Late Quaternary Nile flows as recorded in the Levantine Basin: The palynological evidence

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Abstract

This study aims to trace changes in the River Nile flows over the Late Quaternary and is based on palynomorphs which were embedded in the sea floor of the Levantine Basin. The palynomorphs were extracted from two marine sediment cores, which cover the last 86 ka and are located at the two ends of the Levantine Basin: MD-9509, at the southern part of the Levantine Basin, and MD-9501, at its northern part. Core MD-9509 was taken from the Nile cone and is characterized by high sedimentation rates and a good state of palynomorph preservation. The assemblages included palynomorphs which were transported via the Nile headwaters and therefore enabled the reconstruction of the River Nile flows. The results demonstrate that the last glacial period (~75–16 ka) was characterized by a decrease in Nile water discharge and an increase in sediment flux, while opposite trends were observed prior to the last glacial period as well as during the deglaciation and the Holocene. Based on the study of the spores, it is suggested that during the last glacial, the main contributors of freshwater and sediment load to the Eastern Mediterranean Sea were the Blue Nile and the Atbara and only during interglacials was there a more significant contribution of the White Nile. Within the northern core, MD-9501, pollen was preserved only during the formation of sapropels S3 and S1. The comparison of the sapropelic palynological spectra in both core sites clearly indicates that during sapropel deposition, climate conditions were more humid in the Northern Levant, reflecting the north-south regional Mediterranean climatic moisture gradient. Sapropel formation was a result of the intensification of the monsoonal climate system which was most probably related to the maximum insolation values at 65°N, while, currently, the Atlantic is the main influencing climate system in the region. One of the most interesting observations in this study is that during Heinrich Events H2-H6, which originated in the north Atlantic and were identified in MD-9509 based on minimum arboreal pollen percentages, pollen originating from tropical regions was not embedded in the Levantine Basin. These results lend support to the view that episodes of dryness in tropical/sub-tropical Eastern Africa were associated not only with low-latitude climate controls, but also with high-latitude glacial stress.

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1. Introduction

Studying the paleoenvironmental conditions of the Levant region during the Late Quaternary is of a great importance since this area played a major role in the spreading and evolving of Neanderthals and early modern human groups (e.g., Bar-Yosef, 1995; Hovers et al., 1995; Bar-Yosef and Belfer-Cohen, 2013, pp. 36–39; Hershkovitz et al., 2015). Several marine palynological records which were extracted from the Levantine Basin enabled the reconstruction of regional changes in vegetation and climate during the Late Pleistocene (Rossignol, 1963; Rossignol-Strick, 1972, 1973; Cheddadi and Rossignol-Strick, 1995a,b; Kadosh et al., 2004; Langgut et al., 2011). Yet, these marine palynological studies focused mainly on changes in the Mediterranean vegetation zone on the eastern and northern coasts of the Levantine Basin, as well as on shifts in the steppe and Saharo-Arabian vegetation zone which mainly covers the eastern and southern parts of the region, respectively (Fig. 1a). In this study, new information is presented which enables the reconstruction of climate changes that occurred...
in the area extending from the Nile headwaters in tropical East Africa, and up to the Eastern Sahara Desert (Fig. 1a). The new data include aquatic pollen, algae, dinoflagellate cysts and trilete and monolete spores, which had been embedded in the sea floor of the southern Levantine Basin. Palynological evidence for the accumulation of sapropels in both the Northern Levantine Basin and the Southern Levantine Basin is also presented in this study.

The Nile River is the greatest contributor of freshwater into the Eastern Mediterranean Sea. The Nile encompasses a wide variety of climates, vegetation zones and river regimes — from the Equatorial Lakes Plateau of the White Nile headwaters to the delta in the Eastern Mediterranean Sea (Fig. 1a; Woodward et al., 2007). Therefore, the palynological spectra from Nilotic origin which are embedded in the sea floor of the South-Eastern Mediterranean Basin are from diverse origins and include palynomorphs such as tropical pollen, different types of fresh water algae and varies spores. East African climatic belts migrated considerably during the Late Quaternary, modifying Nile discharge and sediment influx into the Eastern Mediterranean Basin. Climatic fluctuations have been recorded by paleoclimatic proxies along the Nile course and in its delta (Adamson et al., 1980; Williams and Adamson, 1980; Foucault and Stanley, 1989; Woodward et al., 2001, 2007, 2015; Stager et al., 2003; Revel et al., 2010; Williams et al., 2010, 2015; Marshall et al., 2011; Macklin et al., 2013, 2015 and references therein; Macklin and Lewin, 2015) and by well-defined depositional cycles, mainly of sapropel layers, in the Levantine Basin (Stanley and Maldonado, 1977; Stanley and Warne, 1993; Fontugne et al., 1994; Krom et al., 2002; Almogi-Labin et al., 2009; Box et al., 2011; Blanchet et al., 2013; Hennekam et al., 2014, 2015; Revel et al., 2014). In this study mostly palynomorphs were used in order to trace Late Quaternary climate changes in Nile discharge and sediment load.

The research is based on two marine sediment sequences which cover the last 86 ka and are situated in the northern and southern parts of the Levantine Basin (Fig. 1b; Langgut, 2008). The northern core, MD-9501, is located southeast of Cyprus and is mainly influenced by the mid-latitude westerly Atlantic/Mediterranean climate system. The MD-9509 sequence was also strongly influenced by the River Nile input, which originates in the low-latitude monsoonal system. The location of the cores at the two ends of the Levantine Basin enabled the evaluation of the extent of the influence of the River Nile through time in the Levantine Basin. The identification of tropical elements which originated from the Nile headwaters and were eventually deposited on the sea floor of the Levantine Basin allowed the evaluation of possible links between the monsoonal and the westerly Atlantic climate systems.

Fig. 1. (a) River Nile Basin including its main tributaries and main vegetation zones; (b) Eastern Mediterranean vegetation map (modified after Zohary, 1973), together with the location of core MD-9509 at 32°1 0′ N, 34°16′ E, from the Nile cone, representing the South Levantine Basin, and core MD-9501 at 34°32′ N, 33°59′ E, southeast of Cyprus, representing the North Levantine Basin. The two cores reflect sedimentation under the influence of two different climate regimes. While core MD-9501 was mostly under the influence of the North Atlantic/Mediterranean climate system, the MD-9509 sequence was also strongly influenced by the River Nile input, which originates in the low-latitude monsoonal system. Arrows indicate the prevailing surface currents (in grey) and the Levantine Intermediate Water (in blue; modified after Schmiedl et al., 2010). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)
The study also focused on organic rich layers known as sapropel events (Kidd et al., 1978), which were embedded in the Eastern Mediterranean Sea floor during periods of increased Nile discharge. These periods are generally thought to be due to precession-forced insolation changes causing increased monsoonal activity (Rossignol-Strick et al., 1982; Rossignol-Strick, 1985; Rohling, 1994). The increased Nile outflow may have consequently influenced ventilation and/or productivity in the Eastern Mediterranean, thus supporting sapropel accumulation (Rohling, 1994). In this research, sapropel identification was based on palynological and sedimentological markers. While pollen in core MD-9501 was only preserved during the formation of sapropels S3 and S1, within the MD-9509 record, palynomorphs preservation was continuous during the last 86 ka.

2. Cores: geographical settings and origin of palynomorphs

The southern core MD-9509 and the northern core MD-9501 were extracted by the R/V Marion Dufresne during February 1995 (the “VALPAMED” set of cores). The 17.8 m long core MD-9509 was taken from the Nile cone, off southern Israel, an area located under the River Nile plume in the Southern Levantine Basin at 884 m water depth. Core MD-9501 was extracted some 380 km farther north, southeast of Cyprus at 980 m water depth (Fig. 1b). The Nile is the only major river flowing into the Levantine Basin along the south eastern coast. Other streams are mostly small and dry throughout most of the year with only an insignificant amount of runoff. The River Nile is a mega-basin; its channel network spans the 4°S to 31°N latitudes, from just south of the Equator to the shores of the Mediterranean Sea (˃35°; Woodward et al., 2007; MacKlin and Lewin, 2015). The flow regime of the Nile encompasses two parts of the global climate system: the Northern Hemisphere summer monsoon and Equatorial rainfall in the Intertropical Convergence Zone (ITCZ; e.g., MacKlin et al., 2013). The Main Nile, north of 18° latitude, contains flow from three main tributaries: the Blue Nile, the Atbara River and the White Nile (Fig. 1a). At present, their sediment load and hydrology are distinctly different (e.g., Hurst, 1952). The Blue Nile contributes more than half of the Main Nile freshwater input and nearly three-quarters of the sediment influx into the Eastern Mediterranean Basin. The Atbara contributes only a small portion of the total discharge (14%), but one quarter of the Main Nile sediment load. The White Nile contributes about a third of the total outflows of the Nile, but only a negligible amount of sediment influx (3%; Foucault and Stanley, 1989). The differences in outflow of these three tributaries derive from differences in precipitation as well as differences within the surface areas of their drainage basins (Foucault and Stanley, 1989 and references therein). Differences in sediment influx are due to differences in vegetation cover in the various basins (Adamson et al., 1980) and seasonal variations in precipitation (Hurst, 1952). The White Nile emerges from the lake plateau of Uganda and disappears into the massive swamps of South Sudan where it reemerges as a river of almost steady flow throughout the year, while the Blue Nile is highly seasonal. According to Williams (2009), during the last 15 ka, at least, times of high flow in the Main Nile and Blue Nile were synchronous with those of the White Nile.

Within the Eastern Mediterranean Basin, surface water originating from the Atlantic follows an eastward path. This surface water flows anticlockwise along the Israeli, Lebanese, and Syrian coastlines to southeastern Turkey (Fig. 1a). It is this current that transports much of the Nile sediment load to the location of core MD-9509, resulting in high sedimentation rates, and to a much lesser extent to the Northern Levant (Krom et al., 1999; Almogi-Labin et al., 2009), where core MD-9501 is situated. The Nile outflow is diverted in the same anticlockwise direction. This is evident by the occurrence of a distinct freshwater anomaly in the South-East Levantine Basin, which was detected prior to completion of the Aswan High Dam (e.g., Hecht and Gertman, 2001). Along the Levantine coast, during periods of sea level rise (e.g. Early Holocene), Nile-driven sands transported by longshore currents formed dunes that blocked the local streams and estuaries and led to the formation of wetlands and swamps (Sivan et al., 2011; Elyashiv et al., 2016).

In the two cores, the palynomorphic spectra have a diverse origin, especially in the southern record – MD-9509 (Fig. 1b). The southern shore is a desert beyond the littoral dunes (the Eastern Sahara Desert). The northern and eastern shores of the Levantine Basin are characterized by a Mediterranean climate. The floral components within these vegetation zones, as well as pollen production, are different (detailed in Langgut et al., 2011). Tropical pollen was delivered to the Levantine Basin from the Nile headwaters (Fig. 1a). With relation to the spores, in a previous study it was shown that trilete and monolete spores originated from the upstream Nile; in the delta, no spores were observed except for Adiantum capillus-veneris (Täckholm, 1974). The trilete spores are most probably reworked from the Jurassic layers underlying the basalt traps of Ethiopia, and widely eroded into deep canyons by the Athara River, the Blue Nile, and their tributaries (Rossignol, 1969). Spore frequencies are lower in the White Nile in comparison to the Main Nile. This provides evidence of the heavy selective destruction or deposition along the river course, which progressively enhances the percentage of resistant palynomorphs (Cheddadi and Rossignol-Strick, 1995b).

3. Material and methods

3.1. Sampling and palynological analysis

The 17.8 m long core MD-9509, covering the last 86 ka, was sampled continuously for palynological analysis in ~5 cm intervals in sapropel layers and ~10 cm intervals in non-sapropel layers. Core MD-9501 represents a longer period of deposition, at least the last 15 ka. The 17.8 m long core MD-9509, covering the last 86 ka, was sampled continuously for palynological analysis in ~5 cm intervals in sapropel layers and ~10 cm intervals in non-sapropel layers. Core MD-9501 represents a longer period of deposition, at least the last 250 ka, based on the occurrence of eight distinct sapropel layers; however, only the last 90 ka were palynologically studied (the top five m out of a total length of 11 m; Langgut, 2008). The MD-9501 sequence was sampled in ~2 cm intervals in the sapropel layers and ~4 cm intervals in non-sapropel sediments. Samples were processed at the Geological Survey of Israel using standard palynological techniques (Faegri and Iversen, 1992), without the acetylsol process that can be destructive for some of the palynomorphs (e.g., dinoflagellate cysts). Palynomorph concentrations were calculated based on Lycopodium clavatum C. Linnaeus tablets which were added to each sediment sample at the beginning of the palynomorph chemical extraction process (Stockmarr, 1971; Faegri and Iversen, 1992). Palynomorphs, including pollen grains, spores, dinoflagellate cysts, and algae were identified to the most specific systematic level. For palynomorph identification, a regional reference collection was used (University of Haifa), as well as relevant palynomorph atlases (Bonelleille and Riollet, 1980; Head and Wrenn, 1992; Reille, 1995, 1998, 1999; Fensome et al., 1996; Beug, 2004). Palynological diagrams were created using POLPAL software (Walanus and Nalepka, 1999). Pollen zones were established based on principal component analysis (PCA; Walanus and Nalepka, 1999).

3.2. The chronologicaframework

Previous isotopic studies of the Soreq Cave speleothem record, which was dated in high-resolution by the U/Th method (Bar-
Matthews et al., 2000, 2003 and updated in Vaks et al., 2006), emphasized that the well-dated δ¹⁸O Soreq Cave profile is well correlated with low resolution δ¹⁸O marine records from the Levantine Basin. Almogi-Labin et al. (2009) and Langgut et al. (2011) applied the same approach when previously studying et al., 2009, Table 1), and the identification of sapropel events which was based on the following line of evidence: changes in the color of the sediments, significant rise in TOC (Total Organic Carbon; Almogi-Labin et al., 2009), and increasing pollen concentrations together with decreasing percentages of coniferous pollen (Langgut et al., 2011). In this study, changes in aquatic pollen and spore frequencies were also used to determine the occurrence and exact duration of sapropel accumulation in the Levantine Basin.

4. Results

In each of the studied samples, all palynomorphs were identified and counted. Samples included on average about 300 palynomorphs. Fig. 2(a–f) is composed of new palynological data which was derived from the MD-9509 record. This diagram contains several curves: (a) Aquatic pollen – this group includes the following submerged fresh-water plants (in declining order): Potamogeton, Lemna, Nymphaeaceae, Myriophyllum and Elatinae. (b) Concentricystes rubinus – a fresh-water alga of Nilotic origin (Rossignol, 1964). (c) Botryococcus – this acritarch is a coenobia of colonial chlorococcales algae, which is considered as a relatively salt-tolerant taxon, sometimes living in brackish water (Batten, 1996). (d) Trilete spores – this group mostly represents reworking of reworked spores originating from the eroded basalt traps of Ethiopia, which were widely eroded into deep canyons by the Atbara River, the Blue Nile, and their tributaries (Rossignol, 1969). (e) Monolete spores – this group of spores originated from the upstream Nile (for a detailed spores diagram see Langgut, 2008, fig. 10c). (f) Dinoflagellate cysts – this group is dominated by the following taxa: Hystrichosphaeridium israelianum, Pterospermannopsis vancampoea, Baltisphaeridium machaerophorum, Baltisphaeridium israelianum and Spiniferites (for a detailed dinoflagellate cyst diagram see Langgut, 2008, fig. 10d). (g) Total pollen – this group includes the total sum of pollen excluding coniferous pollen grains (= bisaccates). The latter were excluded since they are over-represented, due to their high resistance to degradation and good long-distance transportability, especially in marine sediments (e.g., Rossignol-Strick and Planchais, 1989; Cheddadi and Rossignol-Strick, 1995b; in terrestrial Southern Levant pollen records this phenomenon does not exist, e.g., Litt et al., 2012; Langgut et al., 2014, 2015).

Fig. 2 was divided into six pollen zones, chiefly based on the results of the PCA. The lower part of the diagram begins with Pollen Zone I, covering the ~86–83 ka time interval. This zone is characterized by relatively high frequencies of aquatic pollen and dinoflagellate cysts (up to 8.5% and 1.7%, respectively), an almost total disappearance of both algae types, and extremely low values of spores. Pollen Zone II (~83–76 ka) is typified by increasing percentages of the alga Concentricystes rubinus (up to 6.3%) and the two types of spores (trilete up to 23.8% and monolete up to 7.4%) and by decreasing percentages of aquatic pollen and dinoflagellate cysts. Pollen Zone III (~76–16 ka) was further subdivided into three pollen zones (IIla-IIlc), mainly based on changes in the frequencies of the two types of spores. Sub-zone IIla (~76–58 ka) is characterized by medium levels of trilete and monolete spores (not exceeding 14.8% and 13.5%, respectively). Within sub-zone IIlb (~58–31 ka), increasing percentages of trilete spores were documented (up to 34.7%) while monolete spore values decreased (not exceeding 8.3%). Sub-zone IIlc (~31–16 ka) is typified by medium ratios of trilete spores (8.2–21.4%) and very low levels of monolete spores (0.9–4.4%). Pollen Zone IV covers the period of ~16–10 ka. It is characterized by a dramatic decline in trilete spores (0.0–12.0%). Pollen Zone V, which corresponds to the 10–7 ka time interval, encompasses some dramatic changes: maximum values of aquatic pollen (up to 46.4%), enhancement in dinoflagellate cysts ratios (up to 2.0%), almost total absence of the alga C. rubinus, and an inconsistent presence of trilete spores. The last Pollen Zone (VI ~7 ka until present) is characterized by medium proportions of most palynomorph curves.

While in the MD-9509 profile palynomorph presence was continuous throughout the entire sequence (Fig. 2), in the MD-9501 record, palynomorphs were preserved only during sapropel S3 and S1 deposition. Fig. 3(a–d) includes concise diagrams of sapropel events S3 and S1 in cores MD-9509 and MD-9501. The over-represented coniferous pollen grains were also excluded from the AP group in this case. The highest AP values were documented at the northern basin during S3 formation, between 85.9 and 85.1 ka, with 33.0–19.4% AP. During S1, AP levels in core MD-9501 are also higher in comparison to the southern core (11.5–19.2% vs. 4.7–16.0% during S1). The most dominant taxa during sapropel deposition in the MD-9509 core are Chenopodiaceae (Cheno/Ams) and Cyperaceae (the latter reached 35.6% at 7.8 ka). The northern core is dominated, among the trees, by evergreen oaks (Quercus calliprinos type) and among the non-arboreal pollen (NAP) by Chenopodiaceae and Artemisia. Tropical elements appear

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**Fig. 2.** Palynomorphs identified in this study from marine core MD-9509 (calculated as percentages from the total identified pollen and non-pollen palynomorphs): (a). Aquatic pollen (submerged fresh-water plants); (b) Concentricystes rubinus (a fresh-water alga from Nilotic origin; Rossignol, 1964). (c). Botryococcus (a chlorococcales alga). (d). Trilete spores (mostly reworking of reworked spores originating from the eroded basalt traps of Ethiopia; Rossignol, 1969). (e) Monolete spores (originated from the upstream Nile); (f). Dinoflagellate cysts (g). Total pollen grains excluding the over-represented coniferous pollen grains. (h-j). PCA 1-3.
inconsistently in S3 (0–2.9%) and S1 (0–1.9%) at the southern core, and they are totally absent from the northern core, as is Ephedra pollen. High palynomorph concentration values were recorded in both sequences during S3 (reaching up to 150,415 palynomorphs/g sediment at ~85.6 ka in core MD-9501, and with ~167,898 palynomorphs/g sediment at ~85.0 in MD-9509 record; Fig. 4f–g).

Fig. 3. Concise palynological diagrams of sapropels: sapropel S3, marine cores MD-9509 (a) and MD-9501 (b); sapropel S1, marine cores MD-9509 (c) and MD-9501 (d). Remark: Coniferous pollen grains were excluded from the total Arboreal Pollen (AP).

Relatively high concentration values were also documented during S1, reaching up to 91,572 palynomorphs/g sediment at ~8.7 ka at the northern core and up to 70,441 palynomorphs/g sediment in the southern core at ~9.2 ka (Fig. 4f–g).

Fig. 5 presents spores and Cyperaceae pollen which were recovered from core MD-9509. These palynomorphs are also
Fig. 4. Evidence for sapropel S3 and S1 accumulation in the Levantine Basin. (a). Insolation (65° N July): peaks are associated with North African humid periods and the accumulation of sapropels (S) in the Eastern Mediterranean Basin. (b). Sedimentation rates MD-9509 (cm/ka; Langgut et al., 2011); (c). Sedimentation rates MD-9501 (cm/ka; this study); (c). TOC (wt%) MD-9509 (Langgut et al., 2011); (d). TOC (wt%) MD-9501 (Almogi-Labin et al., 2009); (e). Palynomorph concentrations MD-9501 (g/sediment; Langgut et al., 2011); (f). Palynomorph concentrations MD-9501 (g/sediment; this study); (g). Total arboreal pollen (AP) excluding coniferous (bisaccate) pollen MD-9509 (Langgut et al., 2011); (h). Total arboreal pollen (AP) excluding coniferous pollen MD-9501 (this study).
typified by low frequencies when sapropel S3 and S1 were embedded (Fig. 5a and d). High values of Cyperaceae pollen were recorded between 80.0 ka and 63.1 ka, reaching a maximum of 50.8% at 72.6 ka (Fig. 5d). From 63 ka until the end of the glacial period, relatively low Cyperaceae levels were found (3.5–28.1%). The Holocene was characterized by relatively high Cyperaceae percentages (8.6–35.6%). The trilete spores (Fig. 5b) and the monolete spores (Fig. 5c) exhibit opposite trends: low monolete spore values were recorded during the last glacial while higher values were recognized during interglacials and vice versa.

Detailed sedimentological and isotopic analyses were performed on cores MD-9509 and MD-9501 by Almogi-Labin et al. (2009). Their study showed that the relatively constant low content of the sandy fraction in both cores demonstrated that these marine records were not disturbed by any turbidities. The average sedimentation rate in core MD-9501 is 5.75 cm/ka, compared to 20.7 cm/ka in core MD-9509 (Fig. 4b–c). The sedimentation rates are not consistent through time with variations being most noticeable in the southern core: between 57 and 43 ka the calculated sedimentation rates reached a peak of 34.5 cm/ka, while in sediments older than 74 ka, as well as during the last 35 ka, the ratios are lower than 20.0 cm/ka (with exceptions of high sedimentation rates for short periods). In the northern core (MD-9501) the calculated sedimentation ratios do not exceed 20.0 cm/ka before 70 ka and during the deglaciation and the Holocene (16 ka till present), while during the last glacial period sedimentation rates are lower with ~4.3 cm/ka on average.

5. Discussion

During the last 90 ka, in core MD-9501 palynomorphs, mainly pollen grains, were preserved only during two time intervals:
85.9—85.1 ka and 9.5—8.2 ka, which correspond to sapropel S3 and sapropel S1 (Figs 3b, d and 4g, i). Palynomorph preservation within the MD-9509 core was continuous (Fig. 4f and h). The MD-9509 AP curve clearly defines the last glacial period with low AP values between ~76 and 16 ka and an increase in Mediterranean tree pollen percentages in sediments older than 75 ka and younger than 16 ka (Fig. 4h; Langgut et al., 2011). The last glacial-interglacial cycle is also evident based on PCA1, which was performed on the new palynomorph curves presented in this study and which derive from Nilotic origin (Fig. 2).

5.1. Sapropel accumulation and regional comparison

The sapropels are shown to be time markers by most proxies: extremely high pollen concentrations, increasing TOC content, high frequencies of aquatic pollen, and an increase in dinoflagellate cyst levels (Figs 2 and 4). It was previously shown that in the studied cores, at the base of the sapropel the pollen preservation is the best for all taxa. Later, as oxidation rises, the frequencies of the most resistant pollen grains, such as coniferous pollen, grow and the relative contribution of the resistant pollen is less governing (Langgut, 2008; Langgut et al., 2011). It was found in the current study that in core MD-9509 this is also the case with the fresh water alga Concentricystes rubinus (Fig. 2b), the group of spores (Fig. 5a), and Cyperaceae pollen (Fig. 5d). These taxa are characterized by low values at the beginning of sapropel S3 and S1 formation, and by increasing values slightly after. Furthermore, the trilette spores are totally absent from the beginning of the Holocene sapropel – S1 (Fig. 3c). Similar palynological markers were used in previous studies to define the formation of sapropels in 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). The palynological markers used for sapropel identification are synchronized with the sedimentological markers defined by Almogi-Labin et al. (2009, fig. 2) on the same cores (MD-9509 and MD-9501): change in sediment color and increase in the percentage of the >63 mm size fraction. The isotopic analyses of cores MD-9509 and MD-9501 show low δ18O values of dwelling planktonic foraminifera at the beginning of sapropel S3 and S1 deposition, representing an enhancement in River Nile discharge into the Eastern Mediterranean (Almogi-Labin et al., 2009).

While comparing the palynological assemblages of the two records during the accumulation of sapropel layers (Fig. 3), the following observations emerge: (i) sapropel events terminated earlier in the northern basin (MD-9501) in comparison to the southern basin (MD-9509): sapropel S3 - 85.9—85.1 ka vs. 85.9—83.0 ka (Pollen Zone I), respectively, and sapropel S1 - 9.5—8.2 ka vs. 9.5—7.2 ka (Pollen Zone V), respectively; The reasons for these differences are not clear, but according to Almogi-Labin et al. (2009), it may be related to earlier ventilation in the northern Levantine Basin. (ii) Whereas the Northern Levant record is characterized by higher frequencies of AP, dominated by evergreen oaks (Quercus calliprinos type), higher percentages of semi-desert and desert elements (Chenopodiaceae and Ephedra) were documented in the MD-9509 record; it is worth noting that Ephedra pollen is totally absent from the northern core. Another fundamental difference between the northern and the southern sapropel pollen records is that in the latter profile, higher values of Cyperaceae pollen were recorded. Whereas the appearance of tropical elements is discontinuous in the southern core, they are totally lacking from the northern one (Fig. 3). The continuous presence of Cyperaceae together with the fragmented appearance of the tropical elements clearly indicates that the Southern Levantine Basin is strongly influenced by the River Nile contribution, which is also evidenced by the higher sedimentation rates and by the 2—3 times higher TOC values, compared with the northern core (Fig. 4b—e). Pollen was not preserved throughout the MD-9501 profile because of relatively low sedimentation rates and ventilated bottom water. Only during the accumulation of sapropels is pollen present in the northern core due to the dramatic decrease in oxygen. The higher arboreal pollen percentages in the northern record indicate that more moisture was available in the northern parts of the Levantine region in comparison to its southern areas (Fig. 4h—i).

The relative increase in dinoflagellate cyst percentages in core MD-9509 during the formation of S3 and S1 (Fig. 2f, Pollen Zones I and V) may be related to a rise in nutrients representing a growth in marine productivity, as evidenced also by the dramatic increase in TOC values (Fig. 4d—e), as was already presented in previous studies (e.g., Rohling, 1994). Since the most important nutrient source is river input (e.g., Bethoux, 1989), the higher dinoflagellate cyst ratios during sapropel events are most probably related to enhancement in River Nile flows (Revel et al., 2010). While van Helmond et al. (2015) suggested that marine productivity (as reconstructed with total dinocyst accumulation rates) begins to rise ~1 ka prior to sapropel S1 formation in the Southern Levantine Basin and begins to decline three centuries after the sapropel onset; in the MD-9509 profile the dinoflagellate ratios during S3 and S1 are relatively stable throughout the entire period of deposition. According to Krom et al. (2002), the reduced inputs of Blue Nile sediments during periods of sapropel formation (detailed below) contributed to the increased primary productivity by reducing the amount of phosphate removed from particles.

Sapropels S3 and S1 were also identified in other parts of the Eastern Mediterranean in several palynological profiles (Rossignol-Strick, 1972, 1985; Rossignol-Strick et al., 1982; Cheddadi and Rossignol-Strick, 1995a,b; Rossignol-Strick and Paterne, 1999; Kotthoff et al., 2008a,b; and references therein). The palynological markers used for sapropel identification are synchronized with the sedimentological markers defined by Almogi-Labin et al. (2009, fig. 2) on the same cores (MD-9509 and MD-9501): change in sediment color and increase in the percentage of the >63 mm size fraction. The isotopic analyses of cores MD-9509 and MD-9501 show low δ18O values of dwelling planktonic foraminifera at the beginning of sapropel S3 and S1 deposition, representing an enhancement in River Nile discharge into the Eastern Mediterranean (Almogi-Labin et al., 2009).

5.2. Reconstruction of Nile flows into the Mediterranean during the last 86 ka

The group of spores extracted from core MD-9509 is
characterized by higher frequencies during the last glacial period in comparison to the values prior to ~70 ka and subsequent to ~16 ka (Fig. 5a; Pollen Zones I, II and IV-VI). The trilete spores (Fig. 5b) and the monolette spores (Fig. 5c) (which together compose the group of spores in Fig. 5a), indicate that the last glacial was typified by higher levels of trilete spores, which are more durable in terms of preservation in comparison to monolette spores. This can be explained by the observation that the trilete spores represent a redeposition of reworked spores originating from the eroded basalt traps of Ethiopia (Rossignol, 1969). During periods typified by dry climate conditions, vegetation cover was reduced and an increase in erosional processes in the Ethiopian Highlands and lowlands was documented (e.g., Adamson et al., 1980; Box et al., 2011), eventually resulting in a higher discharge of reworked trilete spores into the Levantine Basin as is evident in the MD-9509 record. Therefore, high frequencies of trilete spores are markers for relatively dry conditions, lower vegetation cover, and an increase in sediment influx (mainly that of the Blue Nile and Atbara). Indeed, experimental studies demonstrate that deforestation of East African upland catchments results in a more rapid and more seasonal runoff regime and in a distinct rise in sediment load (Rapp et al., 1972).

Conversely, wetter conditions in the Ethiopian Highlands when the monsoon monsoon increased in intensity, lead to an increase in freshwater discharge from the Blue Nile headwaters. The availability of moisture resulted in vegetation cover enhancement, increase in slope stability and soil formation, which reduced the erosional process. Therefore, sediment flux from the Blue Nile Basin is sensitive to climatic conditions and decreased during wet periods (Adamson et al., 1980). The curves of Cyperaceae pollen and monolette spores (Fig. 4c–d) present an opposite trend to the curve of the trilete spores (Fig. 5b): high values were documented before ~60 ka (Pollen Zones I, II, IIIa) and after 14 ka (Pollen Zones IV-VI). Increasing Cyperaceae values represent a greater distribution of swamps and ponds along the River Nile and its delta, which are indicative of a rise in Nile freshwater supply. That may explain the relatively low percentages of Cyperaceae during the glacial period which was characterized by dryer climate conditions and therefore by a decrease in River Nile flows and an enhancement in sediment load, as evidenced also by other studies (e.g., Stanley and Maldonado, 1977; Schilman et al., 2001; Krom et al., 2002). Box et al. (2011) in a previous study which was conducted on the same cores (MD-9509 and MD 95–01) and dealt with changes in sediment provenience over the last 25 ka, showed that during the accumulation of sapropel S1, sedimentation rates increased due to the greater importance of the White Nile sediment influx in comparison to the Blue Nile sediment influx (Box et al., 2011). In the Ethiopian Highlands (Blue Nile catchment, Fig. 1a), increases in the intensity and duration of the monsoonal system during the early Holocene led to enhancement in vegetation cover, resulting in less soil erosion. Contrarily, in the White Nile catchment, an increase in precipitation caused more erosion and higher sediment load through the Sudd Marshes (Fig. 1a; Box et al., 2011). Indeed, monolette spore percentages increased during sapropels S3 and S1 while trilete spores decreased (Fig. 5b–c). It is therefore suggested in this study that during the last glacial, the main contributors of freshwater and sediment load to the Eastern Mediterranean Sea were the Blue Nile and the Atbara and only during interglacials was there a more significant contribution of the White Nile.

Saharan dust flux also diminished in MD-9509 sediments when sapropel S1 was embedded due to the ‘greening of the Sahara Desert’ (Box et al., 2011), as evidenced, for example, by the relatively-deep stratified paleolake sediments in the Eastern Sahara which revealed that the area was surrounded by tropical savanna woodland vegetation (Ritchie et al., 1985). The low frequencies of semi-desert and desert elements such as Artemisia within the palynological spectrum of MD-9509 during the accumulation of sapropel S1, corroborates these findings (Fig. 3c).

### 5.3. Possible links between the monsoonal and the Atlantic climate systems

Cold dry Heinrich Events (Heinrich, 1988) were previously identified in core MD-9509 based on distinct spikes of minimum Mediterranean arboreal vegetation (Table 1) and high values of steppe elements, indicating that the vegetation in the South-Eastern Mediterranean responded rapidly to the short-lived North Atlantic cold climate spells (Langgut et al., 2011). The current study demonstrates that Heinrich Events H2–H6 were also characterized by an almost total disappearance of the tropical elements which originated at the headwaters of the Nile in East Africa (Fig. 6b, Table 1). It is therefore suggested here that Heinrich Events were synchronized with arid conditions in tropical East Africa. Inter-relations between the two climate systems – the Atlantic and the monsoon system – are also evidenced by PCA1 (Fig. 2h), where the palynomorphs from Nilotic origin exhibit the general trend of the last glacial-interglacial cyclicity of the Northern Hemisphere.

Heinrich Events were caused by the anomalous surge of icebergs into the North Atlantic Ocean due to ice-sheet instability. The meltwater related to the icebergs led to surface water cooling and freshening (Bond and Lotti, 1995; Bond et al., 1999; Hemming, 2004) and frequented the sudden rapid collapse of the thermohaline circulation (Broecker et al., 1990). These short-lived colder and dryer episodes were recognized in the Eastern Mediterranean also on land (e.g., Soreq Cave - Bar-Matthews et al., 1999; Dead Sea - Bartov et al., 2003; Lake Van – Pickarski et al., 2015). Thus, the decrease in oceanic heat transport to the high northern latitudes was also responsible for dramatically cooler and dryer climate conditions in the Eastern Mediterranean. The thermohaline circulation also plays an important role in the cross-Equatorial transport of heat from low latitudes to northern Polar Regions (Carto et al., 2009). Indeed, a previous study from the Equatorial Atlantic beneath Africa’s bulge showed that Heinrich Events were associated with dry episodes (Broecker and Hemming, 2001). Schefuß et al. (2003), suggested that changes in atmospheric moisture content—driven by tropical sea surface temperature (SST) changes and the intensification of the African monsoon forced aridity on the African continent and led to large-scale climate and vegetation cover changes. The ITCZ is sensitive to changes in the tropical SSTs. The colder-than-normal SSTs in the northern tropical Atlantic create a SST gradient between the Northern and Southern Hemispheres, which in turn creates a north-south pressure gradient in the atmosphere. As a result, the ITCZ and its associated precipitation belt moves further south of the Equator than normal, causing continuing drought conditions, especially distinct in the Sahel

<table>
<thead>
<tr>
<th>Heinrich Event</th>
<th>Age (ka BP)</th>
<th>Arboreal Pollen Percentages</th>
<th>Tropical Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>H2</td>
<td>~24.2</td>
<td>2.3%</td>
<td>0%</td>
</tr>
<tr>
<td>H3</td>
<td>~30.1</td>
<td>3.1%</td>
<td>0%</td>
</tr>
<tr>
<td>H4</td>
<td>~37.4</td>
<td>2.4%</td>
<td>0%</td>
</tr>
<tr>
<td>H5</td>
<td>~47.2</td>
<td>2.8%</td>
<td>0.9%</td>
</tr>
<tr>
<td>H6</td>
<td>~59.4</td>
<td>2.5%</td>
<td>0%</td>
</tr>
</tbody>
</table>

Heinrich Events were identified in this study based on minimum AP percentages and almost total disappearance of tropical elements. The latest event (H1) was not identified based on the above criteria, probably due to relatively low sampling resolution at this specific section of the MD-9509 core.
region (Carto et al., 2009 and references therein). Conversely, humid periods are linked to global warming which leads to a northward movement of the ITCZ. These changes are coeval with fluctuations in summer monsoon strength and are associated with SST oscillations in the South Atlantic Ocean and Indian Ocean (Gasse, 2000). The almost total disappearance of tropical elements in the MD-9509 profile, which is synchronized with Heinrich Events (Table 1), corroborates that cold spells of the SST in the North Atlantic could have been weakened by the seasonal migration of the African monsoon and the ITCZ, thus allowing dry, arid conditions to prevail in tropical/sub-tropical Africa, resulting in a significant decrease of River Nile flow into the Eastern Mediterranean Basin. It is even possible that during these extreme short-lived spells, freshwater from the Nile was not delivered into the Mediterranean.

6. Conclusions

In this study palynomorphs were extracted from two Late Quaternary marine sediment cores which are located at the two ends of the Levantine Basin: MD-9509, at the southern part of the Levantine Basin, and MD-9501, at its northern part. While the southern core exhibits a continuous palynological record, in the northern core, palynomorphs have been preserved only during the formation of sapropel S3 and S1. The conclusions from this study can be summarized as follows:

1. Palynomorphs from Nilotic origin enabled the reconstruction of River Nile flows during the last 86 ka. In general, the last glacial period (~75–16 ka) was characterized by a decreasing Nile water discharge and an increasing sediment influx while opposite trends were observed prior to the last glacial period as well as during the deglaciation and the Holocene. Based on the study of the spores presented here, it is suggested that during the last glacial, the main contributors of freshwater and sediment load to the Eastern Mediterranean Sea were the Blue Nile and the Atbara and only during interglacials was there a more significant contribution of the White Nile.

2. The two cores reflect sedimentation and palynomorph accumulation under the influences of two different climate regimes. While core MD-9501 was mostly under the influence of the North Atlantic/Mediterranean climate system, the MD-9509 sequence was also strongly influenced by the River Nile input, which originates in the low-latitude monsoonal system. This is evident from the higher presence of palynomorphs of Nilotic origin and higher sedimentation rates in the southern record vs. the northern record. Sapropel S3 and S1 terminated earlier in the northern part of the Levantine Basin as opposed to the southern part of the basin. The comparison of the sapropelic palynological assemblages of the two records clearly indicates...
that during the formation of S3 and S1, climate conditions were more humid in the North Levantine region, reflecting the north-south regional Mediterranean climatic moisture gradient. The formation of sapropels S3 and S1 is most probably a result of the intensification of the monsoonal system, which was related to the maximum insolation values at 65°N, while, currently, the Atlantic is the main influencing climate system in the region.

3. It is demonstrated that during Heinrich Events H2–H6, pollen originating from tropical regions was not embedded in the Levantine Basin. These results lend support to the view that African cooling and drying episodes were associated not only with low-latitude climate controls, but also with high-latitude glacial stress such as during Heinrich Events.

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