Palaeoenvironmental reconstruction in the Southern Levant: synthesis, challenges, recent developments and perspectives

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Palaeoenvironmental research in the Southern Levant presents a series of challenges, partly due to the unequal distribution of palaeoenvironmental records and potential archives throughout the region. Our knowledge of climatic evolution, during the last approximately 25,000 years, is of crucial importance to understand cultural developments. More local, well-dated, multi-proxy studies are much needed to obtain an accurate picture of environmental change in respect of the Late Pleistocene and the Holocene.

This contribution reviews the current state of knowledge regarding Late Quaternary palaeoenvironmental changes in the Southern Levant, including some examples of more recent developments in palaeoenvironmental reconstruction in Israel and the Dead Sea area, and introduces the major challenges researchers face in the region. It also presents the first results of a new case study in Jordan, based on an analysis of peaty deposits located in the mountain slopes east of the Dead Sea. Such new studies help refine our knowledge of local environmental changes in the Southern Levant and especially the more arid areas, for which little information is presently available. More material suitable for palaeoenvironmental research, for example extensive tufa and travertine series, still awaits consideration in Jordan, opening up exciting perspectives for future research in the area.

Keywords: Southern Levant; Late Pleistocene; Holocene; palaeoenvironments; environmental change

1. Introduction

Palaeoenvironmental research in the Southern Levant (modern Israel, Palestinian territories and Jordan) presents a series of challenges. Most of the well-preserved archives are located in restricted areas, in the northern and eastern regions, which receive more abundant rainfall (figure 1). Dating constraints and the potentially variable interpretation of the different proxies available to study further complicate constructing a regional picture of environmental change. However, obtaining reliable palaeoclimatic reconstructions from the Levant is becoming increasingly important. Such evidence is key to our understanding of past societies and their relationship with (and vulnerability to) climate change, particularly water availability and changing landscapes through prehistoric and recent times.

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historic times. The Levant is a region of general water scarcity; in particular, Jordan is presently one of the 10 most water-deprived countries in the world (e.g. Kfouri et al. 2009), and understanding of its climatic conditions, past, present and future, is crucially needed. Although the western part of the Southern Levant has been more extensively studied, the region that lies east of the Dead Sea and Jordan Valley is still lacking a series of well-constrained, high-resolution palaeoenvironmental records that would help understand its evolution during the Late Pleistocene–Holocene period and compare it with the palaeoenvironmental changes recorded west of the Dead Sea. It cannot be taken for granted that these evolutions will prove to be similar, either in timing or in intensity.

In this contribution, I will review the palaeoenvironmental context of the Levant established by previous studies, including some of the more recent developments in Late Quaternary palaeoenvironmental research for the region. I will then present the major challenges regarding environmental research in the Southern Levant. Section 4 describes the preliminary results of an analysis of pollen within peaty deposits from the Dead Sea region. In §5, I describe the potential of the region for further palaeoenvironmental reconstructions, which would help gain a better understanding of the environmental evolution of the Southern Levant during the last approximately 25 000 years.

2. The palaeoenvironmental context: summary of literature

A series of reviews, compiling the palaeoenvironmental evidence and comparing it with the evolution of human societies, have recently been produced for the Levant (e.g. Issar 2003; Robinson et al. 2006; Cordova 2007; Rosen 2007; see also Sanlaville 1996, 1997; Henri 1997; Rambeau & Black in press) in respect of the Late Pleistocene and the Holocene. These reviews rely on a variety of palaeoenvironmental proxies, such as pollen analyses, stable isotopes (e.g. from speleothems, lake sediments, land snails or wood) and geomorphological indicators.

The next paragraphs summarize a series of major climate changes that seem to be recorded in most of the Levantine region during the Late Pleistocene and the Holocene. The palaeoenvironmental proxies available for the Levant are presented in more detail in Robinson et al. (2006). A schematic location of the major records, and the period they individually cover, is shown in figure 1, along with the rough characteristics of each record in terms of continuity, dating constrain and resolution, parameters that are crucial to determine their potential for palaeoenvironmental reconstructions.

(a) The period 25 000–5000 BP

During this period, the major Northern Hemisphere climatic events can be recognized in the Eastern Mediterranean and the Levant (Robinson et al. 2006). Thus, the terms defined in the Northern Hemisphere for specific climatic periods, such as the Bølling–Allerød or the Younger Dryas, will be used by analogy
in this review. However, it should be kept in mind that this terminology must be employed with care when considering the Levantine sequences, since the relative timing and extent of these events are still not fully understood in the Eastern Mediterranean.

The Last Glacial Maximum (approx. 23–19 cal. ka BP) was probably colder than present (e.g. Affek et al. 2008); there is still some debate about the intensity and distribution of precipitation in the region during this period (e.g. Robinson et al. 2006; Enzel et al. 2008). The Bolling–Allerød (approx. 15–13 cal. ka BP) was a relatively warm and wet period, as evidenced by palynology, speleothems and marine sediments from the Red Sea (Rossignol-Strick 1995; Bar-Matthews et al. 1997, 1999, 2003; Arz et al. 2003a,b; Robinson et al. 2006). The Younger Dryas (approx. 12.7–11.5 cal. ka BP) appears to show a return to more glacial (cold and dry) conditions, even if this view has been recently challenged. (Stein et al. (2010) notably present evidence from Lake Lisan sediments suggesting a wet Younger Dryas.) The Early Holocene corresponds to the warmest and wettest phase of the last 25 000 years in the region, as clearly shown in pollen records, isotopic records, fluvial deposits and soil sequences (e.g. Rossignol-Strick 1995, 1999; Goodfriend 1999; Gvirtzman & Wieder 2001; Bar-Matthews et al. 2003; McLaren et al. 2004; Robinson et al. 2006; Affek et al. 2008; Roberts et al. 2008).

The period encompassing the Late Pleistocene and the Early Holocene witnesses major societal evolutions in the Levant, with the transition from Natufian (Late Epipaleolithic) semi-sedentary complex hunter-gatherer groups, to the first agriculturalists of the Pre-Pottery Neolithic A at the start of the Holocene and finally to the Levantine Pre-Pottery Neolithic B (PPNB), with settlement expansion and the development of animal herding strategies, at the time of the Early Holocene climatic optimum (Rambeau et al. in press). During this transition, it has been suggested that the Younger Dryas brief return to cold and dry conditions had a major impact on Levantine populations (e.g. Mithen 2003; Robinson et al. 2006; Cordova 2007).

At approximately 8200 cal. BP, cold and arid conditions seem to settle in the Eastern Mediterranean (e.g. Staubwasser & Weiss 2006; Weninger et al. 2006; Berger & Guilaine 2009). It is still unclear, however, whether such conditions are related to an abrupt climatic event or are part of a more gradual trend towards climate deterioration starting globally at approximately 8600 cal. BP (Rohling & Pälike 2005). It has been argued that around 8500 BP, large PPNB settlements in the Southern Levant abruptly collapsed and were replaced by the smaller settlements of the Pre-Pottery Neolithic C, which marked a return towards nomadic pastoralism (Rollefson & Köhler-Rollefson 1989; Rambeau et al. in press).

(b) The last 5000 years

The Holocene is characterized in the Eastern Mediterranean region by a trend towards aridity, with several climatic fluctuations being superimposed on this general evolution (Rambeau & Black in press). However, during these more recent times, it becomes increasingly difficult to separate the respective influences of climate variations and human activity on environmental change (e.g. Heim et al. 1997; Neumann et al. 2007; Cordova 2008; Frumkin 2009).
In semi-arid and arid areas, it is generally accepted that increased human influence on the landscape will lead to its progressive degradation. Occasionally, the reverse can be true, however, and ancient human activity has been shown to have a conservative effect on a landscape menaced by erosional processes (Avni et al. 2006).

The fact that the Middle to Late Holocene in the Eastern Mediterranean region is a time of increased human control and modification of the landscape (in particular, in relation to increasing agriculture and vegetation clearance) influences the palaeoenvironmental records. Pollen sequences, in this context, are particularly affected and reflect principally the expansion of cultivation during the last approximately 5000 years (e.g. Baruch 1986, 1990; Baruch & Bottema 1991, 1999; Heim et al. 1997; Schwab et al. 2004; Neumann et al. 2007). The response of human communities to climate variations may also have changed through time, as societies evolved towards bigger centres with more economically productive agriculture (Rosen 1995) and were included into extensive trade networks. This renders the link between cultural evolution and potential climate change all the more difficult to decipher.

In the Southern Levant, several climatic events can be recognized at a regional scale, which had, to a certain extent, an impact on human communities (Rambeau & Black in press). The cultural developments (decline in cultivation and demise of settlement centres) at the end of the Early Bronze (EB) Age (approx. 4200 cal. BP) and the Byzantine period (approx. 1400 cal. BP), respectively, probably relate to a shift towards more arid conditions. It seems that increased precipitation during the EB Age II–III triggered a decline in settlements in the Israeli coastal plain, related to flooding and illnesses linked to expanding marshy environments (Faust & Ashkenazy 2007). The relatively humid conditions that prevail during the Hellenistic to Byzantine period led to a time of thriving agriculture, marked by an increase in anthropogenic indicators in the pollen sequences (e.g. Heim et al. 1997; Baruch & Bottema 1999; Schwab et al. 2004; Neumann et al. 2007; Rosen 2007; Cordova 2008). At this time, olive and grape cultivation was extensive in the Southern Levant (Neumann et al. 2007). In contrast, arid conditions seem to prevail during most of the early Islamic to modern times. Generally, more contradictory information is available on a regional scale for the Middle Bronze to Iron Age, although it appears that arid conditions may have dominated at the end of the Middle Bronze Age and during the first half of the Iron Age (Rambeau & Black in press). Brief phases of climate instability occurred at approximately 5200–5000 BP and 1000 BP (Rambeau & Black in press); it is possible that the latter holds some responsibility for the demise of the Decapolis society (Lucke et al. 2005).

Part of the most recent, detailed case studies conducted in the Southern Levant, a series of investigations in the Dead Sea region, reconstruct the vegetation history (dominated by cultivation) and climatic fluctuations for the last 3500 years. This reconstruction draws on pollen and sedimentological observations from sections on the Dead Sea west shore (Neumann et al. 2010) and a core from the Dead Sea itself (Leroy 2010). These recent studies indicate the presence of wetter periods in the Dead Sea region during the Middle Bronze Age, part of the Iron Age and particularly during Roman–Byzantine times, which allowed intensive cultivation to take place, as well as during the end of the nineteenth to early
twentieth century. In addition to climatic fluctuations, two earthquakes, in 31 BC and AD 363, affected agricultural practices in the area, inducing a clear drop in cultivated species in the pollen records (Leroy et al. 2010). These events have been shown to disrupt agriculture in the Dead Sea rift for periods of a few (4–5) years.

New detailed information for the period approximately 2300–1900 BC has also been recently derived from the study of the stable isotopic composition of tamarisk wood from the Mount Sedom cave (Frumkin 2009). In previous studies, it has been shown that tamarisk wood fragments (Yakir et al. 1994; Issar & Yakir 1997) from the siege at Masada (AD 70–73) yield stable isotopic composition compatible with twice the present-day annual rainfall. Frumkin’s (2009) study develops, to a greater extent, the potential of stable isotopes in wood to record rainfall variations, for a much longer and older period approximately 2265–1930 BC (determined by radiocarbon dating). Frumkin (2009) used both $\delta^{13}C$ and $\delta^{15}N$ from the fossil wood, calibrated using modern values, to link isotopic enrichment to environmental deterioration and rainfall decrease. Frumkin’s (2009) results indicate a progressive desiccation for the period approximately 2265–1930 BC, with rainfall diminishing roughly by half (consistent with Leroy (2010) and Neumann et al. (2010)). The record shows a succession of droughts, with a prominent but short-lived event at approximately 2020 BC, followed by a longer event at approximately 1930 BC that ultimately killed the tree. This environmental crisis is contemporaneous with the Intermediate Bronze Age cultural changes, with the abandonment of urban centres and a return to pastoralism. The last, prolonged drought recorded in the tamarisk wood sequence seems in particular contemporaneous with the abandonment of the prominent site of Bab edh-Dhra, on the southeastern shore of the Dead Sea (Frumkin 2009).

3. Problems and challenges

(a) Collating palaeoenvironmental evidence on a regional scale

Considerable difficulties arise when one tries to extrapolate a regional history of climate change in the Southern Levant from palaeoclimate evidence derived from local records.

The first difficulty comes with the necessity of obtaining reliable dates. Dating potential and related uncertainties varies; discontinuous records or records with deposition rates that are susceptible to change through time (such as may be the case for fluvial or lacustrine sequences) are more difficult to date accurately. Comparing the various records may already prove difficult while one is faced with the problem of adjusting the respective time frames. This is emphasized by the need to calibrate radiocarbon dates, so that they can be directly compared with calendar years BP, such as may be obtained by uranium-series techniques, and archaeological periods, which are usually reported in calendar years BC/AD. Unfortunately, despite calls for uniformity in the way dates are presented in the literature (e.g. Cordova 2007), it is sometimes unclear which calibration (if any) has been used by the authors.
The resolution of the records is also a crucial element. Some of the records, e.g. palaeosols or fluvial sequences, can only provide estimates of climate change over large time scales such as millennia; other proxies, such as speleothems, give far more detailed records, potentially to the decanal–centennial scale. Pollen, under certain circumstances, may give information about seasonal patterns, since different plants have a different annual cycle. Such a fine resolution may also be attained, in certain cases, with laminated sediments or wood.

Another challenge arises with the interpretation of the various proxies. Each proxy possesses limitations or uncertainties regarding how they relate to climatic fluctuations. For example, the stable isotope (oxygen and carbon) composition of carbonate precipitates (speleothems, tufa and travertine deposits, pedogenetic nodules and lake carbonates; e.g. Deutz et al. 2001; Andrews 2006; Fairchild et al. 2006; Jones & Roberts 2008; see also Rambeau et al. in press) depends on the site location, plus various parameters such as water and air temperature (and potentially evaporation), the composition of the parent water (itself dependent on the amount and source of associated rainfall) and, in the case of carbon isotopes, the local vegetation cover. Determining which parameter most influenced the carbonate isotopic record, on a specific time scale, may be difficult and should be considered with great care. Bar-Matthews and co-workers give a good example of integrative study in Soreq Cave (central Israel; Bar-Matthews et al. 1996, 1997, 1998, 1999, 2000, 2003; Ayalon et al. 1999; Bar-Matthews & Ayalon 2004). In parallel to studying ancient speleothems, they compared modern precipitates with climate parameters and determined a link between the isotopic composition of speleothems and the amount of rainfall. Sometimes, a direct comparison of modern samples and current climatic conditions is not possible, and the potential interpretation of isotopic records should be cautiously addressed.

Pollen records, to consider another example, can be easily biased due to different processes. Species can be under- or overrepresented due to unequal preservation, especially when conditions of preservation are not optimal, such as in a riverine sequence. It seems, for example, that Asteraceae liguliflorae (i.e. the dandelion group) produces pollen particularly resistant to deterioration, which would explain its domination in several archaeological records (e.g. Bottema 1975; Cordova 2007). An uneven distribution of pollen grains can also arise due to different types of pollinization (wind- versus insect-assisted). In archaeological deposits, the amount of pollen grains can be too little to get an accurate picture of the vegetation, and the record is usually greatly influenced by human activities (e.g. Fish 1989) as it is in regions of intense cultivation, especially during the last 5000 years, due to large-scale agriculture and vegetation clearance (e.g. Neumann et al. 2007; Rambeau & Black in press).

Whenever possible, the use of several proxies (and several records) to determine the climatic and environmental evolution of a specific location may help greatly in resolving difficulties arising from the timing and interpretation of individual sequences. Multi-proxy studies represent an increasingly popular way of conducing research, with integrative case studies in the arid and semi-arid regions of the globe being more and more frequent (e.g. Salzmann et al. 2002; Wick et al. 2003; Hunt et al. 2004; Kieniewicz & Smith 2007; Neumann et al. 2007; Parker & Goudie 2008). Such an approach yields great potential for future palaeoenvironmental reconstructions in the Levant.
The Southern Levant is a region of contrasting climates and associated environments that change sharply over tens of kilometres (Zohary 1962; Al-Eisawi 1985, 1996; EXACT 1998). These gradients are due to topographical contrasts and a dominant source of moisture from the Mediterranean. As a result, the eastern and southern parts of the Levant experience lower and more variable annual precipitation rates than the northern and western areas. These climatic gradients determine, for a great part, the location of the various palaeoenvironmental records available for the Southern Levant (figure 1). The more continuous records are located in the wetter part of the region (the Mediterranean coast and the northern and central mountain ranges), whereas to the east and south, the records are less continuous, set widely apart or lacking altogether.

Sharp climatic gradients may partly explain the contradictions shown in the various palaeoenvironmental records, with different regions reacting variously to small-amplitude climatic fluctuations. Moreover, it is likely that past populations living on the margin of arid areas were especially susceptible to the impact of climate variations, as such locations are more vulnerable to environmental change. A good example of localized climate fluctuation in the Dead Sea area is given in Neumann *et al.* (2007). Although a short period of more arid conditions, marked notably by a decrease in olive cultivation, seems to be recorded in the Ze’elim sequence (southeast of the northern Dead Sea basin; see also Rambeau & Black in press) between 1800 and 1600 BP, followed by a return towards more humid conditions during the later Byzantine period, the more northern record at Ein Feshkha remained unaffected (Neumann *et al.* 2007).

It is therefore somewhat dangerous either to assume that past climate change was of similar intensity over the whole area of the Southern Levant or to assume that the whole region would have reacted similarly and simultaneously to climate change. It is most likely (a point of view already emphasized in Enzel *et al.* (2008)) that climate gradients, similar to today’s or even more accentuated, were already present in the Southern Levant during the Late Pleistocene/Holocene. It is probable that the southern Negev has been hyper-arid during the whole Holocene (and even before; Enzel *et al.* 2008); this is also valid for the eastern Jordan desert (Davies 2005). A wet phase during the Early Holocene would have little significance to these regions; doubling the rainfall amount such areas receive yearly would have a next to zero impact on their environment (Enzel *et al.* 2008). Changes in the gradients’ intensity would, however, have impacted the relative extend of desertic or semi-desertic areas, and marginal zones would have been the most affected by such changes. In the currently semi-arid northern Negev, some palaeoenvironmental evidence indeed suggests that the location of desert boundaries has changed during the Holocene (Goodfriend 1999).

Using the well-constrained records from the northern and western parts of the region to assess the environmental evolution of the whole Southern Levant, although tempting (see a similar line of reflection in Rosen (2007)), will not reflect the complexity of local conditions. It leads to an oversimplification of the climate and environmental history of specific climatic zones (e.g. Enzel *et al.* 2008) and should be avoided, if at all possible, whenever the modern evidence shows great climate discrepancies (e.g. between central and southern Israel;

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figure 1). More detailed, local studies in the more arid parts of the Southern Levant are crucially needed to understand their evolution during the Late Pleistocene/Holocene. In a context of scarcity of palaeoenvironmental indicators, new studies might have to rely upon a broader range of materials than previously used (see §§4 and 5).

(c) Seasonality

One of the greatest challenges currently faced by researchers in the Southern Levant is the study of seasonal variations. Of particular importance for understanding the evolution of past environments is a better knowledge of how rainfall was distributed throughout the year. This is of particular interest when studying the development and evolution of agricultural practices. In the Eastern Mediterranean, some proxy records suggest greater summer moisture availability during the Early Holocene (Rossignol-Strick 1995, 1999). There have been recurrent suggestions of monsoon-induced summer rain reaching the Southern Levant during the Climatic Optimum (e.g. El-Moslimany 1994; Abed & Yaghan 2000; Issar 2003).

Such information is very difficult to derive from palaeoenvironmental proxies alone. However, climate models suggest that although enhanced precipitation during the Early Holocene occurred in the Southern Levant, summer rains were unlikely (Brayshaw et al. in press). This has significant implications for our perception of the development of agricultural practices and associated cultural evolutions during the Climatic Optimum.

4. The Holocene evolution of a semi-arid area: insights from a new analysis of peaty deposits

Pollen assemblages are important archives of palaeoenvironmental changes, as they record variations in the local and/or regional type of vegetation cover, itself related to parameters such as precipitation, temperature and seasonality. In a context of general water scarcity, continuous and well-dated pollen records—which are best preserved in waterlogged environments—are rare for the Southern Levant, albeit they appear to exist in slightly unusual contexts, as will be described in the following.

Here, we present the preliminary results of an analysis of peaty deposits discovered in the desertic mountain slopes of the east of the Dead Sea (figure 2). More than 50 wetlands or former wetlands, varying between approximately 2 and 80 m in diameter, were mapped within a 2 km² area of reduced vegetation (figure 3), which bears clear marks of on-going desertification processes (including extensive grazing and trampling). Most of these structures are dome-shaped; some bear remnants of grass vegetation cover and others are covered by shrubs, which have been interpreted as a sign of decreased moisture content (figure 4). A few are capped by carbonate crusts. All these structures show preferential alignment, most likely related to tectonic faults (figure 3), and are probably fed by artesian springs (figure 4). Some of them have been excavated by local farmers to gain access to the groundwater, especially since the 1980s.
At one of the domed structures, named EDSA (figures 3 and 4), a 450 cm core was extracted, revealing the presence of approximately 225 cm sequence of organic sediments overlying a transition zone and subsequent clayey deposits, and capped by more clayey sediments (last approx. 80 cm; figure 5). Organic matter (OM) contents were determined by loss on ignition at 550°C (following the method described in Heiri et al. (2001)). Four radiocarbon ages were obtained on the main organic sequence (AMS analysis, Beta Analytic Radiocarbon Dating Laboratory, Miami, FL) and were used to construct an age model (table 1 and figure 5). Calendar years have been determined using the calibration database IntCal04 (Reimer et al. 2004), with a two-sigma interval (95%). The sample at 84 cm (table 1) has been considered to have an age of approximately 0 BP.

Pollen analyses have been performed on the EDSA core, with a division as follows. The first 80 cm were considered as modern sediments, and four discontinuous slices of 5 cm thickness were analysed at 0–5, 15–20, 40–45 and 55–60 cm depth (samples A–D, figure 6), to obtain information on the more recent (last approx. 60 years) vegetation cover. The main organic sequence was
Figure 3. Simplified geological map and location of the wetlands east of the Dead Sea, showing preferential alignment on structural lines. Scale bar, 200 m.
Figure 4. A selection of the domed wetlands east of the Dead Sea. (a) The active EDSA dome (note water under pressure springing at the borehole after the sediment core has been retrieved). (b) An excavated wetland showing its capping of clayey sediments. (c) A still partially moist dome, with remnants of grass cover. (d) A former, inactive and degraded dome, with shrub coverage. (e) A heavily encrusted dome.

divided into 18 successive layers of varying thickness, according to the age model, so as to obtain slices of equal duration (500 years). The underlying transition zone, for which no age control has been obtained, was divided into three successive samples of 5 cm thickness, at 311.5–316.5, 316.5–321.5 and 321.5–326.5 cm depth, respectively (samples 1–3, figure 6). Pollen analyses were realized at the University of Jordan under the supervision of Prof. Dawud Al-Eisawi.

OM contents in the main organic sequence (peaty deposits) reach up to 55 per cent (figure 5). Radiocarbon dating and the subsequent age model (figure 5) indicate that the main organic sequence started to form approximately 8500–9000 years ago (figure 5) and finished very recently, sometime after 1950. This implies a drastic change in the sedimentation type and rate during the last approximately
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Figure 5. EDSA core: (a) sequence description, age model and (b) organic matter contents. The equation of the age model is \( y = 338.1347 + (258.4998 \times \exp(0.0002526 \times x)) \).

Table 1. Radiocarbon dates from EDSA. pMC, percent modern carbon.

<table>
<thead>
<tr>
<th>depth (cm)</th>
<th>reference</th>
<th>pre-treatment</th>
<th>radiocarbon age</th>
<th>date cal. BP</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>84</td>
<td>β234856</td>
<td>acid/alkali/acid</td>
<td>112.2 ± 0.5 pMC</td>
<td>post 1950</td>
<td>—</td>
</tr>
<tr>
<td>157</td>
<td>β236440</td>
<td>acid washes</td>
<td>1580 ± 40 BP</td>
<td>1465 ± 85</td>
<td>95</td>
</tr>
<tr>
<td>230</td>
<td>β236441</td>
<td>acid washes</td>
<td>3140 ± 40 BP</td>
<td>3280 ± 10</td>
<td>95</td>
</tr>
<tr>
<td>301</td>
<td>β234857</td>
<td>acid washes</td>
<td>6850 ± 50 BP</td>
<td>7695 ± 95</td>
<td>95</td>
</tr>
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60 years, which can be attributed to increased desiccation of the area surrounding the EDSA system, possibly linked with a lowering of the local water table. This change of sedimentation at approximately 80 cm depth is observable in other peat-bearing bodies in the area (figure 4b).

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Pollen analyses were surprisingly successful, considering the aridity of the region (approx. 100–150 mm average rainfall), with a total of more than one hundred species identified. The ratio between arboreal (tree and shrub) pollen and non-arboreal pollen in particular shows dramatic variations (figure 6), with an unexpectedly large tree and shrub community developing during the last approximately 5000 years (only a few isolated trees grow at present in the studied area). The composition of the arboreal association also varies through time. The modern samples show a predominance of *Atriplex halimus* shrubs. Although the profile of arboreal pollen is largely dominated by acacia species for most of the peaty sequence and underlying sediments, it also shows large percentages of more Mediterranean species, led by *Arbutus andrachne*, for several time slices, including the period 2000–2500 BP. Acacia woodlands are a common feature of the Sudanian rocky vegetation that is natural to the Dead Sea rift valley and the slope of the mountain escarpments, whereas *A. andrachne* is currently only found, in Jordan, in the Mediterranean northern highlands (e.g. Al-Eisawi 1996; Cordova 2007). This shift in the local arboreal vegetation seems to confirm the presence of a wetter climate in the Dead Sea region during the Hellenistic and Roman times, such as suggested by previous studies (e.g. Yakir et al. 1994; Issar & Yakir 1997; Neumann et al. 2007, 2010; Leroy 2010).
Pollen analyses at EDSA furthermore suggest a very low cultivation impact on this new record during the Late Holocene, which would render this sequence a real rarity in the area.

In summary, the simple fact that organic sequences exist within the currently desertic environment edging the Dead Sea indicates that palaeoenvironmental archives for the region may be more abundant and more informative than previously thought. The first results from the study at EDSA show both a drastic change in the landscape during the last approximately 60 years and a Holocene evolution of the vegetation featuring significant variations in the tree and shrub cover as well as in the species associations. A significant amount of the information obtained from the pollen record and sedimentological observations at the Dead Sea domed wetlands is still being processed, and these exciting new archives will produce important new palaeoenvironmental records for the region.

5. Potential for further palaeoenvironmental reconstructions within this region

More local studies, based on well-dated sequences, may help refine our understanding of Middle to Late Holocene climate change in the Southern Levant. New studies can make use of the latest developments in dating techniques, such as uranium series for carbonate deposits, and in particular the isochron method, which allow for reliable dating of ‘impure’ (i.e. detrital-rich) carbonates (e.g. Candy et al. 2005; Rambeau et al. in press and references therein). Numerous outcrops of tufa and travertine, former lake sequences, carbonate roots, rock-shelter speleothems and carbonate deposits within historic and prehistoric water systems occur in various parts of the Southern Levant. They represent a potential for palaeoenvironmental reconstructions that is still largely unexploited.

For example, a multi-proxy study has been recently conducted around the archaeological site of Beidha in southern Jordan (Rambeau et al. in press), aiming to compare human occupation and climatic variability for the period between approximately 18 000 years BP and 8 500 years BP. Beidha is a reference site for the agricultural, PPNB occupation in the Levant (approx. 10 300–8 600 cal. years BP at Beidha), but the site was also occupied earlier on (approx. 15 200–13 200 cal. years BP) by semi-sedentary Natufian (late Epipaleolithic) populations (Byrd 1989, 2005; see also Kirkbride 1968). This study drew primarily on the detailed analysis of the stable isotopic composition (oxygen and carbon) of a carbonate sequence related to a fossil spring close to the site and of pedogenic carbonate nodules from a sedimentary section located on the edge of the archaeological site itself. Age control was provided by uranium series (isochron method) and radiocarbon dating. This study suggests an overall strong coupling between environmental variations and population response at Beidha during both the Natufian and the Neolithic and illustrates the potential of spring and pedogenic carbonates to record palaeoenvironmental changes that can be compared on a very detailed scale with the local chronology of settlement. Other similar studies, however, are needed to determine whether a causal link exists on a wider geographical scale between climate change and the abandonment of PPNB sites in the Southern Levant.
In the area near Wadi Faynan (figure 1) in semi-desertic central Jordan, travertine series, carbonate flowstones covering former pebble layers related to ancient wadi beds and stalactite-shaped deposits related to springs in rock-shelters offer a great opportunity to reconstruct both palaeoenvironmental conditions in Wadi Faynan and the former levels of Wadi Ghuywer in the gorges upland of Wadi Faynan. This is of direct interest to the understanding of human occupation in the Faynan area, which goes back to the Pre-Pottery Neolithic A and is recorded in a series of archaeological sites ranging from this period to the extensive Iron Age to Byzantine settlement and mining centre, exploiting the local copper ores (e.g. Hunt et al. 2004, 2007; Grattan et al. 2007). In a locality of such sharp altitudinal gradients, from the mountainous plateau of Shawback to the desertic plains of Wadi Araba, even minor changes in the climatic system (rainfall amounts and/or distribution throughout the year) would have induced great variations in the local environment, influencing infiltration rates, vegetation cover and wadi flows (Smith et al. in press). The palaeoclimatic conditions in the Wadi Faynan area, such as recorded in carbonate deposits, are presently being studied by the author. Tufa deposits from Wadi Hammam, a lush oasis located in the mountainous slopes bordering the archaeological centres of Wadi Faynan, have been dated to between approximately 13000 and 5200 cal. BP, and several excursions have been recognized in the associated isotopic record. This record, and those derived from associated carbonate deposits in the Wadi Faynan area, will provide a direct comparison to the Beidha sequence, approximately 30 km south.

An impressive succession of travertine/tufa deposits is also present on the sharp topographical slope of the eastern Dead Sea shore. Travertine deposits are still forming today in the area, notably in the hot spring system of Zara, on the Dead Sea shore. The elevation of the upper sequence is at approximately 45 m above sea level, and the presently active Zara hot spring system is located at an elevation of approximately −360 m (the Dead Sea levels were at −412 m in 1997; Migowski et al. 2006); a series of intermediate systems lie in between at various elevations.

Carbonate deposits within aqueducts, baths or other water-management structures also offer potential for palaeoenvironmental reconstruction during the historic period, all the more since such deposits are usually very finely laminated. Carbonate deposition has been observed, for example, in the public baths at Jerash (northern Jordan). Land snails embedded within dammed-lake sequences also present interesting possibilities for the reconstruction of historical palaeoenvironments, especially in eastern Jordan where other potential records are scarce. Root concretions and other pedogenic carbonates, especially in fast-buried sequences (Deutz et al. 2001), along with cemented gravels from former wadi terraces, give possibilities to both date and gain palaeoenvironmental information from fluvial sequences, alluvial plains and soil systems around springs. As an illustration, the study around the archaeological site of Beidha presented in Rambeau et al. (in press) is currently being complemented by a geomorphological investigation of the area, conducted by Robyn Inglis (Department of Archaeology, University of Cambridge) and by the author, and based on the uranium-series dating of a series of geomorphological indicators: pedogenic carbonate nodules, root concretions and carbonate-cemented gravel terraces.

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The Lake Lisan and following Dead Sea lacustrine sequences have been seldom studied on the eastern shore of the basin (see previous studies by Abed & Helmdach (1981), Abed & Yaghan (2000) and Landmann et al. (2002)). The eastern sequences, however, present a great potential for palaeoenvironmental reconstructions, with numerous outcrops of finely laminated lacustrine deposits. Led by Black, a recent study of the Lisan/Dead Sea laminated sediments on the eastern shore, dated by uranium series, will allow for a better knowledge of lake levels in the Dead Sea basin for the period approximately 25,000–8,500 cal. BP (Black et al. in press).

The multiplication of local studies, using in particular the great potential of Jordan for further palaeoenvironmental reconstructions, is the key to our understanding of how the various parts of the Southern Levant—and in particular the more arid regions—reacted to climatic and environmental changes during the past 25,000 years.

6. Conclusions

Palaeoenvironmental research in the Southern Levant, although being challenging (due partly to the presence of great climatic gradients over reduced geographical areas), presents great opportunities for future research, thus opening interesting perspectives. New proxies and studies are currently being developed to further constrain palaeoenvironmental conditions in various parts of the Southern Levant, including the more arid parts, with a particular emphasis on a better characterization of temperature and rainfall fluctuations; the impact of climate change on cultural developments; and the intertwined influence of natural changes and human activity on arid and semi-arid landscapes.

Most of the large-scale climatic fluctuations seem by now identified: the Last Glacial Maximum was probably a colder period in the Levant, whereas the Bølling–Allerød was relatively warm and wet. Most of the evidence points to cold/dry conditions during the Younger Dryas, followed by a very warm and wet Early Holocene. More arid conditions characterize the Middle and Late Holocene, with superimposed climatic fluctuations, such as a (probably prominent) wetter period during the Hellenistic to Byzantine times.

It therefore remains to determine with more accuracy climatic fluctuations on a local (e.g. less than 100 km) scale, their impact on the environment and societies, especially at the desert margins. In this context, using palaeoenvironmental evidence collected from the wetter areas to reflect on the climatic and environmental changes in the more arid parts of the Southern Levant may lead to misconceptions. Only the multiplication of local studies will allow for a better knowledge of the respective evolution of the various Southern Levantine landscapes during the Late Pleistocene and Early Holocene and help refine our understanding of how human societies reacted to local environmental change. In semi-arid and arid Jordan, numerous tufa and travertine series, other carbonate concretions and even organic sequences provide adequate material for further palaeoenvironmental research. The combined use of various proxies, whenever possible, is another decisive step towards a better understanding of past climate variations, as it allows for a more accurate interpretation of the palaeoenvironmental records; multi-proxy studies should therefore be encouraged.
Comparison between climatic models and environmental proxies should equally be developed further and will help better constrain parameters such as seasonal variations in rainfall.

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