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Cover illustration: Impression of a third millennium BC cylinder seal from Tell Arbid in Syria combined with the depiction of a mermaid – a motif from Warsaw’s coat of arms. Designed by Łukasz Rutkowski.
CONTENTS

FOREWORD OF THE EDITORS .......................................................................................XI
PROGRAMME OF THE CONGRESS ...............................................................................XIII

VOLUME III

ARCHAEOLOGY OF FIRE

AGNIESZKA PIEŃKOWSKA
The Fire and Light. Mesopotamian Lamps from Polish Archaeological Excavations on Tell Arbid .................................................................3

ANNA SMOGORZEWSKA
Cooking, Heating and Processing. The Function of Fire Installations in Household Activities at Tell Arbid (NE Syria) ..............................................17

MONICA TONUSSI
Pierced Andirons and Vessel Supports for Fireplaces from the Caucasus to the Near East: A Way to Optimize the Heat of Fire? ......................31

KATHRYN GROSSMAN
Fire Installations in a Late Ninevite 5 Complex at Hamoukar, Syria ..........47

SARA PIZZIMENTI
A Light in the Darkness. Some Hints on Fire Perception and Rituality as Represented in 2nd Millennium BC Mesopotamian Glyptic ...............61

ELISA GIROTTO
The Symbolism of Fire in War in Ancient Mesopotamia ............................73

PAOLO MATTHIAE
Fire and Arts. Some Reflections about the Consideration of Art in Assyria ..........................................................................................93

ALINE TENU, STÉPHANE ROTTIER
Fire in Funeral Contexts: New Data from Tell Al-Nasriyah (Syria) ..........123

SILVIA FESTUCCIA
Metallurgical Activities and Moulds: the Case of Ebla ..............................137

KRISTINA A. FRANKE
The Metallurgical Inventory from Tell Chuera: A Direct Comparison of Qualitative pXRF and Quantitative WDS Data ...........................151

NICOLAS GAILHARD
JOHNNY SAMUELE BALDI
Ceramic Production and Management of Fire Between Late Ubaid and LC1. The Potters’ Kilns of Tell Feres al-Sharqi ........................................187

LUCA PEYRONEL, AGNESE VACCA
From Clay to Pots: Pottery Production and Workplaces in Syria during the EB III-IV .................................................................201

ANDREA POLCARO
Fire and Death: Incineration in the Levantine Early-Middle Bronze Age Cemeteries as Mark of Cultural Identities, or as Technical Instrument of Purification? .................................................................223

FRANCESCO LEPIRAI
The Collapsed Wood Accumulation in the Well-Room of the Royal Palace of Tall Miṣrife/Qatna: a 3D Reconstruction .............235

CONSERVATION, PRESERVATION AND SITE MANAGEMENT

ANDREW JAMIESON, DIANNE FITZPATRICK
Sustainable Management Strategies for Near Eastern Archaeological Collections ................................................................................251

JEANINE ABDUL MASSIH
The Roman House of Cyrrhus – the Restoration Project ..................269

ZEIDAN A. KAFASI
Modern Human Activities Impact on the Archaeological Heritage: an Example from the Site Jebel Abu Thawwab .................................283

AHMED FATIMA KZZO
The Image of Arab Museums. Some Consideration about the Presentation of Arab Museums in Internet Sites .................................295

BIOARCHAEOLOGY IN THE ANCIENT NEAR EAST

CHIE AKASHI
Grazing and Fodder-Gathering in the Early Bronze Age Syria: the Case of Tell Ghanem al-‘Ali (TGA) ..........................................................309

RAFAŁ A. FETNER
The Results of Anthropological Research of Human Remains from the Old Babylonian Tomb from Bakr Āwa, Iraq .................................319

JACEK TOMCZYK, MARTA ZALEWSKA
Pilot Study of Dental Erosion in the Middle Euphrates Valley (Syria) ....329
ANNE-MARIE TILLER  
Diagnosis of Skeletal Lesions within Levantine Upper Pleistocene Populations. Evidence from Early Nomadic Hunter-Gatherers at Qafzeh (Israel) .................................................................341

Giovanni Siracusano, Giulio Palumbi  
“Who’d be Happy, Let Him Be so: Nothing’s Sure about Tomorrow” Discarded Bones in an Early Bronze I Elite Area at Arslantepe (Malatya, Turkey): Remains of Banquets? ...............................................349

ROBERT SATAEV, LILIYA SATAEVA  
Results of archaeozoological and archaeobotanical researches at the Bronze Age site Gonur Depe (Turkmenistan) ........................................367

EMMANUELE PETITI, ANDREA INTILIA, ARNULF HAUSLEITER  
Bioarchaeological Investigations at a 4th – 3rd century BC Cemetery at Tayma, North-West Arabia .........................................................371

ISLAMIC SESSION

BETHANY J. WALKER  
Exercising Power on the Mamluk Frontier: The Phenomenon of the Small Rural Citadel, Case of Tall Hisban ........................................393

ABED TAGHAVI, HOSSEIN TAROMIAN  
An Archaeological survey of Tomb Towers and Sepulchral Buildings in Semiran City in Islamic Periods ..................................................407

RAFFAELLA PAPPALARDO  
“Wheel-free”: The Islamic Handmade Pottery From Tell Barri (Syria) ...417

AYALA LESTER  
Reconsidering Fatimid Metalware .........................................................437

JULIE BONNÉRIC  
An Archaeology of Light in Classical Islam: Studying an Immaterial Phenomenon in Medieval Mosques ........................................455

SOPHIA LAPARIDOU  
Identifying Land Use Practices in Medieval Jordan Using Phytolith Analysis .........................................................................................467

ALAN WALMSLEY  
Islamic Archaeology in Qatar: Al Zubarah and its Hinterland(s) ...........479
SELECTED PAPERS FROM WORKSHOP SESSIONS

JEANINE ABDUL MASSIH
Le Liban de la Fin des Royaumes Hellénistiques
à l’Avenement de l’Empire Romain ..........................................................497

JULIEN CHANTEAU
The Chalcolithic Shrine at En-Gedi.
Aesthetics – Symbolism – Structure .........................................................509

ZAUR HASANOV
A Reflection of the Cimmerian and Scythian Religious Rites
in Archaeology ..........................................................................................527

DAFNA LANGGUT
Southern Levant Pollen Record, Palaeo-Climate and Human Impact
from the Late Bronze Age to the Persian period ........................................541

DR. STEVEN MARKOFSKY
Windows on a Delta Margin: A Case Study from the Murghab Delta,
Turkmenistan ............................................................................................559

JOYCE NASSAR
A New Necropolis Uncovered in Beirut: Analysis of the Funeral Space
Management inside a Classical Hypogeum (Preliminary Report) ...........575

KRZYSZTOF ULANOWSKI
Ideology or Religiosity? Factual Context
of the Neo-Assyrian Concept of Kingship ..................................................591
SOUTHERN LEVANT POLLEN RECORD, PALEO-CLIMATE AND HUMAN IMPACT FROM THE LATE BRONZE AGE TO THE PERSIAN PERIOD

DAFNA LANGGUT

ABSTRACT

The highlands of Canaan exhibited dramatic settlement fluctuations during the Late Bronze to the Persian period. In this article, a high-resolution pollen record is presented, available from the Ze’elim gully, which drains the southern Judean Highlands into the Dead Sea, Israel. The evidence for dry climate conditions during the end of the Late Bronze Age was most probably linked to the collapse of eastern Mediterranean cultures in the mid-13th to the 12th centuries BCE. The improved climate conditions in the highlands during the Iron Age I permitted the recovery of settlement activity, which was the backdrop for the rise of ancient Israel.

INTRODUCTION

Palynology (the study of fossil pollen grains) is an important instrument in the reconstruction of former vegetal environments and the elucidation of both past climate and human-plant relationships (e.g. agriculture, grazing, and anthropogenically induced deforestation). Since pollen tends to be well preserved in anaerobic environments (e.g. Faegri and Iversen 1992), the Dead Sea serves as a good archive of pollen grains, which were transported mainly by wind and wadi streams from the Judean Highlands and the Judean Desert (Fig. 1; Horowitz 1979; Baruch 1990).

The Judean Highlands features sharp settlement fluctuations during historical periods (waves of intense settlement activity and periods of decline; Table 1; Finkelstein 1995). Taking into consideration the steppe nature of the eastern and southern parts of this region (Fig. 1a), these oscillations could have resulted from climate fluctuations, and/or reflect changes in human behavior, such as transformation in subsistence patterns influenced by economic and social factors, political struggles, warfare, environmental or natural disasters and pestilence. No coherent explanation for these dramatic settlement fluctuations is yet available, and given the long period under discussion

1 This paper is based on a presentation at the 8th ICAANE Conference, Warsaw 2011, entitled: ‘The Dead Sea and Sea of Galilee Pollen Records, Palaeo-Climate and Human Impact during the Bronze and Iron Ages’.
2 The Laboratory of Archeobotany and Ancient Environments, the Sonia and Marco Nadler Institute of Archaeology, Tel Aviv University, P.O. Box 39040, Tel Aviv 69978, Israel.
This pollen record is named ‘FD Ze’elim’. The Dead Sea is surrounded by three altitudinal phytogeographical belts which depend on the precipitation gradient influenced by both topography (Fig. 1b) and synoptic conditions: The Saharo-Arabian vegetation, which is characterized by desert climate (precipitation < 100 mm/year); the Irano-Turanian vegetation (precipitation <300 mm/year), which is characterized by steppe vegetation with dwarf shrubs; and the Mediterranean vegetation (precipitation >350 mm/year), which exists at higher elevations, in the Judean Highlands and the Moab plateau (Fig. 1a; Zohary 1973; Danin 2004; Danin and Orshan 1999). The origin and routes of rain and dust storms that transport fine particles, including pollen grains, to the Dead Sea are a prime factor in pollen distribution (Horowitz et al. 1975). The major synoptic conditions that produce rain and dust transport to the studied region are: (1) the Cold Mediterranean Depressions associated with the Cyprus Cyclones: these are responsible for most winter rain and dust transport to the Levant (Figs. 1a, 1c; Dayan et al. 2007), while the summer is dry and hot due to the influence of the Persian Trough; (2) abundant dust storms associated with Red Sea Troughs and Sharav Cyclones dominate the autumn and springs (Horowitz et al. 1975).

A palynological study was already conducted in the Ze’elim site by Neumann et al. (2007), but in lower and irregular resolution, representing only a third order scale of environmental variation (e.g. Butzer 1982; Rosen 2007). This kind of resolution is not sufficiently refined to answer questions regarding specific transformations during the studied period, such as the beginning of the wave of settlement in the highlands in the Iron Age I (minimum second order scales of environmental variation). In other words, while third order scales of environmental variation might reveal long-term climate anomalies (e.g. ‘the Little Ice Age’ 14th – mid-19th centuries CE), a time resolution of a few decades or less is necessary to point out short-term climatic anomalies (extended droughts, fluctuations in seasonal availability). These climate changes might have had an enormous effect on ancient civilizations – as in the case of the 10th and 11th centuries CE, when severe droughts and extreme cold conditions affected different parts of the Near East (Ellenblum 2012). Based on detailed written sources, these climate anomalies resulted in famines, migrations, anarchy, wars, the fall of states, and all manner of social, economic and political dislocations (Ellenblum 2012).

The aim of this research was to achieve a reasonably-precise reconstruction of the vegetation history based on high pollen sampling resolution (~20-25 years per sample), and an improvement in the chronological framework. Since the Ze’elim stream catchment area covers the southern border of the Mediterranean vegetation belt with the Irano-Turanian semi-arid vegetation and Saharo-Arabian desert vegetating territories (Fig. 1a), it is a highly sensitive recorder for climate changes. The climate fluctuations derived from the pollen record and the evidence of human influence on natural vegetation were

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3 This pollen record is named ‘FD Ze’elim’.
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examine in relation to settlement history and to the regional climate as independently deduced by the Dead Sea level conditions (Migowski et al. 2006), and by the isotopic record of Soreq Cave, located in the Judean Highlands (Bar-Matthews and Ayalon 2004).

**Material and Method**

Four sediment wall-profiles, each 50 cm long, were recovered from the Ze’elim gully. These vertical profiles were described and photographed in detail in the field and re-examined in the laboratory, while sub-sampled for pollen analysis at ~5 cm intervals. Samples were processed using standard palynological techniques (Faegri and Iversen 1992). In total, 85 samples were taken, but only 40 samples have so far been analyzed and therefore are presented in this paper. Pollen grains were identified to the most specific possible systematic level. A simplified pollen diagram is presented in Figure 2. Taxa from the same geographical origin and/or with similar ecological characteristics were grouped together. The chronological framework of the Ze’elim profile was constructed by integrating the existing radiocarbon chronologies established on the older Ze’elim profile (Bookman (Ken-Tor) et al. 2004; Neumann et al. 2007; Kagan et al. 2011) and new dates achieved in this study. Here, five samples of only terrestrial short-lived organic debris (mainly twigs) were radiocarbon-dated (Table 2). All ages discussed in this text are calibrated (2σ-range).

**Results and Discussion**

*The Late Bronze*

During the Late Bronze Age, pollen was not preserved due to sedimentary erosion (= hiatus) and the accumulation of an ancient beach ridge at the Ze’elim site, in a shore depositional environment. Since the beach ridge was deposited when the Ze’elim site was exposed, it therefore points to a decline in the Dead Sea levels (Fig. 2). The youngest age available for the beach ridge – 1,320-1,040 cal. BCE [Bookman (Ken-Tor) et al. 2004], which marks the upper limit age of this unit, indicates that the beach ridge was embedded most probably during the end of the Late Bronze. The high resolution Sea of

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5 The sediments characterize different environments of deposition (terrestrial / lacustrine) and are classified as belonging to several facies representing the variations in water depth and the limnological configuration of the lake (Fig. 2).
6 The cores were wrapped and kept cool to prevent rapid and damaging halite crystallization.
7 For pollen identification, a pollen reference collection of Israel pollen flora was used (Museum of Biological Anthropology, Steinhardt National Collections of Natural History, Tel Aviv University) as well as pollen regional atlases. At least 500 terrestrial pollen grains were counted per sample.
8 The pollen diagram was plotted using the POLPAL program (Walansus and Nalepka 1999).
9 This beach ridge is comprised of cross-bedded sands and aragonite crusts (Fig. 2), and is almost pollen sterile due to poor preservation under oxygen rich conditions (oxygen destroys sporopollenin: Faegri and Iversen 1992).
10 The oak group (*Quercus*) includes two oak pollen types: the evergreen oak which is represented by *Quercus calliprinos* pollen type and the deciduous oak, which is represented by *Q. boissieri* and also includes *Q. ithaburensis* pollen.

11 The group of other Mediterranean trees includes trees such as *Phillyrea* and *Pistacia* (*terebinth*).

12 The group of cultivated crops consists of high frequencies of olive and cereals, and sporadic occurrences of walnut and grapevines (*Vitis*). The grapevines are one of the most important fruits of the Old World. Cultivated grapes have lower pollen dispersal efficiency than wild grapes (e.g. Langgut *et al.* 2013b), which explains their low presence in Near Eastern pollen diagrams and their sporadic appearance within the Ze’elim diagram, and therefore will not be discussed in this paper.

**IRON AGE I**

On top of the beach ridge unit sandy-marly sediments with ripple marks were deposited in a shallow shore environment (Fig. 2). A sedimentological-chronological correlation to other studies at the Ze’elim gully and at Ein-Feshka indicates that this layer was deposited during the Iron Age I (Bookman (Ken-Tor) *et al.* 2004; Neumann *et al.* 2007; Kagan *et al.* 2011). The pollen data derived from this unit displays a maximum percentage of oaks (Fig. 2), pointing towards higher available moisture. Other Mediterranean trees also appear in high percentages, signaling an expansion of the Mediterranean maquis/forest in the Judean Highlands towards the south. Maximum values along the sequence were recorded for cultivated crops, olive and cereals. The increase in precipitation probably triggered the spread of agriculture and the increase in settlement activity (> 250 settlements in the central hill country). The isotopic
record of Soreq Cave also indicates an increase in annual rainfall around 1,000 BCE\textsuperscript{15} (Fig. 3b; Bar-Matthews and Ayalon 2004), and the Dead Sea levels also slightly increased (however not exceeding 400 m; Fig. 3c; Migowski \textit{et al.} 2006). The rise of Mediterranean elements, such as oaks and pines, together with increasing values of cultivated olive trees were also recorded in previous Dead Sea palynological sequences (Neumann \textit{et al.} 2007; Litt \textit{et al.} 2012).

Towards the end of the Iron Age I, a reduction in the Mediterranean elements and cultivated crops (olive and cereals) was documented at the Ze’elim profile, accompanied by increasing values of Chenopodiaceae (goosefoot).\textsuperscript{16} These pollen spectra indicate less available moisture. At the same time, a slight decline in precipitation was documented at Soreq Cave (c. 950 BCE; Bar-Matthews and Ayalon 2004).

\textbf{IRON AGE II}

The Iron Age II is characterized by low oak percentages (Fig. 2). Olive and cereals pollen appear in lower quantities, whereas open land indicators of rather dry conditions increase strongly. Together with the spread of \textit{Artemisia},\textsuperscript{17} a stronger contribution, especially of the steppe elements, is indicated. The reduction of oaks in the southern Judean Highlands could be a result of the followings factors:

\textsuperscript{13} Olive trees (\textit{Olea europaea}) occur today in Israel in the Mediterranean territory both as cultivated (the vast majority) and natural elements (Zohary 1973). The wild olive is a minor component of the native Mediterranean forest (Horowitz 1979; Weinstein-Evron 1983; Kadosh \textit{et al.} 2004; van Zeist and Bottema 2009; Langgut \textit{et al.} 2011). Since the late Chalcolithic, much higher olive pollen values are documented in several Levantine palynological spectra (e.g. Baruch 1990; Neumann \textit{et al.} 2007, van Zeist \textit{et al.} 2009; Litt \textit{et al.} 2012) and are considered to reflect the spread of olive cultivation in the southern Levant. This palynological evidence is supported by archaeological findings of olive oil extraction facilities and crushed olive pits at Chalcolithic sites (e.g. Eitam 1993). Since the Early Bronze Age, large-scale utilization of olive orchards is evident by both archaeological finds and palynological data. Wild and domestic olive pollen grains are palynologically indistinguishable (Langgut \textit{et al.} forthcoming).

\textsuperscript{14} The Cerealia type pollen (Cereals), which is distinguished from other grasses by its larger pollen size, the thick pollen walls and the pronounced annulus around the pore, includes wild and cultivated cereals, in addition to several other Near Eastern grasses. From regular pollen grain identification one cannot tell whether they are wild or domesticated cereals (van Zeist \textit{et al.} 2009). Since wild cereals grow naturally in the Dead Sea area and in the Judean Highlands (Danin 2004), a rise in the cereals curve with no ecological explanation might be connected to agricultural activity.

\textsuperscript{15} However, the calculated precipitation did not exceed the present annual rainfall in this area – 500 mm.

\textsuperscript{16} Chenopodiaceae are the most dominant plants within the semi-desert and desert elements in the entire Ze’elim sequence. The Chenopod pollen grains embedded in the Dead Sea can be of two different origins: (A) from the hypersaline Dead Sea shore where Chenopodiaceae taxa are the leading pollen types (Baruch 1990); (B) the Sahara-Arabian biome – nearly all chenopods in the region are halophytic and drought-resistant plants (e.g. Danin and Orshan 1999). I assume, in agreement with other scholars (Horowitz \textit{et al.} 1975; Horowitz 1979; Baruch 1990; Neumann \textit{et al.} 2007; Litt \textit{et al.} 2012), that due to the predominance of wind pollination within the family and the open landscape, the parental plants might dwell far away and consequently the influence of local Chenopodiaceae might be low.

\textsuperscript{17} \textit{Artemisia} (wormwood) is a wind pollinated taxa, mainly originating from the Irano-Turanian vegetation territory.
Less available moisture. In addition to pollen indicators, slightly drier climate conditions are manifest from the isotopic records of the Soreq Cave during the period of c. 900-600 BCE (Bar-Matthews and Ayalon 2004).

Less developed Mediterranean maquis/forest in the Judean Highlands due to human pressure (both anthropogenically induced deforestation and intense settlement activity): The inconsistent appearance and low percentages of the two oak types might be a result of deforestation. The almost total disappearance of pines (a pioneer tree in Mediterranean forest rehabilitation; Baruch 1990) indeed indicates that the Mediterranean maquis/forest in the Judean Highlands was under strong anthropogenic pressure. The peak of human activity that started in the Iron Age I reached its zenith during the Iron Age IIB-C (8th-7th centuries BCE) with 520 settlements in the hill country with a specific peak in the Judean Highlands (Table 1 and Figs. 3d, 3e; Ofer 1994; Broshi and Finkelstein 1992). The continuous presence of grazing resistant plants – the thistle plants, reaching maximum values at the beginning of this period – indicates increased animal husbandry in the area. Interestingly, those pollen-types reach a maximum, while grasses (Poaceae) are low or even missing in the pollen record. This might signal the spread of non-palatable herbs (e.g. thistle taxa), during times of overgrazing. Indeed, the archaeozoological evidence points to an increased dependence on livestock from the Bronze to the Iron Ages (e.g. Grigson 1995). Other secondary anthropogenic indicators, which are pre-adapted to survive under human pressure as well, also reach their maximum distribution (Fig. 2). All these palynological indicators support the archeological evidence concerning intense human pressure on the highland’s vegetation.

The long term effects of this anthropogenic interference probably led to a reduction in vegetation cover that resulted in higher runoff which, in turn, exacerbated soil removal and lower water penetration into the ground. In addition, intensive agriculture during earlier periods possibly led to soil deterioration. The drop in Mediterranean forest cover can therefore be a result of a combination of two factors: slightly less available moisture together with strong anthropogenic pressure. The restricted olive orchard distribution characterizing this period can be due to less available moisture and/or the intentional human economic strategy of shift of olive oil production to the Shephelah (lowlands further to the west; e.g. Eitam 1993), due to the intensity of human activity in the highlands (e.g. grazing). The first appearance of the imported tree, the Persian walnut (Juglans regia), in the Judean Mountains occurred during Iron Age II (Fig. 2).

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18 Persian walnut (Juglans regia) grows naturally in the mesic temperate forests of Western Asia, predominantly in cool, hilly areas. Its cultivation probably started before Roman times, most likely in north Iran, northeastern Turkey and the Caucasus. Its earliest wood remnants in ancient Israel were found in the Middle Bronze Age strata (Zohary et al. 2012). Based on Ramat Rahel pollen assemblages, J. regia was first introduced in the northern Judean Highlands during the Persian period (4th century BCE; Langgut et al. 2013).
BABYLONIAN AND PERSIAN PERIODS

The exact point of the Iron Age-Babylonian Period transition is not clearly defined in the Ze’elim sequence. Still, it seems that the uppermost part of the Ze’elim diagram covers the Babylonian and Persian periods. It is characterized by a slight increase in *Artemisia* values, pointing to relatively arid climate conditions. Percentages are low and inconsistent for oaks and medium for other Mediterranean trees. The reappearance of pines (Fig. 2) points to the beginning of the natural rehabilitation process of the Mediterranean maquis/forest in the Judean Highlands, when less anthropogenic pressure took place (Baruch 1990). The presence of thin sandy layers also signifies dry climate conditions. Archaeology indicates a major demographic crisis in the Judean Highlands in the Babylonian and Persian periods. The Persian Period population in the Judean Highlands was c. 15% of the population in the same area in Iron Age II (Finkelstein 2010). Lipschits (2005) estimates a decline of more than 70% in settled area between the end of the Iron Age and the Persian Period. This crisis was a result of the destruction of the kingdom of Judah by the Babylonians (Lipschits 2005).

CONCLUSIONS

Overall, the pollen record provides a high-resolution archive (~ 20-25 years per sample) of climate conditions which allow a comparison to the regional climate (the Dead Sea lake levels reconstruction and the Soreq Cave isotopic record). Most vegetation changes occurred in the Mediterranean and steppe zones, while the desert zone remained rather stable.

The end of the Late Bronze was arid, as is evident by the accumulation of the beach ridge (Fig. 2), by the significant fall in the lake levels (Migowski et al. 2006) and by the decrease in humidity in the Judean Highlands area (Bar-Matthews and Ayalon 2004). The dry climate conditions seem to correspond to the vast occurrence of destruction layers in the region and to references in ancient Near Eastern texts to a period of dryness and droughts, and thus political instability. Severe dry conditions at that time most probably were the main reason for the collapse of eastern Mediterranean cultures in the late 13th and early 12th centuries BCE (the ‘Crisis Years’ – Ward and Joukowsky 1992; Langgut et al. 2013a).

More available moisture characterized the transition to Iron Age I as well as most of this period itself. The improved conditions in the highlands enabled the recovery of settlement activity, which was the backdrop for the rise of ancient Israel (Finkelstein 1995). Similar conditions in other parts of the highlands in the Levant could have led to the development of equivalent settlement systems, which gave birth to other biblical nations – the Arameans in Syria and the Ammonites and Moabites in Transjordan. Towards the end of Iron Age I (c. 950 BCE) and during Iron Age II to the Persian Period, the region experienced slightly drier climate conditions.
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1973 *Geobotanical Foundations of the Middle East*, Stuttgart/Amsterdam.
Table 1: Rough estimate* of number of sites and total built-up area in the Judean Highlands** and the hill country*** from the Late Bronze Age to the Persian Period

| Period                  | Judean Highlands**** | General Central Highlands, including Judean Highlands | Total built-up area
<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td></td>
<td>No. sites*****</td>
<td>Total built-up hectares******</td>
<td>No. sites*****</td>
</tr>
<tr>
<td>Late Bronze 1,550-1,150 BCE</td>
<td>9</td>
<td>9</td>
<td>29</td>
</tr>
<tr>
<td>Iron I 1,150-950 BCE</td>
<td>18</td>
<td>20</td>
<td>254</td>
</tr>
<tr>
<td>Iron IIA 950-780 BCE</td>
<td>34</td>
<td>50?</td>
<td>No data</td>
</tr>
<tr>
<td>Iron IIB 780-680 BCE</td>
<td>70</td>
<td>180</td>
<td>528</td>
</tr>
<tr>
<td>Iron IIC BCE 680-586 BCE</td>
<td>roughly the same as Iron IIB</td>
<td>No data</td>
<td>No data</td>
</tr>
<tr>
<td>Babylonian and Persian periods (586 BCE – late 4th century BCE)</td>
<td>a decline of more than 70% in settled area******</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* The central hill country, the hub of ancient Canaan, was intensively explored in archaeological surveys in the 1980s and 1990s (Ofer 1994; Finkelstein and Magen 1993; Finkelstein et al. 1997; Zertal, 2004; 2008). The result is comprehensive data on the settlement systems, which made possible the production not only of a settlement map for each period, but also a classification of the sites (and in the case of multi-period sites, each period of activity) according to size and hence allowing us to estimate regarding total-built up area.

** From Jerusalem (included) to the south.

*** Between the Jezreel and the Beer-Sheba Valleys.

**** The quality of the data for the different sectors of the central highlands varies. Regarding the Judean Highlands, due to the method of the survey (full-coverage was achieved in only part of the area) and the nature of the region today (much of it built-up and intensively terraced), the picture is more fragmentary. This area is the most arid of the different north-south sectors of the highlands, and hence until the late Iron II both the number of sites and their size (that is population size) are limited. The sedentary population of this region did not exceed a few thousand until Iron Age II. The first meaningful increase is recorded in Iron Age IIA (9th century BCE) and the real leap forward came only in Iron Age IIB. Data according to: Broshi and Finkelstein 1992; Finkelstein 1995; 1996; Ofer 1994.

***** Only habitation sites are included. Pastoral groups are not represented

****** Population estimates can be reached by using the widely accepted coefficient of c. 200 people per a single built-up hectare (e.g. Finkelstein 1990).

******* Between the end of the Iron Age and the Persian Period, there was a decline of more than 70% in settled area. The crisis probably occurred during the time of Babylonian rule, and the epicenter of the crisis was the destruction of the kingdom of Judah (Lipschits 2005).
Table 2: Results of radiocarbon dating and OxCal modeling of FD Ze’elim profile

* Samples were prepared in the Radiocarbon Dating Laboratory of the Weizmann Institute of Science, Rehovot, Israel and measured by the Accelerator Mass Spectrometry (AMS) Laboratory at the NSF-radiocarbon facility of the University of Arizona. Radiocarbon ages are reported in conventional radiocarbon years (before present = 1950) in accordance with international convention (Stuiver and Polach 1977). The 14C ages were calibrated to calendar years (cal BP) defined by the 2σ envelope error using the OxCal v.4.1 program of Bronk Ramsey (2001).

** When possible, different samples were taken from the same horizontal strata. These samples yielded overlapping radiocarbon ages.

<table>
<thead>
<tr>
<th>Serial No.</th>
<th>Sample field ID</th>
<th>Lab.* No.</th>
<th>Depth in m bsl and in field measurements**</th>
<th>C14 yr (BP)</th>
<th>Calibrated age range (68% probability)</th>
<th>Calibrated age range (95% probability)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>FDd I (306)</td>
<td>RTK 6326-1</td>
<td>406.44 3.06</td>
<td>2,340 ± 50</td>
<td>510BC (68.2%) 370BC</td>
<td>735BC (4.9%) 690BC 665BC (1.1%) 650BC 550BC (80.2%) 350BC 295BC (8.6%) 230BC 220BC (0.6%) 210BC</td>
</tr>
<tr>
<td>2</td>
<td>FDd II (306)</td>
<td>RTK 6326-2</td>
<td>406.44 3.06</td>
<td>2,430 ± 50</td>
<td>735BC (14.1%) 690BC 660BC (3.6%) 650BC 545BC (50.5%) 410BC</td>
<td>755BC (20.1%) 685BC 670BC (75.3%) 400BC</td>
</tr>
<tr>
<td>3</td>
<td>FDd I (230)</td>
<td>RTK 6325</td>
<td>407.20 2.30</td>
<td>2,895 ± 50</td>
<td>1,192BC (4.7%) 1,177BC 1,161BC (5.6%) 1,144BC 1,132BC (57.8%) 1,005BC</td>
<td>1,260BC (4.3%) 1,230BC 1,220BC (86.8%) 970BC 965BC (4.3%) 930BC</td>
</tr>
<tr>
<td>4</td>
<td>FDd II (230)</td>
<td>RTK 6325-2</td>
<td>407.20 2.30</td>
<td>2,935 ± 50</td>
<td>1,250BC (3.4%) 1,240BC 1,215BC (64.8%) 1,055BC</td>
<td>1,310BC (95.4%) 1,000BC</td>
</tr>
<tr>
<td>5</td>
<td>FDd I (164)</td>
<td>RTK 6324</td>
<td>407.86 1.64</td>
<td>3,070 ± 50</td>
<td>1,410BC (66.7%) 1,295BC 1,280BC (1.5%) 1,275BC</td>
<td>1,445BC (94.9%) 1,195BC 1,140BC (0.5%) 1,135BC</td>
</tr>
</tbody>
</table>
* Freshwater arrives at the Dead Sea from a very large watershed extending from Mount Hermon in the north to the Gulf of Aqaba in the south. The Jordan River and its tributaries and seasonal runoff from the basin shoulders provide most freshwater to the lake. Most of the wadis draining the Judean Highlands to the west of the lake and the highlands of Moab and Edom to its east only bear water due to occasional winter floods from October through May. A few perennial streams, such as Wadi el Mujib (Arnon) in Jordan, discharge into the lake. Natural fluctuations of the Dead Sea levels are induced by rainfall changes (e.g. Bookman (Ken-Tor) et al. 2004).

** Since the southern Judean Highlands are located on the southern border of the Mediterranean vegetation belt with the Irano-Turanian vegetating territory, it is a highly sensitive area for recording climate changes.

*** Water flows through the Ze’elim wadi only several days a year, associated with storm events in the higher parts of the Judean Highlands and in the Judean Desert.
Fig. 2: Simplified pollen diagram of the Ze’elim sequence.
* The chronology and the division into historical periods are based on 14C dates (Table 2), calibrated in 2 σ-range and the identification of ‘Amos’s earthquake’ (based on lithology).

** A X 10 exaggeration is used to show changes in low taxa percentages.

*** Plants within this group are thorny Asteraceae, mainly thistles (Cirsium, Carduus, Carthamus, Xanthium and Echinops), and different species of Centaurea (knapweeds), which are all grazing-resistant plants. Therefore, increasing values of the members of this group can reflect increase in pasture.

**** Secondary anthropogenic indicators also called ruderal weeds – a group of plants which can be related to human activities (Zohary 1973). The plants that comprise this group are native to the region and often adapt themselves to man-made habitats like members of the Polygonaceae family (knotweed), Urtica (Nettle) and plantain (Plantago lanceolata type, which also include P. lagopus; Danin 2004).

***** Open land indicators – a group of herbs and shrubs belonging to the following families: Poaceae, Caryophyllaceae, Brassicaceae and Asteraceae. They are mainly derived from semi-desert and desert vegetation (Baruch 1990) but can also originate from the Mediterranean territory from sparse maquis/forests, open fields and disturbed areas, e.g. forest clearances and building sites.

****** The lithology of this section (grey marls with small fragmented aragonite = breccia) indicates that part of the clay deposits were later deformed by a seismic event, which was dated by Kagan et al. (2011) to 861-705 cal. BCE and correlated to the earthquake mentioned in Amos 1:1 in the days of Uzziah King of Judah (787–736 BCE) and Jeroboam II King of Israel (788-747 BCE). Austin et al. (2000) suggest a date of c. 750 BCE for Amos’s earthquake.
Fig. 3: Climate changes in the southern Levant – a comparison of various paleoclimate proxies and settlement history:
a. Sedimentological and palynological indicators (= this study);
b. Estimated annual rainfall from the Soreq Cave record (1 = Bar Matthews and Ayalon 2004). Present annual rainfall at Soreq Cave area = 500 mm (dashed line);
c. Reconstructed Dead Sea levels (2 = Bookman (Ken-Tor) et al. 2004; 3 = Migowski et al. 2006). Dashed line = estimated lake level;
d. Settlement fluctuations in the Judean Highlands; e. Settlement fluctuations in the central hill country. The dark column represents the total build up area in hectares and the light column symbolizes the number of sites (the settlements fluctuations data are summarized in Table 1).

LB = Late Bronze; IA = Iron Age; Babylon. = Babylonian