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The Younger Dryas in the Eastern Mediterranean Revisited: Some Additional Notes on Late Glacial and Early Holocene Pollen and Radiocarbon Chronologies

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1. Introduction

This paper revisits the manifestation of the Younger Dryas in pollen diagrams of the Eastern Mediterranean as traced by Bottema (1995) on the basis of uncalibrated ^{14}C dates. The author concludes that the identification of this episode in pollen diagrams is problematic and in some areas undiscernable due to the asynchronous pollen pictures. The main reason for a revision is that radiocarbon specialists and palynologists agree that ^{14}C dates, as used in this paper, do not always represent true dates. It has become clear that sediments may be subject to reservoir effects. The main cause of these reservoir effects is the influence of groundwater upwelling. This is depleted in ^{14}C, resulting in excessively old radiocarbon dates, causing discrepancies in the pollen and radiocarbon chronologies. It is evident that this will lead to errors in the correlation and interpretation of the pollen records. For instance, the implementation of the uncorrected Hula ^{14}C chronology[1] would imply that maximum AP values were attained during

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the Late Glacial. The same holds for the Ghab record[2], whose dating and pollen chronology bears great resemblance to that of Hula. Similar inconsistencies between vegetation sequences and the ^{14}C time scale suggest age offsets present in a part of the Eastern Mediterranean terrestrial cores. By comparison with eastern Mediterranean marine records Rossignol-Strick (1995) concluded that the ^{14}C dates of terrestrial pollen sites covering the Last Glacial and early Holocene are generally too old.

Meanwhile, the varve-dated record of Lake Van[3] has also been revised. This varve chronology did not allow the correlation of its pollen diagram[4] with those of nearby sites such as Söğütlü, Zeribar and Urmia[5]. Since then, new studies provided a continuous varve record covering the last 14,000 years[6], However, this new varve chronology is not in agreement with the radiocarbon chronologies from sites nearby (see chapter 6.3).

In addition to the records of Ghab and Van discussed above palynological studies, including records of Eski Acıgöl[7], Lake Iznik[8] and Sağlık II[9], provide important new data with reference to the Late Glacial/early Holocene time span.

2. Method

Twenty pollen diagram sections are shown in simplified form (Figs. 2-21). Two of the records presented by Bottema have been left out, namely Ladik Gölü and Zeribar I. Ladik Gölü is rejected because about

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[1] Baruch and Bottema, 1991; 1999.

[2] Yasuda et al., 2000.

[3] Kempe and Degens, 1978.

[4] Van Zeist and Woldring, 1978.

[5] Van Zeist and Bottema, 1991.

[6] Lemcke, 1996; Landmann et al., 1996; Wick et al., 2003.

[7] Roberts et al., 2001; Woldring and Bottema, 2003.

[8] Miebach et al., 2016.

[9] Woldring et al., forthcoming.

80 cm of sediment around the PH boundary is devoid of pollen. Also Zeribar Ib, one of the records from Lake Zeribar, has been left out. The diagrams show the percentages of the key pollen taxa Artemisia and Chenopodiaceae, Arboreal Pollen (AP) and Non Arboreal Pollen (NAP). The basic pollen sum on which the percentages were calculated includes all upland pollen (trees and herbs). The zone code names and numbers in the left-hand column refer to the original publications. For various reasons the diagrams of Tenaghi Philippon II, Sağlık II, Van Gölü and Ghab 2000 differ in layout. The simplified diagram of Tenaghi Philippon II (Fig. 6) was redrawn from Diagram A (Poaceae included in the pollen sum). The Sağlık II diagram (Fig. 18) presents the full sequence of analyzed samples as no data have been published elsewhere until now. The simplified diagrams of Van (Fig. 15) and Ghab 2000 (Fig. 20) were redrawn from Wick et al. (2003) and Yasuda et al. (2000), as no 'raw'pollen data were available. Note that Poaceae were excluded from the pollen sum in the original diagrams of Edessa, Khimaditis and Söğüt, and included in the simplified diagrams, in the last-named resulting in a more gradual AP rise. At any rate the high pollen values in the records of Edessa and Khimaditis suggest that local grass vegetation contributed significantly to the pollen precipitation of the time studied.

The dotted line in figures 2 to 21 marks the end date of the Younger Dryas. These end dates were obtained from linear extrapolation of the deposition line and in some cases also from $\delta^{13}C$ correction (Table 3). We have not indicated the start of the Younger Dryas in the diagrams as the pollen sequences at the Allerød-Younger Dryas transition show a more diverse picture and hence are not as clearly visible as the end of the Younger Dryas. The radiocarbon dates relevant for this study are listed in Table 2.

A key pollen type for dating the Eastern Mediterranean pollen diagrams is the early Holocene appearance of *Pistacia*. *Pistacia* is indicative of mild winters and warm summers[10]. Table 4 indicates the level dating the start of a continuous curve in the diagrams discussed in this paper.

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[10] e.g. Rossignol-Strick, 1995.

3. The Younger Dryas phase

The climate of the Younger Dryas (10.900- 10.100 BP) is globally identified as extremely cold and arid. This period was preceded and followed by warmer and more humid conditions in the Allerød and beginning of the Holocene. Grosman and Belfer-Cohen (2002) indicate a drop in temperature by about 6° at the start of the Younger Dryas and a warming by about 7° at its end. There is hardly any doubt that the response of vegetation to such dramatic fluctuations in temperature and moisture will be visible in the diagrams.

Pollen sequences of the Near East corresponding with the Last Glacial are usually dominated by high proportions of steppe vegetation and reduced presence of trees. Most abundantly recorded components of the steppe vegetation are species of *Artemisia*, Chenopodiaceae and Poaceae. As wind-pollinated taxa they release their pollen profusely and therefor may be overrepresentated in the pollen rain. Characteristic woody elements of the Last Glacial include *Betula*, *Ephedra* and *Hippophaë*.

4. Pistacia

Beside the Younger Dryas chronozone, *Pistacia* is a stratigraphic marker in the pollen archives of the Near East[11]. An overview of the earliest continuous *Pistacia* occurrences in the diagrams is given in Table 4. These data suggest that *Pistacia* first expanded in the areas of Xinias, Zeribar, Ghab and Hula at c. 10.000 BP and by about 9000 BP had established itself in most of the Near East. *Pistacia* remained relatively rare in the western Pontic Mountains, the Pisidian Lake District and the Konya area. Present-day precipitation figures (Table 1) suggest that rainfall in the inland parts of western Turkey was high enough to allow the spread and domination of large forest trees such as oaks and pines, which prevented the establishment of *Pistacia* on a larger scale. Most likely severe aridity and winter cold prevented *Pistacia* from becoming widespread in the Konya area. A conspicuous difference can be noted in the recording of *Pistacia* in the cores of the Iznik area. It is completely absent in the Yenişehir record but is present in most of the spectra in the Iznik diagram. Furthermore, a

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[11] Rossignol-Strick, 1995.

distinct time gap can be seen in the timing of the spread of *Pistacia* in the records of Zeribar, Urmia and Van. One could speculate that altitudinal and latitudinal differences determined this later arrival in the Urmia and Van areas. Also different species, e.g. *P. atlantica* and *P. khinjuk*, might have been involved, each with their own ecological requirements and therefore perhaps reacting differently to climatic changes. However, it should be kept in mind that the dating of the Van record is complicated (see Chapter 6.3) and therefore no further inferences should be made.

5. Correction of radiocarbon dates

Radiocarbon ages t are calculated using the radioactive decay law $A=A_{t=0}\exp(-\lambda t)$ or $t = (-1/\lambda)\ln(A/A_{t=0})$. Here A is the measured ^{14}C (radio) activity of the sample and $A_{t=0}$ the ^{14}C activity at the time of death of the organism. The decay constant λ is related to the (conventional) halflife. In the following, we use the so-called activity ratio $^{14}a = A/A_{t=0}$ which is expressed in %[12].

At t=0, the activity ratio $^{14}a_0$ is known as the "recent activity", which for "normal" terrestrial samples (not subject to reservoir effects) is 100% relative to the reference or standard material. The calculation of ^{14}C dates then results in numbers expressed in the unit BP. Samples such as lake sediments, waterplants, marine and riverine organisms and the like originate from carbon reservoirs containing less ^{14}C than their contemporaneous terrestrial or atmospheric reservoirs, resulting in the apparent ages[13]. They have lower $^{14}a_0$ values.

Correction model: Because of reservoir effects, the ^{14}C dates for lacustrine sediments show ages which are too old. This becomes obvious when we make a graph of the ^{14}C dates as a function of depth for the lacustrine samples. Extrapolating them to zero depth (the present-day surface level) then yields an estimate for the offset caused by the reservoir effect, enabling the interpretation of the ^{14}C dates of the core[14].

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[12] Mook and van der Plicht, 1999.

[13] e.g. Lanting and van der Plicht, 1998.

[14] e.g. Meadows, 2005.

This has been successfully applied to other sites relevant for this research because of similar geochemical conditions and locations in the Near East[15].

The Eastern Mediterranean sequences all show this complication, especially related to the dating of the Late Glacial - Holocene transition[16].

In order to derive the magnitude of the reservoir effect, the value for $^{14}a_0$ (the natural ^{14}C activity when the now dated sample was alive) needs to be determined. This can be done because the stable isotope ratio $\delta^{13}C$ of the sample and its $^{14}a_0$ value are related.

For emerged plants living in stagnant water, the $\delta^{13}C$ values range between -16 and -21‰ and the recent activity ratio $^{14}a_0$ is 100% or close to 100%. The latter is a result of isotopic exchange of CO_2 between water and atmosphere.

For submerged plants living in running water, the $\delta^{13}C$ values range between -30 and -40‰ and $^{14}a_0$ is unknown. The latter depends on the ^{14}C activity of the (ground)water flowing into the lake.

We use the following model, based on the numerical values mentioned above. We determine a $^{13}C/^{14}C$ relationship assuming the following endmember values:

- for emerged plants, $\delta^{13}C$ = -36‰ and $^{14}a_0$ = 68% (in a few cases 45%);
- for submerged plants, $\delta^{13}C$ = -21‰ and $^{14}a_0$ = 100%[17].

  These numbers can be used in the linear mixing equations with X representing the proportion of emerged plants and (1-X) that of submerged plants:

- $\delta^{13}C$ (measured sample) = (X) $\delta^{13}C$ (emerged plants) + (1-X) $\delta^{13}C$ (submerged plants), and
- $^{14}a_0$ (measured sample) = (X)$^{14}a_0$ (emerged plants) + (1-X)$^{14}a_0$ (submerged plants).

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[15] Cappers et al., 2002.

[16] Meadows, 2005.

[17] Avisar et al., 2001; Stiller et al., 2001.

From the measured $\delta^{13}C$ equation, the fraction X can be calculated; using this in the equation for the activity then gives the value of $^{14}a_0$.

Linear extrapolation of the ^{14}C data points indicates minimum reservoir ages for the greater part of the Holocene. In our model the calculated reservoir effect is less than 500 years. ^{14}C chronologies of pre-Holocene and early Holocene sediments generally show much older ^{14}C ages than would be expected by extrapolation. Groundwater depleted in ^{14}C is considered the main source of the reservoir effects. In particular, sediments corresponding to the Younger Dryas have been subject to reservoir effects. The significant drop in lake water levels during this arid phase induced the larger influence of old groundwater resulting in large reservoir ages.

As a consequence of increased precipitation, melt water and subrecent groundwater ($^{14}a_0$ = 90%), the influence of old groundwater is significantly reduced during the Holocene. Very likely, sediment build-up during the Holocene also diminished the influence of old groundwater, as the interval between the surface and the groundwater level increased with time.

Where necessary, ^{14}C data are corrected by using our model. Not all locations have the same hydrological circumstances but in general the ^{14}C activity $^{14}a_0$ of groundwater is about 68%.

For sites like the Hula however, ^{14}C activity can be as low as 45% but during the Holocene this is 75% instead of 90%. In Eski Acıgöl reservoir ages remain almost constant for about 3000 years. This may be a result of volcanic ^{14}C activity in the crater lake. The ages of fresh water shells of Ghab are related to the ^{14}C activity of the river water, which proves that reservoir effects are real. During the Younger Dryas period the shell data of Ghab seem to have a reservoir age of about 3000 years, which is equivalent to a ^{14}C activity of 68% of river water (= groundwater). During the Holocene, shell data of Ghab are about 900 years too old, equivalent to a ^{14}C activity of 90%. Illustrative on this point are the ^{14}C data of Ghab I at 1.33 m depth and Ghab 2000 at 4.25 m depth, which have about the same uncorrected ^{14}C dates (Table 2). At 4.25 m depth the reservoir effect is 1800 years, at 1.33 m depth only 900 years as the result of isotopic exchange with the atmosphere in the river upstream.

Note that the ^{14}C activity of 68% and 90% calculated in our model matches with the values of the Ghab 2000 fresh water shells.

6. The Simplified Pollen Diagrams: A Summary Overview

In this overview notes and comments are made as to the dating, pollen behaviour, regional vegetation development and further details. The simplified diagrams (Figs. 2-21) have been grouped in 'units' which show more or less corresponding pollen sequences at the Late Glacial/early Holocene interval. Fig. 1 shows the locations of the pollen sites under discussion. Diagrams with a complicated correlation of the dating and pollen chronologies are discussed in some more detail.

6.1. Ioannina I (Fig. 2); Khimaditis I/III (Fig. 3); Edessa[18] (Fig. 4); Xinias[19] (Fig. 5); Tenaghi Philippon[20] (Fig. 6); Yenişehir[21] (Fig. 7); Lake Iznik[22] (Fig. 8); Abant Gölü (Fig. 9) and Yeniçağa[23] (Fig. 10): Most simplified diagrams of Greece and northwestern Turkey show a rapid decline of steppe vegetation and expansion of forest at the Late Glacial/Holocene boundary. The original diagrams of Edessa, Khimaditis and Söğüt show a much steeper AP curve, since in these cases Poaceae were excluded from the pollen sum (see chapter 2). The high Poaceae values suggest a substantial contribution of local grass vegetation at these sites. By contrast, grasses probably formed part of the early Holocene upland vegetation in the Abant and Yeniçağa areas, which suggests more open (conifer) forest until about 7000 BP uncal.

The Ioannina sample GrN-4875 provides a case that correction of ^{14}C dates is not always necessary. Extrapolation and $\delta^{13}C$ correction places the finish of the Younger Dryas within the last stage of the *Ar-*

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[18] Bottema, 1974.

[19] Bottema, 1979.

[20] Wijmstra, 1969.

[21] Bottema et al., 2001.

[22] Miebach et al., 2016.

[23] Bottema et al., 1995.

temisia/Chenopodiaceae steppe (subzone W3). Based on pollen the start of the Holocene would rather be assigned to subzone X1, and consequently the uncorrected ^{14}C date has a better fit with the pollen record. Below special notice is given to the dating and pollen chronologies of Tenaghi Philippon, Yenişehir and Lake Iznik.

6.1.1. Tenaghi Philippon (Fig. 6): In order to achieve a consistent age model, Wijmstra does not mention the ^{14}C dates GrN-5719 and GrN-5720 (Table 2), which according to the lab measurements date to the early Holocene. In this model the short-lived AP drop in zone Y3 was assigned to the Younger Dryas. The first AP maxima in zone Y2 (5.75-4.75 m) were assigned to Bølling-Allerød interval. Already Bottema (1974: 106, 121) has doubts about this interpretation and assumes that subzones Y2 and Y3 form part of the Holocene. Rossignol-Strick (1995: 906, 907) proposed a revised chronology based on marine records, in which she attributed subzone X5 to the Younger Dryas. This means that the first AP rise in zone Y must be allocated to the early Holocene. On the basis of the pollen evidence from their marine core SL 152 also Kothoff et al. (2008: 1027) proposed an alternative chronology for the Tenaghi Philippon record (they probably did not have the unpublished ^{14}C dates GrN-5719 and GrN-5720 at their disposal). In this chronology, the subzones X5 and Y1 are as well attributed to the Younger Dryas, and the subzones Y2 and Y3 to the early Holocene. Our method positions the end of the Younger Dryas in the upper part of subzone Y1.

6.1.2. Yenisehir (Fig. 7) and Lake Iznik (Fig. 8): The Iznik core comes from the central part of the lake (max water depth 80 m.), the Yenişehir core comes from a paleolake near the town of Yenişehir, located c. 15 km south of the former. Bottema et al. (2001) place the start of the Holocene in the Yenişehir record at the zone 1-2 boundary (decline in steppe vegetation and reforestation thereafter), which is close to the Younger Dryas end date achieved with our method (middle part of zone 1). Miebach et al. postulate the Younger Dryas at the top of zone 5 (c. 10.4 m. depth), corresponding with a temporary decline in AP and NAP increase. The authors suggest that the Younger Dryas phase was condensed due to low sedimentation rates (though the assumed opening up of the vegetation would rather foresee higher sediment influx). The allocation of Iznik zone 5 to the Late Glacial also depended on geochemical and mineralogical proxies, by which the Younger Dryas was clearly defined[24]. We notice that, for whatever reason, dips in AP percentages are a regular feature in regional pollen sequences representing the Holocene forest climax.

Various evidence supports a younger date of zone 5. Linear extrapolation dates the top of zone 5 to c. 9400 BP and places the end of the Younger Dryas at c. 10.8 m. (Table 2). From the base of zone 5 temperate forest expands, whereas the previous zone 6 demonstrates glacial conditions with a high representation of cold and drought-resistant steppe vegetation along with limited tree growth. The concurrent presence of *Juniperus*, *Betula* and *Ephedra* reflects dry and/or cold conditions. $\delta^{18}O$ values support a Younger Dryas age for zone 6 with the coldest conditions in the lake's history. There are no indications for a temperature drop during zone 5. With the peaking in magnetic susceptibility (by FeS deposition) the authors also reasoned the AP reduction in zone 5 could be assigned to the Younger Dryas. However, similar phenomena might just as easily be connected with volcanic activity.

Two pollen records from the Aegean Sea[25] and the Sea of Marmara[26] bear great resemblance to the Iznik and Yenişehir records. In both cases the authors place the termination of the Late Glacial at the level of abrupt decline of *Artemisia*/Chenopodiaceae steppe. Reforestation starts almost instantly at the end of the Late Glacial in the Marmara record, whereas core SL 152 reveals a delay in the maximum expansion of forest until ca. 9.4 kyr BP.

6.2. Söğüt Gölü (Fig. 11) and Beyşehir II[27] (Fig. 12): The Beyşehir record shows relatively low *Artemisia* and Chenopodiaceae percentages during the Late Glacial which only slightly decrease during the Holocene. On the basis of pollen, one would expect the end of the Younger Dryas at about 8.0 m. For the Holocene core section only two radiocarbon dates are available which by extrapolation indicate

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[24] Roeser et al., 2012.

[25] Kothoff et al., 2008; SL 152.

[26] Valsecchi et al., 2012.

[27] van Zeist and Bottema, 1991.

a depth of 8.7 m. for the end of the Younger Dryas. It is evident that these results are based on few data and therefor should be taken with some reservations.

The same applies for the Sögüt record. Based on extrapolation of uncorrected ^{14}C dates, van Zeist at al. (1975) attribute the middle part of subzone 3c to the Late Glacial/Holocene transition. In our view, subzone 3c has multiple characteristics of the Younger Dryas, with dominating steppe vegetation and noticeable values of *Betula* and *Ephedra*. Lithologically, the deposition of marl during the middle part of subzone 3c (3.40-3.60 m) indicates a phase of lake low-stands and very arid conditions. However, if δ^{13}C correction had been applied to sample GrN-6883, the extrapolated Pleistocene/Holocene level would end up in the lower half of subzone 2a (at c. 5 m. depth). In this case zone 1 would correspond with part of the Younger Dryas: even though the pollen picture seems less characteristic for this period compared with subzone 3c. For this reason, omitting correction seems the most realistic option here. Apart from the few radiocarbon dates available, the questionable dating of the diagram may have to do with disturbances during sediment formation. If the Pleistocene/Holocene boundary is assigned to the zone 3/4 transition, only 1 m. of sediment (c. 3.20-2.20 m.) accumulated up to c. 3000 BP, and c. 3 m. (c. 5.20-2.20 m.) if starting from the zone 1/2 transition. By and large, sedimentation rates average around 1 m. per 1000 years, which suggests very low sedimentation rates or substantial loss of sediment during the time concerned. One is inclined to associate sizable sediment loss with landslides or the impact of local hydrological events, e.g. extreme drought followed by wet conditions might cause the drifting and displacement of sediment layers.

6.3. Akgöl Konya[28] (Fig. 13); Eski Acıgöl[29] (Fig. 14); Lake Van[30] (Fig. 15); Urmia[31] (Fig. 16) and Zeribar[32] (Fig. 17): The records from the high plateaux of Turkey and Iran all register a delay in forest advance

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[28] Bottema and Woldring, 1984/1986.

[29] Roberts et al., 2001; Woldring and Bottema, 2003.

[30] Wick et al., 2003.

[31] Bottema, 1986.

[32] van Zeist and Bottema, 1977.

in the first millennia of the Holocene, during which time vegetation is mainly made up of Poaceae. The establishment of grass steppe is determined by moisture availability. Rossignol-Strick (1995) indicates annual precipitation of up to ca. 300 mm for the establishment of grass steppe (tree growth requires minimum precipitation of 400-500 mm). It is deduced from the low AP ratios (mostly < 50%) and relatively large share of *Artemisia*/Chenopodiaceae in the pollen diagrams that moisture was generally more limited at the inland sites than at lowland sites during the Holocene.

In all the records the Younger Dryas chronozone is quite easily discerned by considerable values of *Artemisia*/Chenopodiaceae and extremely low AP percentages (< 10%). The setback of *Artemisia*/Chenopodiaceae steppe and simultaneous advance of Poaceae (Gramineae) marks the end of this phase.

In the Van record, zone V-4 is taken to represent the end phase of the Younger Dryas, the zone V-4/V-5 transition corresponding with 10.000 varve years. Accepting that this event occurred simultaneously at all four sites implies an inconsistency in the dating of the Van record. The dating of the Van sediment is based on the assumption that each varve represents a single year which implies that varve years are the equivalent of calender years. This dates the zone V-4/V-5 transition (simplified diagram zone 5/zone 6) to 10.000 cal BP, in ^{14}C years c. 9000 BP. This suggests the absence of a considerable number of varves in the Van record. By comparison with the GRIP core and tree-ring chronologies from Europe, Wick et al. (2003: 672) argue that about 1100 years are missing in the varve record. The authors reason that at least part of the chronological problem must be traced in the sediment section spanning the time of c. 10.000 to 8000 BP. Until further varve studies have solved this problem, the best option for a correct time-scale of the Van profile seems comparison of the vegetation developments with those recorded at nearby sites.

6.4. Sağlık II[33] (Fig. 18) and Ghab I[34] (Fig. 19): Thus far, no reports have appeared on the palynology of the Sağlık II core. For this reason, a summary diagram with a selection of pollen types is presented here. The core covers the time from c. 15.000 BP to 6500 BP. The core was recovered from the central part of a paleolake (Gavur Göl) in the Kahramanmaraş valley, a large depression south the town of Kahramanmaraş in southern Turkey.

Up to now, few available ^{14}C dates reveal considerable reservoir ages (Table 2). Contamination by near surface material is assumed for the uppermost sample.

The rapid change from steppe vegetation to forest domination at the Late Glacial/early Holocene interval mirrors the contemporary phases in the diagrams of Greece and western Anatolia. A similar vegetation development can be noticed at the zone 1/2 boundary in Ghab I, one of the pollen sequences obtained from corings in the Ghab Valley in northwestern Syria, c. 200 km to the south. The replacement of steppe vegetation by forest in these areas took place within some hundreds of years at most. It suggests a fairly abrupt rise in moisture and temperature since the advent of the Holocene, at least in the lowland regions of Greece and Turkey. The somewhat different pollen pictures of Ghab 2000 and Hula will be discussed in the next chapter.

6.5. Ghab 2000[35] (Fig. 20) and Hula[36] (Fig. 21): Two cores spanning the Late Glacial/early Holocene interval are available from Ghab Valley in northwestern Syria: Ghab I and Ghab 2000 (the latter named to prevent confusion with the various existing Ghab diagram codes). The coring site of Ghab I is located c. 30 km downstream (north) of Ghab 2000. The cores consist of lacustrine sediments which were deposited by the Orontes river running through the valley.

The Ghab records reveal a striking difference in the pollen signals during the Younger Dryas. The domination of steppe vegetation,

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[33] Woldring et al., forthcoming.

[34] Niklewski and van Zeist, 1970; van Zeist and Woldring, 1980.

[35] Yasuda et al., 2000.

[36] Baruch and Bottema, 1991; 1999; van Zeist et al., 2009.

well-defined in Ghab I (zone Y5), is much less distinct in Ghab 2000. In the latter the change in AP/NAP ratios is quite gradual and besides early Holocene AP maxima remain somewhat behind: c. 40% against c. 50% in Ghab I.

By contrast, the Ghab 2000 and Hula record show very similar pollen and dating chronologies and hence are jointly discussed here. It has become clear from the discrepancies in vegetation development and radiocarbon dates that sediments of both locations have been subject to reservoir effects. This issue has been debated comprehensively and investigators have applied different methods in order to determine the magnitude of the reservoir effect at these sites[37]. Meadows (2005), by using the content of modern water (A^0) as a reference, calculated corrections of up to 5500 ^{14}C years for the Late Glacial part of the Hula core. By comparison with Mediterranean marine records, Rossignol-Strick (1995: 908) identified Ghab I zone Y5 (Fig. 19) as corresponding with the Younger Dryas phase. The base of zone 2 in Hula would correlate with the end of the Younger Dryas (Fig. 21) which is consistent with the results we obtained by extrapolation (Table 3). Meadows considers the zone 1/2 boundary in the Hula and Ghab 2000 records to correspond with the start of the Holocene. Van Zeist et al. (2009) rejected the Hula radiocarbon chronology and assigned the date of 10.000 calendar years BP to the zone 1b/2 boundary of the diagram. Accordingly, the Pleistocene/Holocene transition would not be reached in the Hula core.

The Hula and Ghab 2000 diagrams reveal somewhat higher AP values during the Younger Dryas whereas early Holocene AP maxima generally remain below the values achieved in the contemporary phases of the sites in the coastal areas of Greece and Turkey. This results in a more gradual course of the curves and consequently the Late Glacial/Holocene boundary is less well-defined in the diagrams. The pollen evidence suggests somewhat higher humidity during the Younger Dryas and a relatively arid climate in the southern Levant during the early Holocene, relative to most other sites in the eastern Medirerranean.

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[37] Rossignol-Strick, 1995; Cappers et al., 2002; Meadows, 2005; van Zeist et al., 2009.

7. Conclusion

^{14}C reservoir ages have given rise to errors in the interpretation of pollen sequences in Near Eastern pollen archives. When correction for reservoir effect is applied, Late Glacial and early Holocene vegetation sequences are largely brought in line with each other. In most diagrams the Pleistocene/Holocene boundary is quite easily found by the rapid changes in AP/NAP ratios, viz. the sharp decline of steppe vegetation and subsequent spread of temperate forest. The pollen evidence of sites such as Edessa, Tenaghi Philippon and Sağlık II suggest that the change from steppe to forest spanned some hundreds of years at most. Only on the plateaux of Anatolia and Iran forest advance is slow due to inadequate moisture supply. The contemporary Ghab 2000 record diverges slightly from the general picture that appears from this study. Some depths dated by extrapolation show vegetation developments which apparently depart from those expected for that time, e.g. at Söğüt Gölü. Most probably, this is the consequence of hiatuses and disturbances in the lithological record. However, in general terms it can be concluded that the Late Glacial/early Holocene boundary in the terrestrial pollen records of the Eastern Mediterranean can principally be defined by the characteristic changes in the pollen curves.

The results of this study are largely in agreement with the findings of Rossignol-Strick that the Younger Dryas phase is a palynologically well-defined chronostratigraphical episode in the pollen diagrams of the Near East. Kothoff et al. (2008) argue that the Younger Dryas phase is an ideal climatostratigraphic anchor point for correlating the pollen records of mainland Greece. It is evident from this study that most pollen diagrams of the eastern Mediterranean can reliably be correlated by the very contrasting vegetation developments during the Late Glacial/early Holocene interval.

Acknowledgements

We are much indebted to Dr. Andrea Miebach, University of Bonn, for providing the pollen data of Lake Iznik. Many thanks are due to Paul van der Kroft, RAAP, for his assistance in modelling the diagram parts ascribed to the Younger Dryas, and to Sander Tiebackx, GIA, for numerous corrections and adjustments to the diagrams.

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Tables and Figures

	Coordinates		Elevation (m)	Temp (°C)		Precipitation (mm per yr.)
	N	E		January	July	
Ioannina	39°45′	20°43′	470	5.1	24.6 (Aug.)	1195
Khimaditis	40°37′	21°35′	560	1.8	23	800-1000
Edessa	39°03′	32°16′	350	3.4	24.6	800-1000
Xinias	39°03′	32°16′	463	?	?	?
Tenaghi Ph.	41°10′	24°20′	40	3.4	23.9	450
Yenişehir	40°16′	29°30′	200	4	24	600-800
Iznik	40°26′	29°31′	100	0	20-24	552
Abant	40°36′	31°18′	1375	-1/-6	15-20	500-600
Yeniçağa	40°26′	32°00′	980	0.1	19.7	534
Söğüt	37°03′	29°53′	1393	ca. -2	ca. 15	700-800
Beyşehir	37°32′	31°30′	1120	0	22 (Aug.)	499
Akgöl Konya	37°30′	33°44′	1000	0-4	20-24	<300
Eski Acıgöl	38°33′	34°32′	1270	1/-2	23	386
Van	38°30′	43°	1646	ca. -3	ca. 21	600?
Urmia	37°35′	45°28′	1300	-3.3	23.8	200-300
Zeribar	35°32′	46°07′	1300	2	18	600-800
Sağlık	37°19′	36°49′	490	4.5	28	750
Ghab	35°25′	36°15′	300	ca. 7	28	429 (Idlib)
Hula	33°10′	35°35′	300	ca. 10	ca. 25	450

Table 1. Climate dates from the weather stations nearest to the pollen sites (in part taken from Bottema, 1995).

Site name	Depth (m)	Lithogr.	$\delta^{13}C$	^{14}C age	Lab. No.	Corr. ^{14}C age
Ioannina I	2.71	gyttja	-26.2	10190±90	GrN-4875	9400
Khimaditis I	2.27	gyttja	-26.6	975±60	GrN-6595	975
Khimaditis III	2.55	gyttja	-16.1	3135±70	GrN-6182	3135
Khimaditis I	2.82	peat	-25.2	3995±60	GrN-6595	3995
Khimaditis I	4.02	gyttja	-25.9	7110±70	GrN-6597	7110
Khimaditis I	4.42	peat	-26.3	9345±85	GrN-6598	9345
Edessa	2.13	gyttja	-29.8	3510±55	GrN-5403	3510
Edessa	2.95	gyttja	-26.8	3280±55	GrN-6184	3280
Edessa	3.22	gyttja	-27.4	5260±65	GrN-6185	5260
Edessa	4.57	peat	-26.9	6385±55	GrN-6186	6385
Edessa	5.07	gyttja	-25.7	8050±70	GrN-5262	8050
Edessa	6.17	peat	-27.2	9420±60	GrN-6187	9420
Edessa	6.57	peat/ wood	-27.6	9765±45	GrN-6188	9765
Edessa	6.82	gyttja	-26.7	10645±100	GrN-6189	9700
Xinias I	1.28	gyttja	-20.3	8660±250	GrN-10478	8660
Xinias I	1.55	organic	-24.1	10.750±90	GrN-6889	10350
Tenaghi Ph.	4.30	peat		7850±50	GrN-4182	7850
Tenaghi Ph.*	4.60	gyttja	-27.6	8490±55	GrN-5719	8490
Tenaghi Ph.	4.50					8210
Tenaghi Ph.	4.70					8570
Tenaghi Ph.*	5.27	gyttja	-27.7	9575±55	GrN-5720	9575
Tenaghi Ph.	5.10					9290
Tenaghi Ph.	5.45					9920
Yenişehir	5.02	gyttja	-26.4	6320±60	GrN-23136	6320
Yenişehir	5.85	gyttja	-25.8	8410±100	GrN-23137	8410
Iznik	9.65	plant rem.	-26.8	9070±50	KIA 44585	9070
Iznik	10.40					9400
Iznik	10.80					10000
Abant	1.98	peat	-27.7	880±60	GrN-12627	880
Abant	4.77	peat	-27.1	2920±60	GrN-12628	2920

Abant	5.97	peat	-27.1	3880±60	GrN-12629	3880
Abant	9.63	gyttja	-26.8	9880±110	GrN-12630	9000
Abant	9.97	wood/ peat	-26.6	10320±90	GrN-12794	10140
Yeniçağa	8.06	peat	-24.1	4430±160	GrN-14008	4430
Yeniçağa	12.50	peat	-24.7	6920±70	GrN-14009	6920
Yeniçağa	13.42	peat	-24.9	7280±70	GrN-14010	7280
Yeniçağa	15.37	gyttja	-23.4	10180±170	GrN-14011	9800
Yeniçağa	16.15	gyttja	-27.1	12330±90	GrN-12796	11500
Beyşehir II	2.75	gyttja	-26.3	3265±35	GrN-6879	3265
Beyşehir II	5.15	gyttja	-25.4	6175±75	GrN-6878	6175
Beyşehir II	8.95	clay	-25.3	15390±370	GrN-10477	11000
Söğüt	2.13	gyttja	-25.0	2885±85	GrN-6452	2885
Söğüt	3.35	gyttja	-26.6	9255±95	GrN-6883	9255
Akgöl Konya	2.19	peat	-24.9	8040±140	GrN-10474	8040
Akgöl Konya	3.25	gyttja	-23.9	10920±150	GrN-10475	10500
Akgöl Konya	5.91	gyttja	-26.3	13050±950	GrN-10476	-
Eski Acıgöl	0.0	gyttja	-25.2	1360±30	GrN-23467	0.00
Eski Acıgöl	2.70	gyttja	-27.7	5540±280	GrN-22137	2540
Eski Acıgöl	4.60	gyttja	-18.1	6610±60	GrN-22881	3315
Eski Acıgöl	6.64	gyttja	-28.2	9440±230	GrN-21036	6440
Eski Acıgöl	8.33	gyttja	-27.1	11360±100	GrN-22447	8360
Eski Acıgöl	8.38	gyttja	-25.2	10910±100	GrN-22605	7910
Eski Acıgöl	10.46	gyttja	-28.9	11590±180	GrN-21035	8910
Eski Acıgöl	11.63	gyttja	-29.1	13450±140	GrN-24233	10450
Eski Acıgöl	14.52	gyttja	-30.7	14320±170	GrN-19988	11320
Urmia	2.07	shrimp		7505±125	UM	7505
Urmia	2.97	shrimp		9540±130	UM	9540
Zeribar II	9.85	gyttja	-17.1	5640±70	GrN-7628	5640
Zeribar II	11.07	gyttja	-19.1	6890±80	GrN-7629	6890
Zeribar II	13.67	gyttja	-23.4	10600±100	GrN-7630	10300
Sağlık II	2.48	gyttja	-28.3	5990±40	GrA-63541	5990
Sağlık II	6.14	gyttja	-27.4	9990±40	Beta-393636	9400

Sağlık II	8.22	gyttja	-26.4	15240±70	UCIAMS	10990
Sağlık II	9.62	gyttja	-25.7	18530±240	UCIAMS	13500
Ghab I	1.33	shell	-6.16	10080±55	GrN-5810	9200
Ghab 2000	1.30	shell		3450±90	JAS-170	2500
Ghab 2000	2.10	shell		4910±90	NUTA	4030
Ghab 2000	2.55	shell		5010±110	JAS-66	4310
Ghab 2000	3.20	shell		6620±100	JAS-171	6130
Ghab 2000	3.55	shell		7750±100	NUTA	6800
Ghab 2000	4.10	shell		8660±100	JAS-173	7860
Ghab 2000	4.25	shell		9970±100	JAS-176	8050
Ghab 2000	5.20	shell		12890±160	JAS-172	9970
Ghab 2000	5.80	shell		14820±180	JAS-175	11110
Hula	11.30	gyttja	-27.1	10440±120	GrN-17068	8100
Hula	12.38	gyttja	-22.3	11540±100	GrN-14986	8900
Hula	14.87	gyttja	-27.8	14680±480	GrN-23164	10900
Hula	16.12	gyttja	-27.5	17140±220	GrN-14463	14000

Table 2: List of radiocarbon dates and calculated reservoir ages relevant for the determination of the Younger Dryas end point at the sites discussed in this paper. * Note that 20 cm of sediment has been submitted for the Tenaghi Philippon samples GrN-5719 and GrN-5720. This results in a wide range of ages and therefore linear extrapolation has been applied to the top and base of the samples.

Site location + fig. nrs.	Depth finish Younger Dryas	Intersecting depth	Linear extrapolation	δ^{13}C model calculation
2 Ioannina I	3.0 m.	0.0	+	+
3 Khimaditis I	4.7 m.	2.0	+	
4 Edessa	6.9 m.	0.0	+	+
5 Xinias	1.7 m.	0.0	+	+
6 Tenaghi Phil. II	5.7 m.	0.0	+	
7 Yenişehir	6.9 m.	0.0	+	
8 Iznik Gölü	10.8 m.	0.0	+	
9 Abant Gölü	10.0 m.	0.0	+	+
10 Yeniçağa	15.4 m.	0.0	+	+
11 Söğüt Gölu	3.0 m.	0.0	+	
12 Beyşehir II	8.7 m.	0.0	+	
13 Akgöl Konya	3.2 m.	0.0	+	+
14 Eski Acıgöl	12.0 m.	0- 3000	+	
15 Van Gölü	Base zone V-6 (see text chapter 6.3)			
16 Urmia	3.2 m.	0.0	+	
17 Zeribar II	13.2 m.	4.0*	+	+
18 Sağlık II	7.2 m.	2.5- 6700	+	
19 Ghab I	1.5 m.	0- 600	+	+
20 Ghab 2000	5.2 m.	0-800	+	
21 Hula	14.3 m	0- 2500	+	

Table 3: Indicated are the depths of end-Younger Dryas based on intersecting of the extrapolation line, also including the δ^{13}C model for correcting radiocarbon dates. For further explanation see chapter 4. * Zeribar II water depth – 4 m.

	Xinias	Zeribar II	Ghab I	Hula	Tenaghi Philippon	Ghab 2000	Eski Acıgöl	Sağlık II	Urmia	Ioannina	Khimaditis	Edessa	Iznik	Lake Van
8500														
8600														
8700														
8800														
8900														
9000														■
9100												■	■	
9200														
9300											■			
9400										■				
9500									■					
9600							■	■						
9700						■								
9800					■									
9900														
10000	■	■	■	■										
10100														
10200														
10300														
10400														
10500														

Table 4: Date of first consistent occurrences of *Pistacia* in the pollen diagrams under consideration, based on corrected ^{14}C dates.

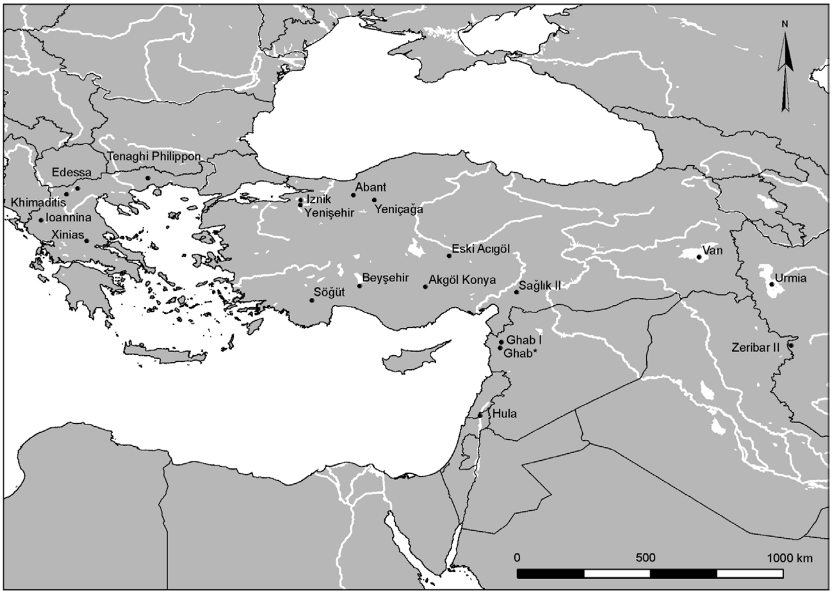
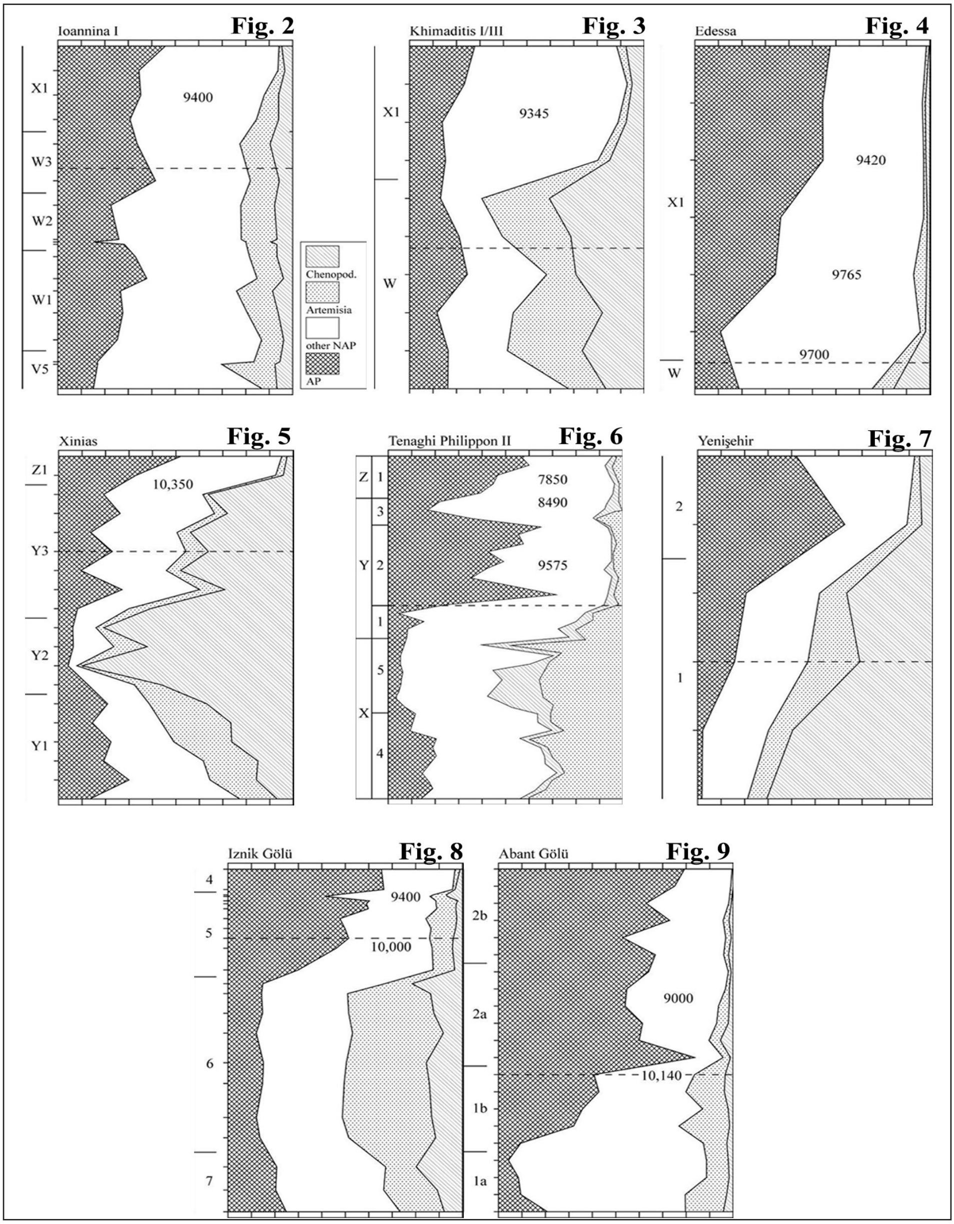
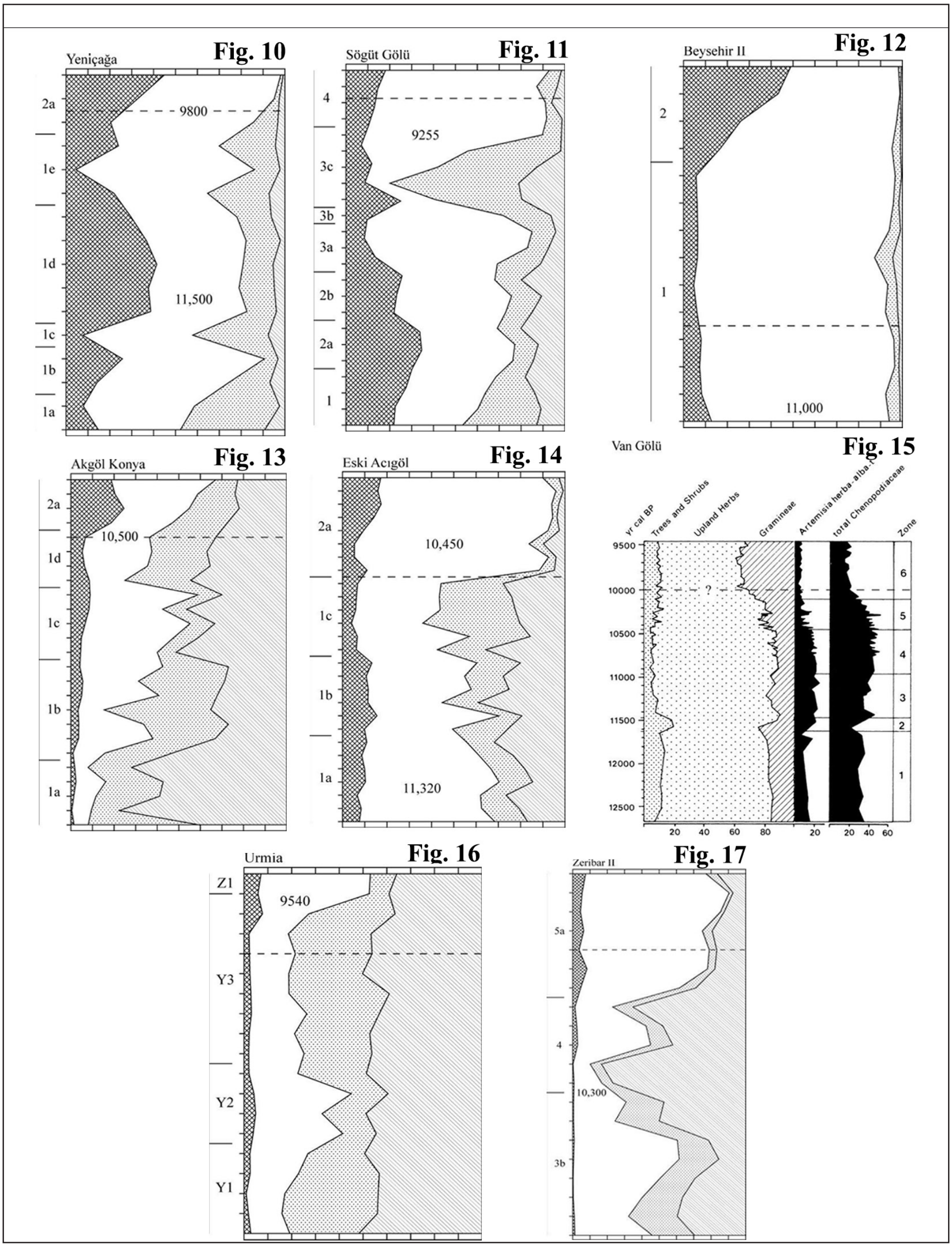


Fig. 1: Map of the area. The numbers 2 to 21 refer to the coring locations from which pollen diagrams were prepared. Ghab* is Ghab 2000 (drawing S. Tiebackx, GIA).



Figs. 2-9: Sections of simplified pollen diagrams (see also chapter 2 for further information).



Figs. 10-17: Sections of simplified pollen diagrams
(see also chapter 2 for further information).

Fig. 18

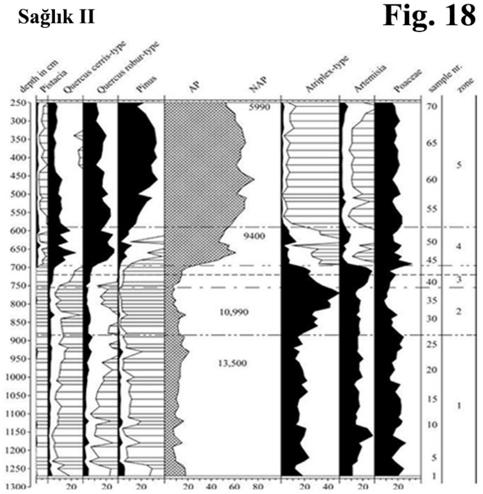


Fig. 19

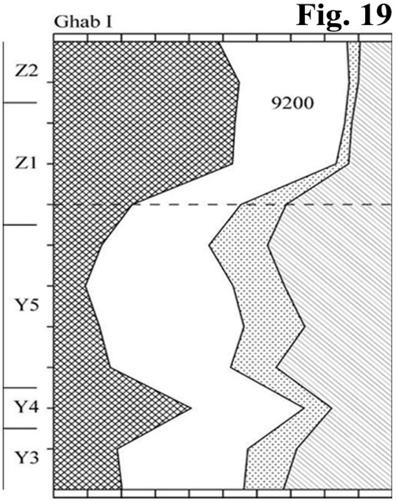


Fig. 20

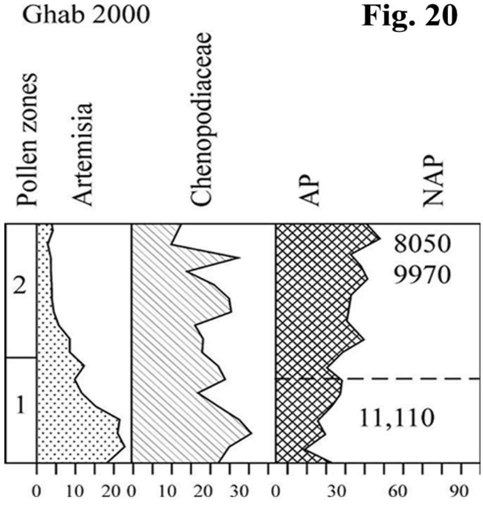
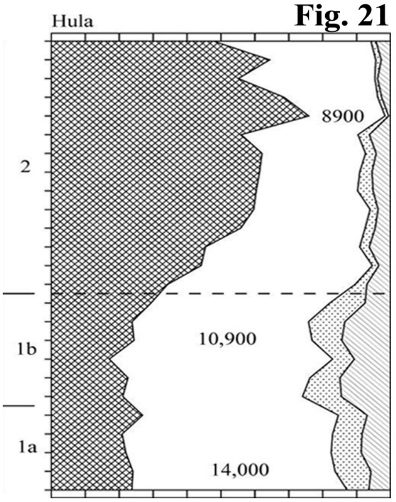


Fig. 21



Figs. 18-21: Sections of simplified pollen diagrams (see also chapter 2 for further information).