
Volume 30 Issues 27–28 December 2011 ISSN 0277-3791
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Quaterary Science Reviews 30 (2011) 3960–3972

Contents lists available at SciVerse ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

Vegetation and climate changes in the South Eastern Mediterranean during the Last Glacial-Interglacial cycle (86 ka): new marine pollen record

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ARTICLE INFO

Article history:
Received 15 May 2011
Received in revised form
3 October 2011
Accepted 31 October 2011
Available online 22 November 2011

Keywords:
Paleoclimate changes
Pollen
Vegetation reconstruction
Eastern Mediterranean Sea
Late Pleistocene
Holocene
Levant

ABSTRACT

The Eastern Mediterranean, located at the meeting between the Mediterranean vegetation of the Eurasian continent and the desert vegetation of the Saharan-Arabian desert belt, is ideal for tracking changes in regional vegetation as function of climate changes. Reconstruction of these changes in the South Eastern Mediterranean during the last 86 ka is based on a palynological record, from deep-sea core 9509, taken by R/V *Marion Dufresne*, off the southern Israeli coast. The chronological framework is based on the correlation of $\delta^{18}O$ records of planktonic foraminifera with the high resolution, well-dated U-Th speleothem record from the Soreq Cave, Israel and the occurrence of sapropel layers. Several cycles of humid/dry periods were documented during the last 86 ka. The record starts with the moderate humid and warm sapropel S3 marking the end of Marine Isotope Stage (MIS) 5. The climate during the Last Glacial period (75.5–16.2 ka) was cold and dry, with low Arboreal Pollen (AP) levels, and high values of semi-desert and desert vegetation (e.g. *Artemisia* - sagebrush). The driest and coldest period during the last 86 ka corresponds to MIS 2 (27.1–16.2 ka), characterized by the lowest tree cover along the sequence and the dominance of steppe vegetation. Some slightly more humid fluctuations were identified during the period of 56.3 and 43.5 ka with its peak between 56.0 and 54.4 ka. The most pronounced climate change started at the beginning of the Deglaciation (16.2–10 ka) and continued throughout the Holocene (last 10 ka), notwithstanding some short fluctuations. High AP levels were dominated by *Quercus calliprinos* (evergreen oak), suggesting that the Mediterranean forest was more extensive in the area and the climate was wet.

Sapropels S3 and S1 were clearly recognized here by the high concentrations and good state of preservation of pollen because of the development of anoxia in the bottom water that may be related to more extensive Nile discharge coinciding with high insolation values at 65° N and enhanced westerlies activity. Another wet and warm event is the Bölling-Allerød (14.6–12.3 ka). Cold and dry spells identified by low AP and high steppe elements correspond with Heinrich Events H2–H6, the Last Glacial Maximum, Younger Dryas and the 8.2 ka event. Similar pattern of vegetation trends was observed also in Lake Zeribar Western Iran, Tenaghi Philippon North East Greece and the Alborán Sea. There is a clear general difference between the South East Mediterranean and western and central Mediterranean because of W-E climatic moisture gradient reflected in the dominance of Mediterranean maquis, lower tree population and higher steppe vegetation in the South East Mediterranean.

1. Introduction

Pollen records from the Eastern Mediterranean Sea serve as direct indications for the paleovegetation and paleoclimate of the Levant and nearby area, and yet a relatively detailed pollen resolution from the South Eastern Mediterranean is still scarce. During the last ~90 ka the region experienced large climatic fluctuations (e.g. Horowitz, 1979; Bar-Matthews et al., 1997, 2003; Frumkin et al., 1999; Almogi-Labin et al., 2004, 2009), that must have affected the vegetation (e.g. Rossignol-Strick, 1993). There are increasing numbers of high resolution paleoclimate studies on the Levant both on the marine and land realm (e.g. Robinson et al., 2006; Almogi-Labin et al., 2009; Box et al., 2011, and references therein), showing that the paleoclimate and paleohydrology in the South East Mediterranean region responded to glacial-interglacial cyclicity and that the long-term trend is often punctuated by

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doi:10.1016/j.quascirev.2011.10.016

several shorter climatic events such as the Last Glacial Maximum (LGM), Heinrich Events, the Bölling-Allerød phase, the Younger Dryas (YD) episode and the 8.2 ka event.

Previous palynological marine records from the Levant were studied by Cheddadi and Rossignol-Strick (1995a,b). They documented the paleoclimate of the area during the last 250 ka, based on three marine pollen records (MD 84 642, MD 84 629, MD 84 627), located at the distal part of the Nile Cone (Fig. 1b). During the interglacial period, the abundance of tree pollen reached its maximum, indicating an optimum Mediterranean climate of great humidity, including some summer rainfall. During glacial maxima pollen of steppe and semi-desert plants were abundant and low for trees, suggesting more arid, continental and probably colder climate. Short-lived climatic events were not identified in these records due to relatively low sampling resolution. Moreover, Rossignol (1963, 1969) examined Pleistocene and Holocene cores from the Israeli coast and found only minor fluctuations along the sequences because of low resolution and interpreted them as slight oscillations in humidity. Horowitz (1974, 1979) studied two cores from Haifa Bay, covering the last 6 ka and suggested that during the early part of this period tree cover was more extensive in the area than at present, and therefore the climate was probably wetter whereas during the last 3 ka arboreal vegetation decreased, pointing to dryness. From the Levantine coastal plain only limited palynological records are available, indicating an existence of marshes at the beginning of the Holocene and a notable expansion of oak maquis suggesting a relatively wet early Holocene (Galili and Weinstein-Evron, 1985; Kadosh et al., 2004).

Several Eastern Mediterranean marine palynological studies in higher resolution focused on the paleoclimate conditions during the formation of sapropel layers (e.g. Rossignol-Strick et al., 1982; Rossignol-Strick and Paterne, 1999; Kotthoff et al., 2008a). Sapropels are dark-colored marine sediments, thicker than 1 cm, with a high content (>2%) of organic matter (Kidd et al., 1978). Sapropel deposition is most common in the Eastern Mediterranean, related to deep-water stagnation. Increased riverine runoff caused a reduction of surface-water salinity, thus weakening deep-water formation. At the same time, it may have provided an enhanced nutrient supply (e.g. Rohling, 1994; Kotthoff et al., 2011). A particularly important contribution to the formation of sapropels is the discharge of the River Nile to the Levantine Basin (e.g. Rossignol-Strick et al., 1982; Rossignol-Strick, 1985; Fontugne et al., 1994; Rohling, 1994; Calvert and Fontugne, 2001; Scrivner et al., 2004).

This study discusses the palynological sequence of the last 86 ka in a higher resolution as compared with previous marine pollen records from the South Eastern Levantine Basin. Pollen was extracted from core 9509, taken from the distal part of the Nile Cone (Fig. 1b). The importance of this marine palynological record is: 1. The time frame is well constrained and is based on the comparison of the $\delta^{18}O$ of the planktonic foraminifera *Globigerinoides ruber* with the accurately dated, high resolution isotopic record of Soreq Cave speleothems (Almogi-Labin et al., 2009); 2. Core 9509 was already subjected to a high resolution study of sediment characteristics including index color parameters, Total Organic Carbon (TOC) and Sea Surface Temperatures (SST) based on alkenones (Almogi-Labin et al., 2009) as well as the identification of

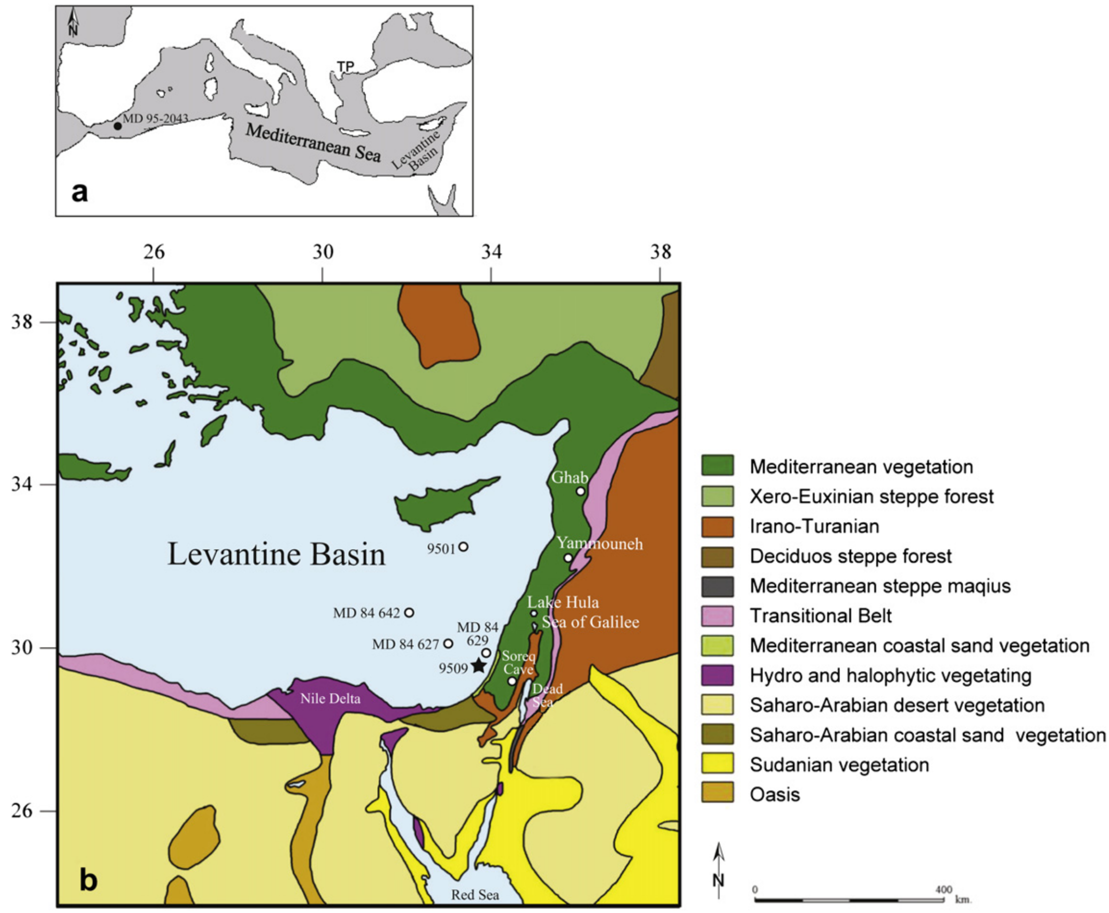

Fig. 1. a. Map showing the Mediterranean Sea with the location of the Levantine Basin. b. Eastern Mediterranean vegetation map (modified after Zohary, 1973) together with the location of marine core 9509 and other sites mentioned in the text.

benthic foraminifera assemblages (Avnaim-Katab, 2005); 3. Identification of periods of enhanced dust supply vs. periods of enhanced Nile sediment supply (Box et al., 2011) and clear identification of sapropels S3 and S1 (Almogi-Labin et al., 2009). However no detailed palynological study was performed in this key region to verify how the vegetation surrounding the South East Mediterranean Sea responds to paleoclimate, paleoenvironment and paleohydrological changes. In this study an integration of the vegetation history of a large geographical area will be performed. In contrast to terrestrial records, pollen grains deposited in marine settings derive from a large catchment area and therefore usually represent an extended reconstructed zone which is located in the current study at a meeting point of the Eurasian continent, the Saharan-Arabian desert and the Eastern Mediterranean region. Another important advantage of studying core 9509 is its unique location under the Nile plume, which makes the sedimentation rates high. Hence it allows good palynomorph preservation, enabling detailed analysis of short-term terrestrial ecosystem changes in the Levantine region.

1.1. Present climate and vegetation

The location of the Eastern Mediterranean region between the Mediterranean vegetation belt to the north and the desert vegetation belt to the south makes this area an ideal site to track how these belts shifted as a function of climate changes. The major climate system that affects the Levant is the Cyprus Low, responsible for both rain and dust transport to the Levant (Dayan et al., 2007). During winter, the westerly winds bring in cyclonic low barometric pressures, causing cold air masses to arrive from the Atlantic and the North Sea. While traveling over the relatively warm Mediterranean, the air masses become saturated with moisture, which later discharges as rain and snow (Dayan, 1986; Eshel, 2002). The summers are hot and dry caused by sinking air of the subtropical highs. A strong high-pressure ridge pushes eastwards from the Azores subtropical high and develops over the Mediterranean. The Persian trough active during the summer extends north-west from the Persian Gulf and is associated with the West Asian (Indian) summer monsoon. In the autumn and spring, when dust storms are most abundant, the hot and dry periods can come to an abrupt end with a heavy rainstorm (Ganor and Foner, 1996). Another important system which affects mainly the hydrology of the Mediterranean Sea is the monsoonal system, which originates in the tropical Atlantic or the Southern Indian Ocean, passes over North East Africa and is associated with a low-latitude rainfall system. The monsoonal system is and was at its most intense during periods of summer maximum insolation in the northern Hemisphere that coincides with elevated discharge from the River Nile (Rossignol-Strick et al., 1982; Rossignol-Strick, 1985; Haynes, 1987).

The Eastern Mediterranean region today is divided into three main phytogeographical regions (Fig. 1b; Zohary, 1962, 1973; Danin, 2004): Mediterranean, Irano-Touranian and Saharo-Arabian: The Mediterranean territory covers the mountainous areas bordering the Mediterranean in Western and Southern Anatolia and along the Levantine shores and the coastal plain of Cyprus, where the arboreal vegetation extends from sea level up to 1200 m elevation. The Mediterranean maquis appears on both sides of the Jordan River Mountain ranges with typical evergreen trees such as *Quercus callipprinos*, *Olea europaea*, *Pistacia lentiscus*, several coniferous species (e.g. *Pinus halepensis* and *P. brutia*) and some deciduous trees (e.g. *Quercus boissieri and Quercus ithaburensis*). Above 1200 m of altitude conifers such as *Pinus nigra*, *Abies cilicica* and *Cedrus libani* are predominated. Mesophytic vegetation occupies the northern parts of Anatolia, throughout the shores of the Black Sea. The very wet and mild climate of this area supports an extensive temperate forest with various deciduous trees (e.g. *Acer*, *Corylus*, *Betula*, *Alnus*, *Carpinus*). This territory receives 350–1200 mm annual rainfall and is generally influenced by north synoptic systems together with more regional orographic phenomena.

The Irano-Touranian phytogeographic region occupies central Anatolia and spreads crescent-like in the Syrian plateau east of the Mediterranean coastal strip and the central Jordanian mountain area. It ends at the southern part of the Israeli coastal plain. This is an almost treeless landscape with semi-arid vegetation, often described as steppe. Different species of Poaceae and Chenopodiaceae are the main components of this region as well as *Artemisia*. The Irano-Touranian territory is typified by an extremely continental climate with four seasons and summer droughts. The annual rainfall in the area is 150–350 mm on average, mainly because of western depressions. The region is also characterized by relatively broad seasonal and daily temperature distributions.

The Saharo-Arabian territory includes the Sahara Desert, the Arabian Desert, the Arava Desert and the Mediterranean shores in Israel, Egypt and Libya. The vegetation is typified by relatively low species diversity with an abundance of shrubs and biennial plants. The desert strips adjacent to the Mediterranean Sea are dominated by different species of Poaceae, Chenopodiaceae *Artemisia monosperma* and *Ephedra distachya* type. The Saharo-Arabian region has a typical desert climate: the mean annual rainfall does not exceed 150 mm and is usually lower than 50 mm. Seasonal and daily temperature distributions are broad. This area is influenced by southern and southeastern synoptic systems as well as by western depressions which are widespread in the spring and autumn. The coastal plain, although receiving more than 150 mm rainfall, is characterized by the same vegetation due to its sandy soil and saline environment.

2. Materials and methods

Core 9509 was taken from the VALPAMED set of cores, collected by the R/V Marion Dufresne in February 1995. This 17.8 m long core was recovered from the South Eastern Levantine Basin, at 32°01.90 N, 34°16.98 E and 884 m water depth (Fig. 1b), off the southern coast of Israel. It was sampled for palynological analysis, at ~10 cm intervals in non sapropel and 5 cm in sapropel layers. One hundred twenty samples were processed using standard palynological techniques (Faegri and Iversen, 1992). *Lycopodium* spores tablets were added in order to calculate pollen concentrations. Pollen grains were identified to the highest possible systematic level.

The pollen sum is composed of arboreal pollen (AP) and the non arboreal pollen (NAP). Components which were excluded from the total sum are: Hydrophilous plants (with the exception of Cyperaceae; cf. Cheddadi and Rossignol-Strick, 1995a,b, to enable comparisons between the studies), spores, algae, fungal and dinoflagellates. Bisaccates were first calculated as part of the pollen sum (Fig. 3a) but were later excluded since they are greatly overrepresented, especially in marine sediments, owing to their good long-distance transport ability and particularly high resistance to degradation (e.g. Rossignol-Strick and Planchais, 1989; Cheddadi and Rossignol-Strick, 1995b). The proportions of the various pollen types are expressed as percentages of the basic total sum, meaning % of AP + NAP excluding bisaccates (Fig. 3b–q). Taxa from the same origin and with similar ecological characteristics were grouped together.

The chronological framework of the current study is based on a correlation of the planktonic foraminifera $\delta^{18}O$ *G. ruber* record with the high resolution, well-dated speleothem record from the Soreq Cave, Israel and with the ^{14}C chronology of core 9501 (Fig. 1b and Almogi-Labin et al., 2009). It also takes into account the

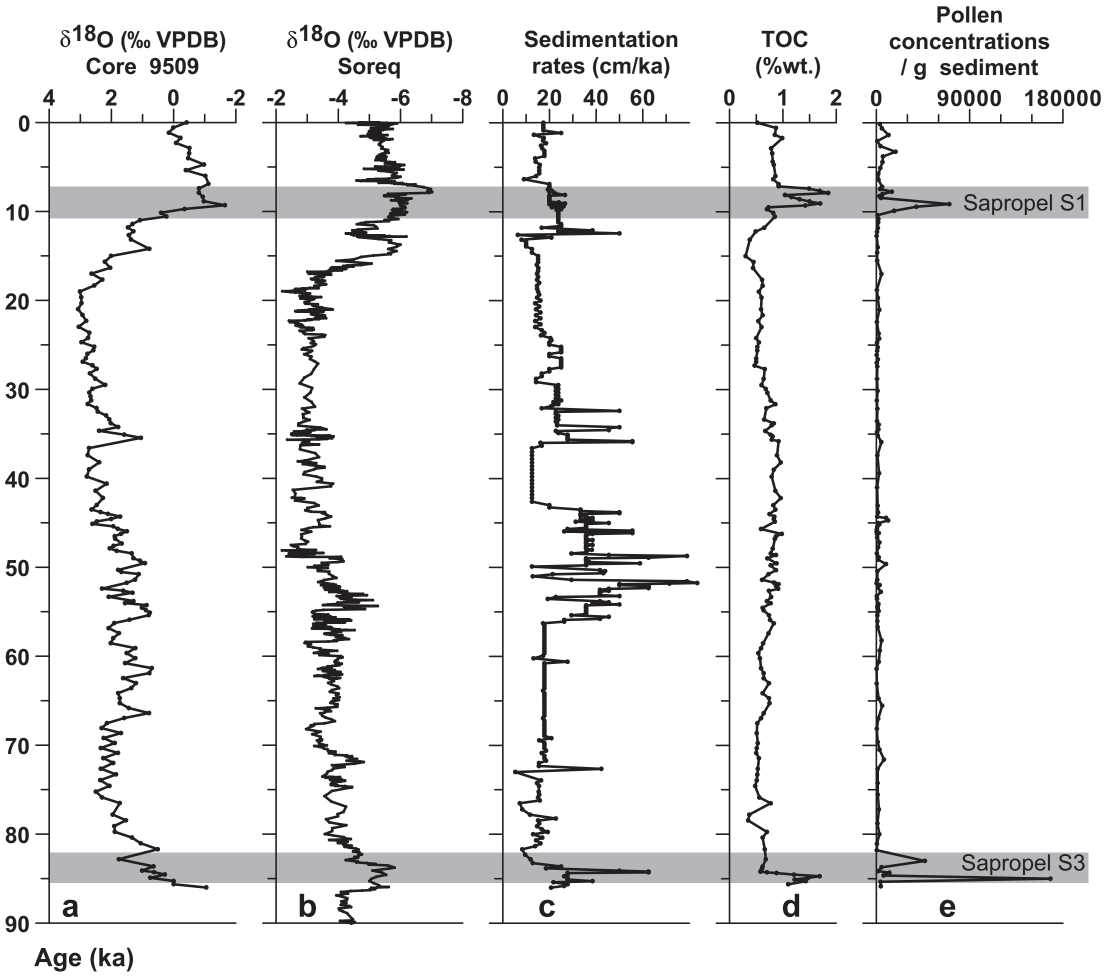

Fig. 2. a. The $\delta^{18}O$ of the planktonic foraminifera *Globigerinoides ruber* of core 9509 (Almogi-Labin et al., 2009) vs. age; b. The $\delta^{18}O$ of Soreq Cave speleothems (Bar-Matthews et al., 2003); c. Sedimentation rates; d. Total organic carbon content (wt.%) following Almogi-Labin et al. (2009) and e. Pollen concentration/g sediment in core 9509. The horizontal gray bars indicate sapropel S1 and S3.

identification of sapropels, based on the significant increase in both TOC content and pollen concentrations, as well as the good state of pollen preservation. The record starts at 86.0 ka at the end of Marine Isotope Stage (MIS) 5 and lasting till present.

3. Results

3.1. TOC, pollen concentrations and sedimentation rates

Detailed sedimentological analyses were performed on core 9509 by Almogi-Labin et al. (2009). TOC values and pollen concentrations are relatively constant (0.6–0.9 wt% and 2334/g sediment on average, correspondingly) except for a distinct increase in both parameters during sapropels S1 and S3 (Fig. 2). Sedimentation rates are 20.7 cm/ka on average, and they fluctuate over time. Extremely high rates occur at 85.8–83.6 ka (33.6 cm/ka on average), 55.8–43.5 ka (40.9 cm/ka on average) and 35.9–32.4 ka (32.9 cm/ka on average).

3.2. Pollen Zones

The pollen diagram in Fig. 3 includes mainly the key pollen taxa. It was divided into five pollen zones chiefly based on changes in the AP values, main vegetation groups, pollen concentrations and the state of pollen grain preservation.

3.2.1. Pollen Zone I: 86.0–75.5 ka – MIS 5a

The lower part of the diagram begins with high values of the two pollen oak types (evergreen up to 21.6% and deciduous up to 6.8%) together with medium presence of other Mediterranean trees (up to 2.2%) and temperate trees (that do not exceed 7.3%). AP levels as well as Cheno/Ams decline substantially (2.5–27.0%) throughout the zone (it is worth noting that Chenopodiaceae and Amaranthaceae pollen grains are palynologically indistinguishable and therefore were grouped together as Cheno/Ams; Faegri and Iversen, 1992). Semi-arid and desert vegetation such as *Artemisia* (5.4–18.6%), both *Ephedra* types (1.4–11.7%), Poaceae (0.5–5.8%) and other NAP (3.6–17.7%) appear in medium proportions. The highest percentages in AP and oak values around 85 ka is also accompanied by a better state of pollen preservation and coincides with sapropel S3. Significantly, high pollen concentrations (up to 167,897/g sediment) occur between 85.9 and 83.0 ka, whereas the high TOC values (1.1–1.7 wt%) of sapropel S3 are restricted to a shorter time interval between 85.9 and 84.5 ka (Fig. 2). During the base of sapropel S3 the bisaccates occur in minimal percentage (5.3–8.5%) and increase sharply immediately after (33.4%; Fig. 3).

3.2.2. Pollen Zone II: 75.5–56.3 ka

A sharp decline in evergreen oak (0.4–6.3%) characterizes the beginning of the Last Glacial period. At the same time other pollen taxa change more gradually with Cheno/Ams (13.1–55.8%),

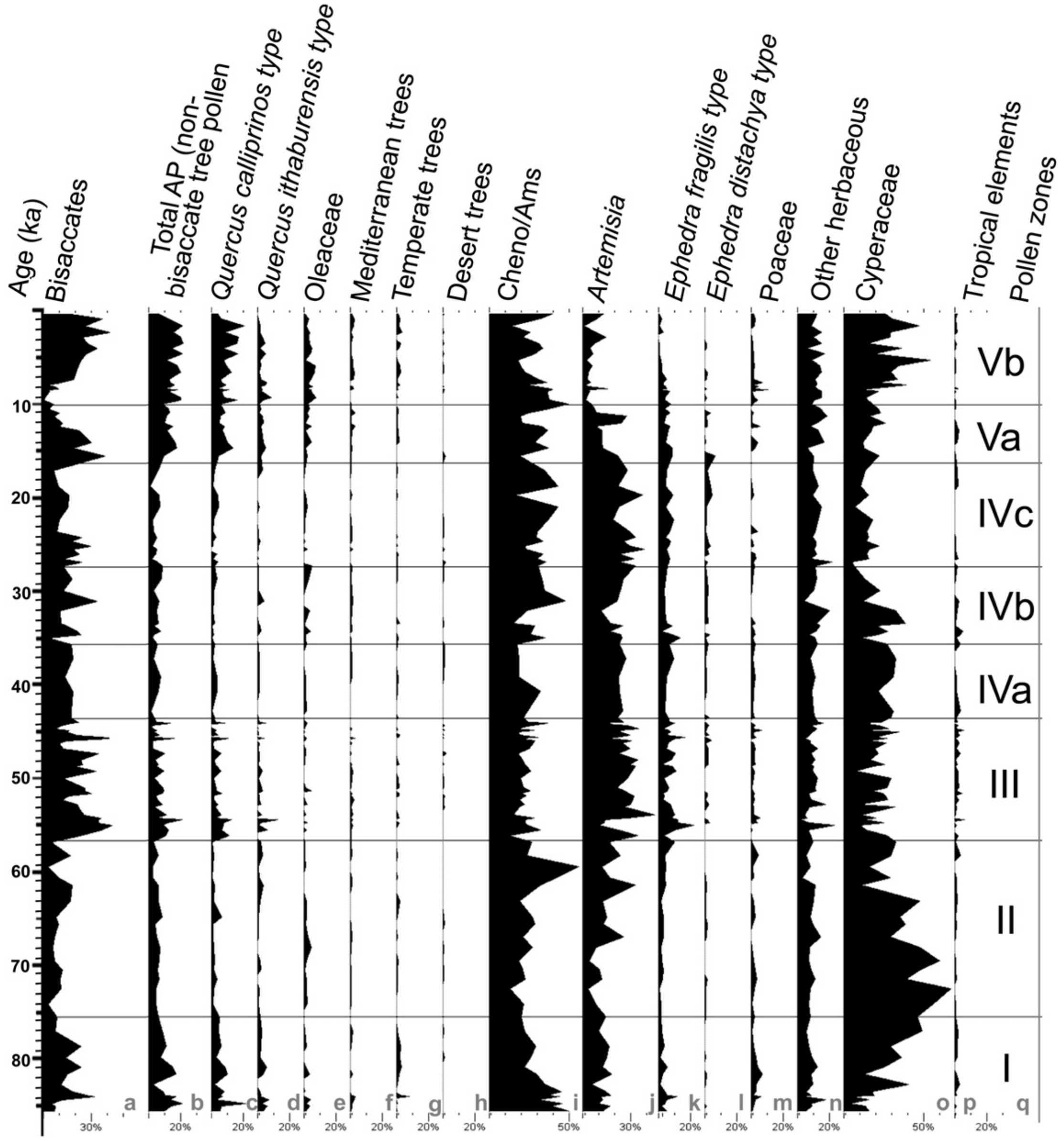

Fig. 3. Concise palynological diagram of core 9509 and Pollen Zones vs. age. The diagram comprises (from left to right): a. Bisaccates which were calculated separately (see text for explanation). b. Total AP – the sum of all woody taxa presented in curves b–h, excluding bisaccates. c. *Quercus calliprinos* type (evergreen oak), d. *Quercus ithaburensis* type (deciduous oak), e. Oleaceae (*Olea europaea* and *Phillyrea*), f. Mediterranean trees (sclerophyll trees such as *Ceratonia siliqua*, *Cupersuss* sp. and *Arbutus*), g. Temperate trees (deciduous trees such as *Acer*, *Corylus*, *Betula* and *Alnus*) and h. Desert trees (e.g. *Acacia*, *Tamarix*). NAP curves i–o: i. Cheno/Ams (Chenopodiaceae and Amaranthaceae), j. *Artemisia*, k. *Ephedra fragilis* type, l. *Ephedra distachya* type, m. Poaceae, n. Other herbaceous (different herbs which appear in low quantities) and o. Cyperaceae. p. Tropical elements (pollen from Nilotic origin) and q. Pollen Zones.

Artemisia (3.5–32.8%) and the two *Ephedra* types (1.3–10.1%), increasing toward the top of the upper part of this zone while Oleaceae (0–4.3%) and Cyperaceae (16.3–68.0%) decrease.

3.2.3. Pollen Zone III: 56.3–43.5 ka

This phase is characterized by low AP values (0.9% at their minimum), and very little Oleaceae (0.0–4.3%), although in comparison to the previous zone there is a slight increase of the two oak types (to less than 12.7%). At the same time the steppe elements increase: *Artemisia* (9.3–45.3%) and both *Ephedra* types (3.4–22.1%). The most pronounced minor fluctuations during the Last Glacial of the dominant pollen types occur during this time interval. Maxima in both evergreen and deciduous oaks appear between 56.0 and 54.4 ka, comprising up to 12.7% with extremely low values (9.8%) of *Artemisia*. Other AP maxima occur at 46.1 ka (10.4% evergreen oak and 3.9% deciduous oak) and 44.4 ka (8.8% evergreen oak and 4.9% deciduous oak).

3.2.4. Pollen Zone IV: 43.5–16.2 ka

Mediterranean and temperate trees decline in this zone (0.0–1.0% and 0.0–2.4%, respectively), AP levels do not exceed 11.3% and arid herbaceous flora is predominant. This zone is further subdivided into three pollen zones:

Subzone IVa: (43.5–35.9 ka), in which all pollen taxa have a homogenous appearance and tree levels are relatively low (2.4–7.5%): *Quercus calliprinos* type values decrease (0.4–3.8%) and *Q. ithaburensis* type shows extremely low values (0.0–1.3%). Oleaceae is discontinuous and appears in low percentages (0.0–1.4%).

Subzone IVb: (35.9–27.1 ka), characterized by low oak levels (evergreen 0.5–3.5%, deciduous 0.0–5.5%) and a minor increase in Oleaceae (up to 4.7%). *Artemisia* appears in high values (up to 32.5%). Cyperaceae levels decrease toward the upper part of this subzone (38.7–5.1%), to their lowermost levels of the sequence. Subzone IVc: (27.1–16.2 ka) characterized by the lowest AP levels of the entire sequence (7.4–1.5%) with very sporadic temperate elements (0.0–2.4%), very few Mediterranean trees (0.0–0.8%) and little Oleaceae (0.0–2.1%). The lowest tree values (1.5%) were recorded at 18.8 ka. A slight increase in Cheno/Ams and *Artemisia* levels is notable (up to 43.0% and 38.9%, correspondingly).

3.2.5. *Pollen Zone V: 16.2 ka till present*

A sharp increase occurs in AP (up to 25.3%), in evergreen and deciduous oak types (up to 20.4% and 8.6%, respectively), in temperate trees (up to 3.6%) and in Mediterranean elements (up to 1.8%). This zone was further subdivided into two subzones: Pollen Zone Va, that covers the Deglaciation Period (between 16.2 and 10.0 ka) and Pollen Zone Vb which coincides with the Holocene (10 ka till recent). The latter distinguishes itself from subzone Va by higher AP levels, mainly evergreen oaks and Oleaceae, an increase in Cyperaceae and a distinct drop in *Artemisia* and *Ephedra*.

Pollen Zone Va shows a strong increase in tree pollen values: evergreen oaks (5.2–13.6%), deciduous oaks (up to 4.9%), Oleaceae (1.1–4.7%) and temperate trees (up to 1.7%). AP levels reach their maximum values at 14.6–12.3 ka (12.9–20.1%), mainly as a result of high values of *Q. calliprinos* type pollen (7.1–13.6%). Shortly after, a peak in *Artemisia* (24.0–27.6%) is notable. Cyperaceae levels are similar to the previous subzone (up to 25.8%).

Pollen Zone Vb is typified by the highest tree levels along the sequence (AP up to 26.3%) including: evergreen oaks (3.4–20.4%), temperate trees (up to 3.6%) and Oleaceae (up to 7.4%). In addition, during this phase the lowest values of *Artemisia* and both *Ephedra* types were recorded (1.7–15.4% and 0.0–7.0% respectively) while Cyperaceae appears in relatively high values (11.7–53.8%). High pollen concentrations (up to 70,441/g sediment; Fig. 2), good state of pollen preservation, a sharp increase in evergreen oak values (up to 16.0%), in accordance with high TOC values between 9.9 and 7.2 ka, characterize sapropel S1. At 8.2 ka *Artemisia* values reached their Holocene maximum (15.4%). During the base of sapropel S1 the bisaccates occur in minimal percentage (0.4–7.0%) and increase sharply immediately after (10.6–22.5%; Fig. 3). At the second half of the Holocene *Q. calliprinos* values are relatively high (3.8–20.4%). A minor decline in Oleaceae (3.8–20.4%) is notable as well as a slight increase in *Artemisia* (up to 14.6%).

3.2.6. *Recent pollen*

The two uppermost samples of the core represent the recent and the sub-recent vegetation. The top sample (0–2 cm depth) that dates to 0.1 ka contains pollen of a tropical African origin indicating that the closure of the River Nile by the Aswan Dam (1964) is not yet detected in this sample. In addition, the sample lacks foreign vegetation such as *Eucalyptus* (of Australian origin) and *Casuarina* (native to Australia and South East Africa), common in the recent pollen rain of the area (Van Campo, 1975; Horowitz, 1979). Therefore, the sample is older than the end of the 19th century, when those trees were first introduced to the Eastern Mediterranean region. In another sample, dating to 0.6 ka (taken from 10 to 12 cm depth) agglutinated foraminifera with organic cement still occur (Avnaim-Katab, 2005). This corroborates a recent to sub-recent age since these benthic foraminifera tend to disintegrate shortly after death (cf. Schröder, 1988; Edelman-Furstenberg et al., 2001). The top two samples show lower tree levels compared to older parts of the Holocene record (6.7–13.5%) with low evergreen oak (5.8–3.8%), deciduous oak (0.0–0.6%), Oleaceae (0.5–2.9%), and temperate (0.9–1.8%) trees. Cheno/Ams and *Artemisia* on the other hand, appear in relatively high values for the Holocene (32.2–39.3% and 8.8–12.8% respectively).

4. Vegetation reconstruction of the Levantine Basin during the last 86 ka

Q. calliprinos type (evergreen oak) and *Artemisia* were found as the best palynological indicators for the identification of humid and dry cycles, respectively (Figs. 3 and 4), because the transition from an *Artemisia* steppe to an oak park-forest corresponds to an increase in annual precipitation. The interplay between these two components helps define the main changes in humidity and vegetation during the period under discussion. Other main steppe elements beside *Artemisia* characterizing dry stages are Chenopodiaceae and *Ephedra* (mainly *E. distachya* type) while *Q. ithaburensis* type together with Oleaceae and other Mediterranean and temperate trees are the main non steppe elements associated with more humid conditions. High Oleaceae levels also indicate warm spells.

4.1. *MIS 5a: 86.0–75.5 ka – Pollen Zone I*

High values of the two oak types (evergreen and deciduous) together with the presence of Mediterranean vegetation and temperate trees indicate that this period was humid. The AP levels declined substantially toward the end of this phase, pointing to a reduction in available moisture. However the period was not very dry as evident from the medium proportions of the semi-desert and desert vegetation (mainly *Artemisia* and *Ephedra*). Three Levantine marine cores that were studied by Cheddadi and Rossignol-Strick (1995a,b) also show similar trends that were interpreted as representing intermediate conditions between Mediterranean and arid continental climates.

The accumulation of sapropel S3 between 85.9 and 83.0 ka is palynologicaly characterized by extremely high pollen concentrations together with a better state of pollen preservation. The lowest percentages of bisaccates at the base of sapropel S3 clearly define the boundary between non-sapropelic and sapropelic sediments. This is because at the base of the sapropel the pollen preservation is the best for all taxa and the relative occurrence of the bisaccates is less dominant. Later, as oxidation increases, the percentage of the most resistance bisaccates relatively increases (e.g. Cheddadi and Rossignol-Strick, 1995b; Figs. 2 and 3). The humid conditions at the time of deposition of sapropel S3 is evidenced also by a peak in oak values around 85 ka. Sapropel S3 was also identified based on palynological characteristics in different parts of the Eastern Mediterranean (Rossignol-Strick, 1972, 1999; Cheddadi and Rossignol-Strick, 1995a,b; Rossignol-Strick and Paterne, 1999; Kotthoff et al., 2008a,b, and references therein). Beside the definition of Sapropel S3 in core 9509 by pollen characteristics, it is also well constrained by the high TOC content, high sedimentation rates and low foraminifera $\delta^{18}O$ values (Figs. 2 and 4). This is due to increasing hydrological activity in the Levantine Basin, as a result of the intensification of the monsoon system associated with high insolation values at 65° N (Fig. 4), leading to increase flow of the River Nile (e.g. Almogi-Labin et al., 2009).

4.2. *The Last Glacial*

4.2.1. *75.5–56.3 ka – Pollen Zone II*

A sharp decrease in evergreen oak representing drier conditions took place at the beginning of the Last Glacial period. The increase in *Artemisia* and the two types of *Ephedra* and the decrease in Oleaceae were gradual, indicating a gradual aridification and cooling. The gradual decrease of Cyperaceae pollen also suggests

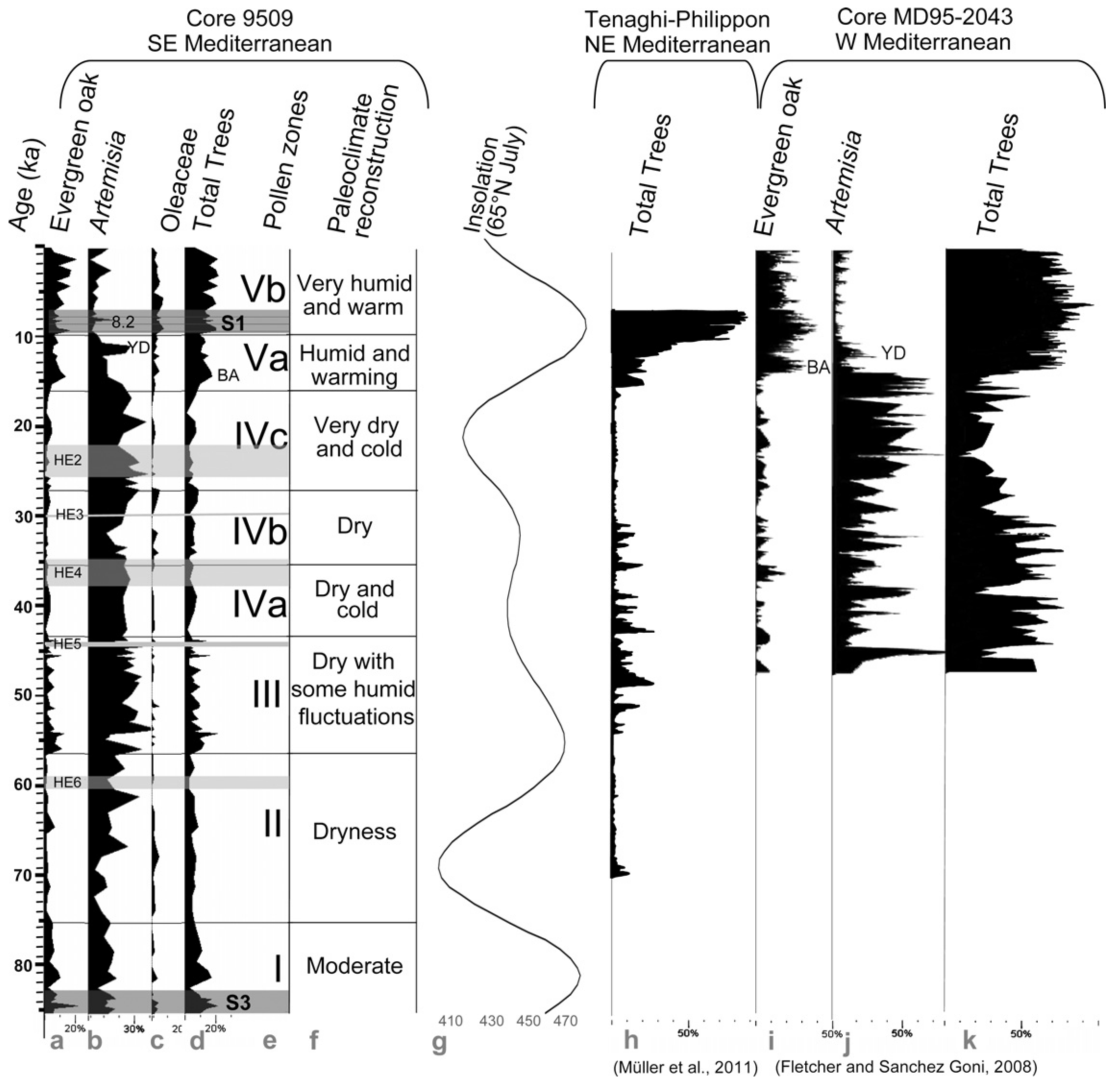

Fig. 4. a–f. Main climatic characteristics of core 9509: a. Evergreen oak. b. *Artemisia*. c. Oleaceae. d. Total trees (excluding bisaccates). e. Pollen Zones and f. Paleoclimate reconstruction. g. Insolation (65° N). h. Total trees at TP (excluding bisaccates; Müller et al., 2011). i–k. Pollen markers from the Alboran Sea (Fletcher and Sanchez-Goni, 2008): i. Evergreen oak. j. *Artemisia* and k. Total trees (excluding bisaccates). Shaded horizontal bars correspond to sapropel accumulation (S3 and S1; dark gray) and to Heinrich Events (HE2-HE6; light gray). BA = Bölling-Allerød; Younger Dryas = YD.

a gradual transition to the glacial period with the reduction in River Nile flow connected to the weakening of the monsoon system. Other proxies such as the foraminifera $\delta^{18}O$ values also increase gradually (Fig. 2). In other Levantine marine cores a gradual transition to the last ice age was also observed (Cheddadi and Rossignol-Strick, 1995a,b). Aridification was probably more pronounced at the end of this pollen zone, when *Artemisia* and later Chenopodicaeae and *Ephedra fragilis* type become more abundant.

4.2.2. 56.3–43.5 ka – Pollen Zone III

This period is characterized by relatively low tree levels, a slight reduction in Chenopodiaceae values and most pronounced frequent fluctuations of the pollen taxa. The slight increase in both oak types suggests somewhat more humid conditions compared with the previous and subsequent zones although the *Artemisia* values are high. The frequent minor fluctuations of the pollen taxa may reflect a climatic instability (e.g. Cheddadi and Rossignol-Strick, 1995a). This interval is also typified by a significant increase in sedimentation rates (Fig. 2) and the highest SST during the entire Last Glacial, varying between 13 and 17 °C (Emeis et al., 2003; Almogi-Labin et al., 2009). Significantly, a short pluvial event was recognized during this phase by a peak in oak values at 56.0–54.4 ka. This minor increase in humidity within the general aridity is associated with maximum northern hemisphere insolation (Fig. 4) and minimum precession values (Rossignol-Strick, 1985). A similar trend of general dryness with short pluvial event around ~54 ka was also observed in Lake Yammoûneh (Lebanon), based on increase in tree population (Develle et al., 2011).

Pollen assemblages from the Northern Ghab and Hula lakes (Fig. 1b; Niklewski and Van Zeist, 1970; Weinstein-Evron, 1983, 1990) are characterized by relatively high AP levels during the entire Zone III. They suggested some wetter conditions compared with this study and the pollen record from Lake Yammoûneh. The discrepancy may be a result of insufficient age control (e.g. Rossignol-Strick, 1993, 1995; Cappers et al., 2002; Meadows, 2005; Robinson et al., 2006).

4.2.3. 43.5–16.2 ka – Pollen Zone IV

The Mediterranean and temperate forests were significantly reduced during this period, and arid herbaceous flora dominated the landscape. This arid stage was further subdivided into three pollen subzones. From 43.5 to 35.9 ka (Pollen Zone IVa) all pollen taxa have a homogenous appearance, suggesting a more stable climate than during the previous period. The fragmentary occurrence of Oleaceae and their low percentages indicate that the winters were probably very cold and the available moisture was low. Low oak levels and high *Artemisia* values that characterize the time interval from 35.9 to 27.1 ka (Pollen Zone IVb) are indicative of extensive regional aridity in the Levant. A minor increase in Oleaceae percentages suggests that this subzone was somewhat warmer. During the latest glacial stage, between 27.1 and 16.2 ka (Pollen Zone IVc), tree levels are the lowest with sporadic occurrence of temperate elements, very few Mediterranean trees and little Oleaceae. This represents cooling and increased continental influence, chiefly in the upper mountain areas. The marked abundance of *E. distachya* type might be a result of low sea levels which exposed extensive shelf areas (Kotthoff et al., 2008b). Based on 9509 palynological record, this period was the driest and the coldest during the last 86 ka. Further support for extreme aridity and cold conditions come from the low AP values at Lake Yammoûneh (Develle et al., 2011) and the highest $\delta^{18}O$ values in Soreq Cave speleothems (Fig. 2). The most extreme condition evident from core 9509 is centered at ~19.0 ka (the LGM) when the tree values are the lowest. This cold and dry episode is also corroborated by an increase of steppe elements from the terrestrial Levantine pollen assemblages (Niklewski and Van Zeist, 1970; Van Zeist and Woldring, 1980; Van Zeist and Bottema, 1982; Weinstein-Evron, 1983, 1990). Moreover, the lowest temperatures of ~10 °C were calculated for the LGM for the marine and land records (McGarry et al., 2004; Affek et al., 2008; Almogi-Labin et al., 2009).

Whereas this study shows that Zone IVc, which corresponds to MIS 2, was the driest and coldest during the last 86 ka, the pollen record from the northern Jordan Valley points toward more humid conditions (Niklewski and Van Zeist, 1970; Weinstein-Evron, 1983, 1990) coinciding with high Lake Lisan levels (the Late Pleistocene precursor of the Dead Sea; Picard, 1943) (Bartov et al., 2002, 2003; Lisker et al., 2010). Further discussion on "wet" glacial vs. "dry" glacial in the Levantine Basin is detailed in Bar-Matthews (in press).

4.2.4. Heinrich Events

In this general trend of cooling and dryness short-lived colder climatic spells were recognized on land as coeval with Heinrich Events (Table 1; Bar-Matthews et al., 1999; Bartov et al., 2003). The pollen record of zones III and IV include distinct spikes of minimum arboreal vegetation, mainly evergreen oak, indicating a sharp decrease in the available moisture (Fig. 4). These phases of dryness coincide with Heinrich Events (Table 1; Heinrich, 1988; Bond et al., 1993; Bond and Lotti, 1995) indicating that the vegetation in the South Eastern Mediterranean responded quickly to the rather short North Atlantic cold climate pulses (Table 1). Thus the reduction of oceanic heat transport to the high northern latitudes (e.g. Bond et al., 1993) led also to significantly dryer and cooler conditions in the South East Mediterranean region. A possible link within this teleconnection could be the strengthening of the Siberian High during Heinrich Events, resulting in harsher conditions during the winter and early spring months (Kotthoff et al., 2011). A similar mechanism has already been shown for cold spells in the Eastern Mediterranean during Heinrich Event 1 (Kotthoff et al., 2011), the Holocence (e.g. Rohling et al., 2002; Kotthoff et al., 2008b), and also during present-day conditions (Saaroni et al., 1996).

4.3. Deglaciation and Holocene: 16.2 ka till the present – Pollen Zone V

Pollen Zone V is divided into two subzones: Pollen Zone Va, between 16.2 and 10 ka, and Pollen Zone Vb, covers the Holocene. The most dramatic climate change started at the beginning of the Deglaciation with Pollen Zone Va and continued throughout the Holocene. This period is characterized by a sharp increase in AP, in oak types and other Mediterranean and temperate trees together with a sudden decline in steppe elements. The Mediterranean maquis were most likely much more widespread in the Levant pointing to higher precipitation and the increase in the Oleaceae points toward warmer conditions. High AP levels occur also in the Hula valley (Tsukada, cited in Bottema and Van Zeist, 1981; Weinstein-Evron, 1983, 1990; Baruch and Bottema, 1991, 1999). The increase in available moisture and temperature is associated with increased westerly activity (e.g. Arz et al., 2003; Almogi-Labin et al., 2004, 2009).

Two distinct short climatic events were recognized during Pollen Zone Va (Fig. 4): the first between 14.6 and 12.3 ka contains high AP levels, mainly *Q. calliprinos* type and a pronounced reduction in *Artemisia* with almost total disappearance of *E. distachya* type. The change in vegetation indicates very humid conditions and it coincides with the warm Bölling-Allerød (cf. Stuiver et al., 1995). The pollen data are corroborated by low $\delta^{18}O$ values of both core 9509 and Soreq Cave records (Fig. 2). The second short climatic event, parallels the YD (11.9–11.2 ka), characterized by a considerable rise in *Artemisia* values and reappearance of *E. distachya* type pointing toward increasing dryness (Fig. 4). The YD was recognized in other marine and terrestrial Eastern Mediterranean pollen records by a marked increase in semi-desert and desert elements (e.g. Baruch and Bottema, 1991, 1999; Rossignol-Strick, 1993, 1995). Based on the relatively moderate decrease of arboreal population, we infer that the Levantine YD was less severe in comparison to other glacial stadial events (LGM, Heinrich Events). Milder YD in the terrestrial sites was also identified in other Eastern and central Mediterranean palynological records (e.g. Magny et al.,

Table 1
Chronological framework of Heinrich Events.

Location Heinrich Event	North Atlantic cores (Bond et al., 1999)	North Atlantic cores (Hemming, 2004)	North and South Atlantic cores (Vidal et al., 1999)	Western Med. core (Cacho et al., 1999)	Western Med. core – MD95-2043 (Fletcher and Sanchez-Goni, 2008)	Soreq cave, eastern Med. (Bar-Matthews et al., 1999)	Lake Lisan, Eastern Med. (Bartov et al., 2003)	South Eastern Med. core 9509 (This study[a])
H1[b]	~16	16.8	14	15.2	15.2–18.1	16.5	16	
H2[b]	~24	24	22	23.4	23.5–26.0	25	23.8	26.6–22.4
H3	~30	~31		30.1	29.0–32.6		30	30.1
H4	~39	38	35	38.8	38.2–40.1		38	37.4–35.2
H5	~46	45	45	45.0	45.4–46.6	46	46.5	45.0–44.7
H6[c]	~66	~60						60.6–59.4

[a] The ages represent the boundaries of the event and defined by pollen data.
[b] H1 and H2 are dated by ^{14}C. Other ages are estimated by a correlation to Greenland (GISP2) cores.
[c] The earliest event (H6) was not identified in all of the mentioned studies since some of the records are not long enough.

2006; Brauer et al., 2007, for Italy; Lawson et al., 2004, 2005, for Greece) while in the Northern Aegean Sea the YD is more pronounced (Kotthoff et al., 2008b, 2011). However, Weinstein-Evron (2002, 2009) and Lev-Yadun and Weinstein-Evron (2005) based on the relatively high AP values and low levels of *Artemisia* in the Hula pollen spectra, suggest that the YD was almost insignificant around the Levant (see also Bottema, 1995, 2002). The discrepancy between these records may suggest local responses to the YD event.

The Holocene is characterized by the highest tree levels including marked rise in Oleacea, and the lowest steppe elements levels throughout the sequence (Fig. 3), indicating that the Holocene was the most humid and warm period during the last 86 ka. It is important to emphasize that between 9.9 and 7.2 ka there is a better state of pollen preservation, sharp increase in evergreen oak values, sudden decline in bisaccate pollen percentages and high TOC contents. All are related to the accumulation of sapropel S1 (Figs. 2 and 3). On land, the annual amount of rainfall at the beginning of the Holocene (10.0–8.0 ka) was high (Frumkin et al., 1999; Bar-Matthews et al., 2003) and the temperature both in Sea and land were similar to present (Emeis et al., 2003; McGarry et al., 2004; Affek et al., 2008; Almogi-Labin et al., 2009). These humid and warm conditions derive from increasing hydrological activity due to enhanced rainfall from Mediterranean cyclones coinciding with the intensification of the monsoon system, maximum insolation values (Fig. 4) and the increasing flow of the River Nile (e.g. Almogi-Labin et al., 2009). The continental pollen record from Lake Yammoûneh (Develle et al., 2011), the Hula valley (Baruch and Bottema, 1999) and the northern coast of Israel (Kadosh et al., 2004) also points to wetter conditions at the beginning of the Holocene. The palynological data corresponds to extremely low δ^{18}O values of *G. ruber* in core 9509 and Soreq Cave speleothems (Fig. 2) as well high Holocene stands of the Dead Sea (Frumkin et al., 1991; Frumkin and Elitzur, 2002; Enzel et al., 2003; Bookman (Ken-Tor) et al., 2004; Migowski et al., 2006).

One outstanding event during the Holocene is ~8.2 ka event. At this time *Artemisia* reached its maximum Holocene values (Fig. 4), representing an abrupt response of the vegetation to dryness in the area. At the same time there is a temporary reduction in the pollen concentrations and TOC content (Fig. 2) together with a reappearance of benthic foraminifera in the same core (Avnaim-Katab, 2005) and in a nearby core SL 112 (Kuhnt et al., 2008). This indicates improved bottom water ventilation which was suggested by Myers and Rohling (2000) resulted from climate deterioration associated with 2–3 °C cooling and/or increasing aridity. Cooling induces deep convection in the Adriatic and intermediate water formation in the Aegean and also in the Levantine Basin (Almogi-Labin et al., 2009). Rohling et al. (2002) related this change to a direct atmospheric link between Aegean SST and the high-latitude climate as observed in Greenland ice cores and North Atlantic marine cores (Bond et al., 1997; Alley and Ágústsdóttir, 2005; Rohling and Pälike, 2005). Thus, based on various proxies, the dryness evident by the pollen record was accompanied also by cooling. Kotthoff et al. (2008a) and Pross et al. (2009) identified beside the 8.2 ka event other two weaker cold events during sapropel S1 at ~8.7 and at ~7.3 ka. In this study only one event was identified. We suggest, based on our age model, and the fact that globally it is the most extreme cooling event during the Holocene, that it coincides with the 8.2 ka event. This event is also recognized in marine core 9501 taken from similar water depth ~380 km apart, in the northern Levantine Basin dated by ^{14}C (Almogi-Labin et al., 2009).

The last 5000 years are characterized by more fluctuating pollen curves as well as by minor decline in Oleaceae and some other Mediterranean trees, together with higher *Artemisia* values, representing a slight reduction in the available moisture, although the values of *Q. calliprinos* type continue to be high. Increase in δ^{18}O values in the Soreq Cave speleothems also support transition to dryer conditions (Bar-Matthews et al., 2003). The slightly higher pollen concentration (Fig. 2) and high species diversity during this period is due to their relatively younger age being less affected by diagenesis (e.g. Cheddadi and Rossignol-Strick (1995a).

A significant decrease in oak levels in the upper samples represents human impact on the natural vegetation of the area during the last 1500 years. The δ^{18}O values remain high, since they are not influenced by human activity. In Levantine terrestrial palynological records, anthropogenic influences on the natural vegetation is evident a few thousands years earlier (Van Zeist and Woldring, 1980; Baruch, 1986, 1990; Yasuda et al., 2000; Schwab et al., 2004; Neumann et al., 2007, 2010), reflecting different geographical areas and varying extents of human activity (see also Magri, 1995; Roberts et al., 2004; Jalut et al., 2000; Sadori et al., 2011, and references therein). While these terrestrial sequences may have recorded chiefly local signals, their accumulated impact became clear in the marine record only in later historical times.

4.4. Comparison with other palynological records from the Mediterranean Sea and the Levant region

A comparison between the South Eastern Mediterranean pollen record of core 9509 with relatively two long terrestrial records from the North East Mediterranean at Tenaghi Philippon (TP; Tzedakis et al., 2003, 2006; Müller et al., 2011) and the Western Mediterranean marine core MD95-2043 (Fletcher and Sanchez-Goni, 2008; Fig. 1a) is discussed (Fig. 4 and Table 2). Paleoenvironmental reconstructions indicate a strong match based on the similar main trends of the major vegetation elements. Total AP, Evergreen oak type and *Artemisia* were found as good palynological markers for the identification of humid and dry cycles, in all three profiles (Fig. 4). Evidence of strong climatic links between the North Atlantic and different parts of the Mediterranean region are expressed by minima AP during Heinrich Events identified in both sides of the Mediterranean Basin (Table 1) and by the absence of temperate tree population at TP (Tzedakis et al., 2004; Müller et al., 2011). Slightly wetter climate conditions during the Last Glacial occurred in the South Eastern Mediterranean between 56.3 and 43.5 ka (Pollen Zone III). This relatively humid period is very well recognized in the isotopic composition of *G. ruber* from the same core and further north in core 9501 (Almogi-Labin et al., 2009) and in the terrestrial TP pollen record (Müller et al., 2011). This phase is considered as the North African Humid Period (NAHP – Müller et al., 2011) and it is also equivalent to the missing sapropel S2 (e.g. Cita et al., 1977; Bar-Matthews et al., 2000). However, there are some differences between the records. More developed forest exists around the Western Mediterranean and at TP area compared with the South East Mediterranean dominated by Mediterranean maquis and reduced tree population due to the eastwards decrease of the relative available moisture.

The general picture derived from the comparison with TP and Western Mediterranean is also evident in the central Mediterranean. Moderate MIS 5a, dry and cold Last Glacial cycle and wet and warm Holocene is derived also from continental pollen records from the central Mediterranean (e.g. Lawson et al., 2004, 2005; Magny et al., 2006; Brauer et al., 2007) and even eastwards in Lake Zeribar, Zagros Mountains (Van Zeist and Bottema, 1977). Steppe elements are more developed further to the east (core 9509 and Lake Zeribar) due to the W-E decrease in the moisture balance (Pierre, 1999) and increase in SST (Almogi-Labin et al., 2009, and references therein). W-E moisture gradient occurs due to the increasing continental affect and decreasing moderating influence of the Atlantic Ocean.

Table 2
A comparison of core 9509 pollen record with palynological sequences of Tenaghi Philippon and core MD95-2043.

Location		South East Mediterranean	North East Mediterranean	Western Mediterranean–Alborean Sea
Study site		Core 9509 – Fig. 4a–f	Tenaghi Philippon – Fig. 4h (ref. 1 and 2)	Core MD95-2043–Fig. 4i–k (ref. 3)
Time span		86 ka – till present	The last 1.35 million years (ref. 1) ~70–7 ka (ref. 2)	48 ka – till present
Age model		Based on the comparison with the U-Th Soreq Cave speleothems record and to ^{14}C dates of core 9501 (ref. 4)	Tuned to orbital cyclicity and to SPECMAP (ref. 1). Based on ^{14}C dates, tephrostratigraphy. Beyond the range of ^{14}C dating tuned to SPECMAP (ref. 2)	Based on ^{14}C dates and correlation between the SST and the $\delta^{18}O$ curve of GISP2 (ref. 5)
Pollen signature	MIS 5a	Medium % AP, relatively moderate climate conditions	Medium % AP with extremely high tree population between ~82–78 ka, relatively wet climate conditions	
	MIS 4	A decline in % AP and evergreen oak together with a gradual increase in *Artemisia*, dryness	Dry steppe biome, dryness	
	MIS 3	56.3–43.5 ka: a minor increase in %AP with frequent fluctuations, slightly wetter climate conditions characterizing by instability. 43.5 –27.1 ka: a reduction in tree population, dryness; distinct Heinrich events	Short-term expansions of tree populations, aridity interrupted by interstadials events	Fluctuations in oak forest cover, climate variability, Dansgaard-Oeschger and Heinrich Events
	MIS 2	Dominance of steppe elements, driest and coldest period	High % *Artemisia* and Chenopodiaceae with low tree population, dry period	Semi-desert vegetation dominated by shrub including Ericaceae, driest and coldest period
	Deglaciation	A sharp increase in tree cover at 16.2, increase in available moisture. Greater distribution of evergreen oak, wet Bölling-Allerød. Peak in % *Artemisia*, dry YD	A pronounced increase in % AP mainly temperate deciduous trees	A significance development of oak forest, increase in available moisture from the onset of the Bölling-Allerød. Re-expansion of semi-desert environments, dry YD
	Early Holocene	Maximum development of Mediterranean maquis, wet warm conditions	Reappearance of evergreen oak forest together with high % of other AP, wet period	Transition from evergreen to deciduous oak predominance, wet period
	Late Holocene	Minor decline in Mediterranean trees with higher % *Artemisia*, a slight dryness. Human impact during the last 1.5 ka	High % AP, wet period	Minor decrease in tree population, a slight dryness

References: 1. Tzedakis et al., 2003, 2006. 2. Müller et al., 2011. 3. Fletcher and Sanchez-Goni, 2008. 4. Almogi-Labin et al., 2009. 5. Cacho et al., 1999.

There are some minor differences in vegetation attributed to sampling resolution and dating. For example the vast dryness in the South East Mediterranean region is recorded between 27 and 16 ka, whereas in the Zagros Mountains this dryness is between 22 and 14 ka. This difference may result also from local factors such as a delay in the response of Zagros Mountains to the regional climate changes due to their geographical location, being far distant from the Mediterranean Sea and in higher elevation.

Differences in timing and duration are typical also to the YD. In the South East Mediterranean the pollen record suggests a shorter YD, starting at 11.9 ka and lasting until 11.2 ka, compared with the nearby speleothem record from Soreq Caves which started at 12.7 ka (Fig. 2). This date is well in accord with other cave sites in Europe (Genty et al., 2006), with the pollen record from the Alborean Sea (Fletcher and Sanchez-Goni, 2008) and with continental records from the central Mediterranean (e.g. Lawson et al., 2004, 2005; Magny et al., 2006; Brauer et al., 2007). It is clear that the YD event is recognized in the entire Mediterranean region but is weaker in the southern locations compared with northern Hemisphere records (Fletcher and Sanchez-Goni, 2008). Moreover in the South East Mediterranean the YD pollen record is also shorter, suggesting a delay in the vegetation response to this event.

5. Summary and conclusions

The pollen record covering the last 86 ka derived from the South Eastern Levantine Basin is discussed. The pollen is originated from various phytogeographic zones including Mediterranean, Irano-Touranian, Saharo-Arabian and tropical elements. *Q. calliprinos* type and *Artemisia* were found to be the best palynological markers for the identification of humid and dry cycles, respectively. During the last 86 ka a succession of alternating humid and drier periods was observed. A moderate MIS 5a (86.0–75.5 ka) is followed by a generally dry and cold Last Glacial cycle (75.5–16.2 ka) with low tree levels and high values of *Artemisia*, reaching its peak around 19 ka. The most dramatic climate change started at the beginning of the Deglaciation (16.2–10.0 ka) and continued throughout the Holocene (10.0 ka to the present). During these periods oak maquis were more widespread and climate conditions were much wetter in the region due to intensification of the westerlies and the northward extension of the monsoonal activity.

Several fluctuations were identified during the cold and dry last ice age. The period from 75.5 to 56.3 ka (Pollen Zone II) is considered a transitional stage to full glacial conditions. This phase is characterized by a sharp decrease in evergreen oak and tree levels, while steppe vegetation increased gradually, pointing toward dryer conditions compared to the previous moderate MIS 5a period.

A minor rise in moisture, based on a slight increase in tree percentages, characterized the time period of 56.3–43.5 ka (Pollen Zone III). Furthermore, this period is typified by many minor fluctuations of the pollen curves that reflect climatic instability.

Aridity generally typifies the period of 43.5–16.2 ka (Pollen Zone IV). The driest stage during the last 86 ka was found from 27.1 to 16.2 ka (Pollen Zone IVc) with the lowest oaks and olive levels of the sequence and high values of *Artemisia*.

Several short events were recognized along the sequence: the dry and cold episodes of the LGM around 19.0 ka, the YD at 11.9–11.2 ka and the 8.2 ka event. In addition, Heinrich Events

H2–H6 were recognized based on extremely low tree values. Short-lived humid and warm events identified during the last 86 ka are the pluvial event between 56.0 and 54.3 ka, the Bölling-Allerød episode at 14.6–12.3 ka and sapropel S3 and S1 (85.9–83.0 ka and 9.9–7.2 ka, respectively). The latter were clearly recognized by the high concentrations and good state of preservation of pollen grains, which in turn accord with other proxies and were synchronized with high insolation values in 65° N.

The reconstructed climatic variability is well correlated with other Mediterranean marine and terrestrial pollen sequences and with the accepted northern hemisphere glacial-interglacial cyclicity. However, there is a clear dominance of Mediterranean maquis, lower tree population and higher steppe vegetation in the South Eastern Mediterranean compared to North and Western Mediterranean marine and land sites. This difference reflects the decreasing moisture gradient along W-E Mediterranean due to increasing continental effect and the reduction in the moderating influence of the Atlantic Ocean.

Acknowledgments

This paper is part of a PhD thesis of the senior author performed in the Department of Archaeology, University of Haifa and in the Geological Survey of Israel. The research was supported by the Ministry of National Infrastructures and by the Israel Science Foundation grants no. 20/01-13.0 and 910/05. We thank the master, crew and scientists aboard R/V *Marion Dufresne* for their assistance with special thanks to Dr. Martine Paterne from Gif sur Yvette, France. We gratefully acknowledge Dr. Avner Ayalon for helpful scientific discussion and Mr. Michael Kitin and Ms. Sylvia Chaim for the technical help. Prof. Yuval Goren is acknowledged for providing D.L. with laboratory facilities. Two anonymous reviewers and the editor Prof N. Roberts are thanked for most fruitful reviews and suggestions which significantly improved the manuscript.

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