <i>faba</i>										+
<i>Vicia</i> cf. <i>sativa</i>										+
Fruit trees										x
<i>Ficus</i> cf. <i>carica</i>	xx	x	xx	x	xx	x	xx	x	+	+
<i>Olea europaea</i>	xx	xxx	xx	xxx	xxx		x	x	+	+
<i>Phoenix dactylifera</i>		x	x	x	x			x		+
<i>Vitis vinifera</i>	xx	xx	xx	xx	xxx	x	xxx			+
References	Ramsay and Bedal 2015					Bouchaud 2011, Tholbecq et al. 2008		Sachet et al. 2013	Neef 1987, 1990	Ramsay and Smith 2013