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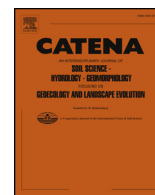
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Late Glacial to mid Holocene lacustrine ostracods from southern Anatolia, Turkey: A palaeoenvironmental study with pollen and stable isotopes

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ABSTRACT

This study investigates the ostracod assemblages obtained from a sediment core from a paleolake in the Sağlık plain in south-central Anatolia (Turkey). In addition to ostracods, oxygen and

carbon stable isotopes of ostracod shells were analysed and pollen analysis of the core undertaken. The sediments comprise the Late Glacial and early Holocene interval with an approximate ¹⁴C age from 18,000 to 6700 ¹⁴C years ago, after applying a correction for reservoir effects. Eight podocopid ostracod species were recorded, among them *Cyprideis torosa* and *Candona* sp. which were used for stable oxygen and carbon isotope analyses. *C. torosa* dominated during the Late Glacial while *Candona* sp. dominated most of the early Holocene assemblages. Both forms of *C. torosa* disappear abruptly close to the onset of the Holocene. Around this time, ostracod preservation was dominated by many black coloured valves and carapaces.

Based on ostracod assemblage data and isotope analyses, relatively wet phases were identified for the Older Dryas, Younger Dryas, and during the mid-Holocene at around 7500 ¹⁴C years ago. Relatively dry phases were identified during the Allerød interstadial, at the end of YD, and at about 6700 ¹⁴C years ago. An oligotrophic and brackish lake persisted until shortly before the end of the YD, when, according to the $\delta^{13}\text{C}$ values, conditions gradually became more eutrophic. The sudden disappearance of *C. torosa* at the end of the YD seems the consequence of anoxic bottom water conditions and/or eutrophication.

Alternating wet and dry phases characterize the early Holocene, with a longer period of wet and oligotrophic conditions around 7500 ¹⁴C years ago (ca. 8300 calBP). Ostracod assemblages and isotope records indicate a dry and more productive lake around 6700 ¹⁴C years ago (ca. 7550 calBP).

1. Introduction

Lake systems in the Mediterranean region are quite different from those in cooler climate ecosystems, which are mainly represented by stratified lakes (Cobelas et al., 2005). Investigating baseline conditions for such Mediterranean ecosystems are essential for developing conservation strategies. It is especially important to know how they may respond to future periods of global climate change.

Past climate conditions in Anatolia during the Late Glacial and the Holocene are important not only for discussing the present ecology of the region, but also to document the interactions of humans and the environment during prehistory. Anatolia has been populated since the Early Holocene and is well known for its many Neolithic settlements.

Several Neolithic sites were identified in the Kahramanmaraş Valley (Atakuman, 2004), e.g. the large Late-Neolithic site of Domuztepe located in the eastern Narlı Valley (Fig. 1). Some of the examples of human-environment interactions during prehistory are the suggested cultural changes (local adaptations or migration) related to climate changes during the Late Glacial and early Holocene boundary (Bar-Yosef, 2011) and rapid climate changes during the Holocene in Neolithic and later societies (deMenocal, 2000; Cullen et al., 2000; Flohr et al., 2015).

There are several studies on the past environmental and climatic history of Anatolia using lacustrine sediments from the Late Glacial (Bottema and Woldring, 1984; Roberts et al., 2001; Wick et al., 2003; Kashima, 2011; Pickarski et al., 2015; Roberts et al., 2016; Miebach

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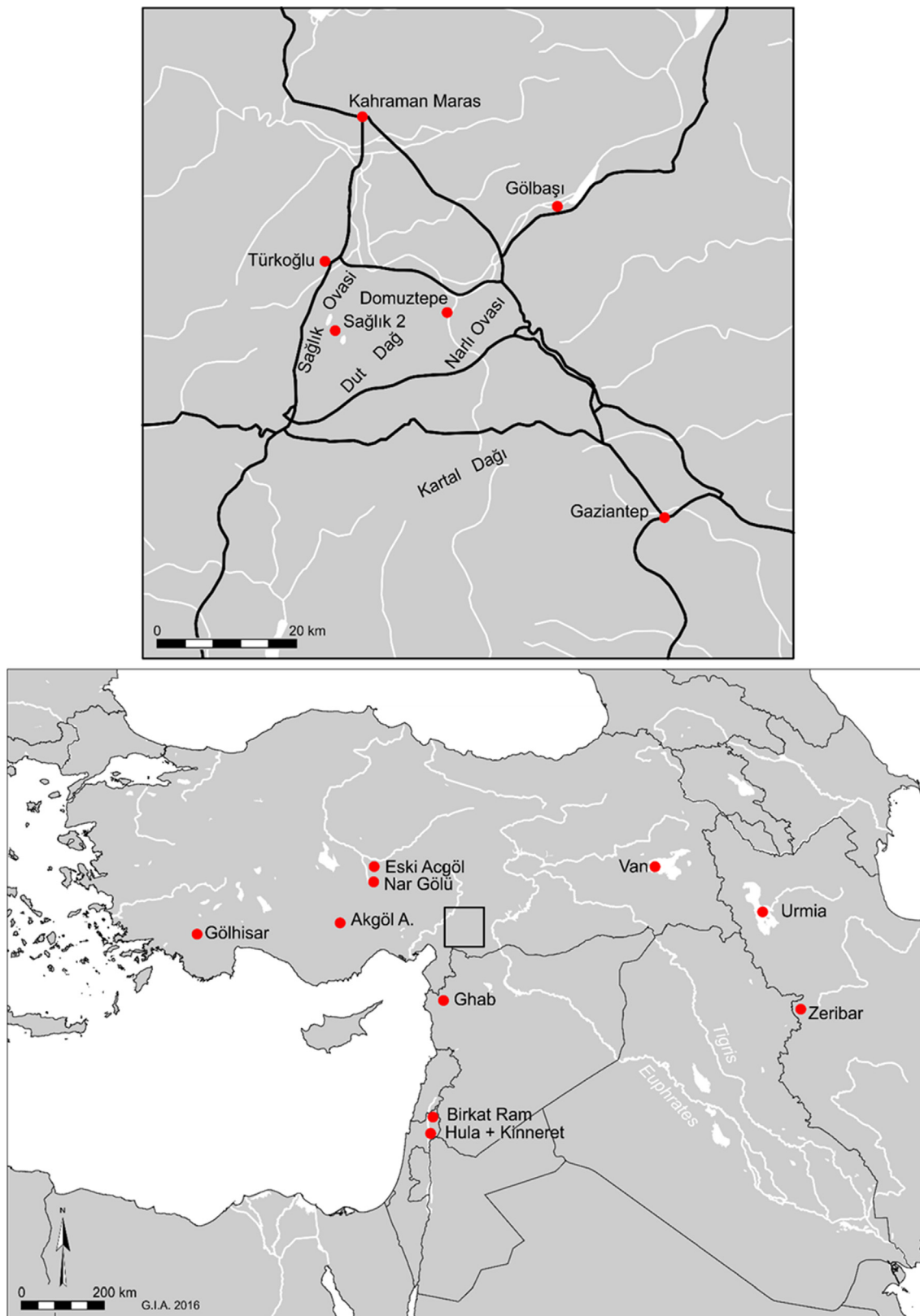


Fig. 1. Map of the study site.

et al., 2016) and the Holocene (Eastwood et al., 1999; Jones et al., 2006; England et al., 2008; Roberts et al., 2011; Woodbridge and Roberts 2011; Dean et al., 2015). These are usually based on analyses of pollen, diatoms, stable isotopes and geochemical proxies to track past environmental changes in Anatolia. Ostracods have a high potential

value as a sediment proxy for past changes in lakes (Frenzel and Boomer, 2005; Boomer and Eisenhauer, 2002; Boomer et al., 2003).

Results from different proxies show that there were water level fluctuations in the lakes of Central Anatolia during the Late Quaternary (Kashima et al., 1997; Kashima, 2002; Kashima, 2003; Roberts et al.,

Table 1

Chronological information for the Sağlık II core, shown as a function of sample depth (in cm, column 1). It shows the 5 AMS measurements (columns 2–4): ^{14}C date in BP, $\delta^{13}\text{C}$ of the sample and laboratory code. Columns 5–6 show temporal anchor points and their ^{14}C age. Both are used to derive sedimentation lines (see text), yielding the final ^{14}C ages (column 7). These ages are calibrated (column 8). Column 9 shows the size of the reservoir effect, which is the difference between the final ^{14}C age (column 7) and the measured ^{14}C date (column 2).

Depth (cm)	Measured ^{14}C date (BP)	$\delta^{13}\text{C}$ (‰)	Laboratory code	Anchor point	Anchor age	Final ^{14}C age	Calibrated age (calBP)	Reservoir effect
240						6710	7580	
246–250	5990 ± 40*	−28.27	GrA-63541			6770	7640	
280				Jordan river level	7000	7000	7850	
613–615	9990 ± 40	−27.40	Beta-393636			9385	10,600	605
720				end YD	10,150	10,150	11,850	
820–824	15,240 ± 70	−26.40	UCIAMS	begin YD	11,000	11,000	12,820	4240
960–963	18,530 ± 240	−25.70	UCIAMS			13,000	15,600	5530
1150				Botryo-coccus	approx. 16,000	15,560	18,800	
1238–1240	18,790 ± 60	−26.50	Beta-393637			16,930	20,400	1860
1300				DO-2	17,800	17,800	21,600	

2001; Kashima, 2011; Roberts et al., 2016). A lake located in the Konya Basin during the Last Ice Age (Kashima, 2011) may have existed during the Younger Dryas (YD) (Kashima, 2002; Kashima, 2003; Kashima, 2011). The climate of the region was relatively dry during the Late Glacial (Roberts et al., 2016; Wick et al., 2003), more so during the YD in the sediment record of Lake Van (Wick et al., 2003). Wetter conditions prevailed in the early Holocene (Roberts et al., 2001; Wick et al., 2003; Roberts et al., 2016), followed by a drier mid Holocene period (Roberts et al., 2001; Roberts et al., 2016) except in north-central Anatolia (Kashima, 2011). Sediment records of Seyfe Lake reveal a wetter period following a period of very dry conditions around 6000 BP (Kashima, 2011).

The Sağlık II core is among the first records of lacustrine sediment that dates back to the Late Glacial in south central Anatolia. In modern day Anatolia there are different climate regions (Türkes, 1996). The Sağlık lake sediment record is the first natural archive revealing past climatic and environmental changes from the sub climatic zone in which it is located. This part of the world has been relatively highly populated since the late Glacial. There are many Neolithic sites excavated and located in this part of the region (Atakuman, 2004). One such is Domuztepe, the large late-Neolithic site mentioned earlier (Atakuman, 2004). Göbeklitepe, the world's oldest temple dated to between 12,000 calBP and 11,000 calBP (Schmidt, 2010), is located in the same sub climatic zone in Turkey, and is almost 200 km from our study site. The aim of our study is to reconstruct the past environmental history during the Late Glacial and early Holocene of south-central Anatolia, one of the early farming regions in the world, using a multi-proxy approach.

2. Study site

The Sağlık Basin is located in the Kahramanmaraş valley, southern Turkey (36°49'40"E and 37°19'05"N, Fig. 1). It is located in the northernmost Great Rift Valley, and includes many important lakes and wetlands. The former lake was located at the deepest part of the Sağlık plain (Korkmaz, 2008). It was an important wetland area until it was drained for mosquito control and agriculture in the late 1950s, its drainage was completed in 1966. After that, the former lake area became known as the Sağlık Plain. Since total drainage was not possible, there is presently an attempt to restore part of the lake. The paleolake, together with two other lakes (Emen and Amik) located in Antakya-Kahramanmaraş rift valley, probably originated as a result of subsidence related to post-Neogene faulting and river capture during the Quaternary (Korkmaz, 2008). Following the river capture the old valley dried and left behind three separate lake bodies (Korkmaz, 2008). The hydrology of the region mainly depends on the surface waters. The local climate is Mediterranean with warm, dry summers and mild and rainy winters and although the lake is currently seasonal, it is not monitored so no further hydrological information is available.

The archaeology of the Kahramanmaraş Valley is comprehensively treated in Atakuman (2004). Domuztepe, a large Late Neolithic (Halaf culture) settlement, is also located in the Kahramanmaraş valley. Excavations show that the site was inhabited around the eighth millennium BP (Carter et al., 2003) from 8100 to 7450 BP (personal comm. prof. E. Carter, UCLA).

3. Materials and methods

3.1. Coring

The coring of Sağlık II (36°49'40"E and 37°19'05"N) was carried out in 2003 using a Russian sampler (Woldring and Kleine, GIA) in cooperation with the University of Manchester and the Cotsen Institute of Archaeology of the University of California Los Angeles (UCLA). Coring started at the base of a small trench (180 cm below surface level, the former lake bed) and terminated at a depth of 1270 cm.

3.2. Dating and isotopes in the sediment

Chronological control was obtained by radiocarbon dating. This could only be done in a limited way because of a lack of suitable datable material.

Two AMS radiocarbon dates were obtained from bulk sediment from different depths (613–615 cm and 1238–1240 cm) in the Sağlık II (SAĞ II) core in November 2014 (Beta Analytic, laboratory code BETA). In addition, one AMS radiocarbon date was obtained for bulk sediment from a depth of 246–250 cm (Groningen University, laboratory code GrA), and two AMS radiocarbon dates were obtained from bulk sediment (University of California, laboratory code UCIAMS). The sediments consist of silts poor in organics (the C content varied between 2.1 and 0.5%). The measured ^{14}C dates are shown in Table 1. They are reported in BP by convention, which means measured relative to the Oxalic Acid standard, using the half-life of 5568 years and including correction for isotopic fractionation based on the stable carbon isotope ^{13}C to $\delta^{13}\text{C} = -25\text{‰}$ (Mook and Streurman, 1983). These conventional ^{14}C dates require a correction for aquatic reservoir effects, which are calculated using the model described below (Section 4.1). The chronological information based on the 5 AMS dates is very limited. Nevertheless, together with other time markers (such as known age events observed in the record) a reasonable chronology could be established. This is discussed in Section 4.1. From these final ^{14}C age ages, absolute dates are obtained by calibration using the curve IntCal13 (Reimer et al, 2013). These calibrated dates are reported in calBP, i.e. calendar years relative to 1950 CE (Mook and van der Plicht, 1999).

3.3. Ostracod analysis

A total of 47 samples from the Sağlık II core were used for ostracod

analyses. To assess the ostracod assemblages, approximately 2 cc (about 3 g at about 20 cm intervals through the long core) of wet sediment was passed through a 63 µm sieve applying a gentle jet of water. The last wash included pre-treatment with ethanol to prepare shells for possible future isotope analyses (Mischke et al., 2008). The retained residue was dried and weighed. All valves in the dry residue was picked and counted. Specimens were identified to species level by means of a stereo microscope under 50x magnification. Ostracod identification is based on Meisch (2000). The ostracod stratigraphy was plotted by means of C2 software for visualization of the paleoenvironmental data (<https://www.staff.ncl.ac.uk/stephen.juggins/software/C2Home.htm>).

3.4. Stable isotope analyses on ostracod shells

About 50–80 µg of ostracod calcite was analysed for stable oxygen and carbon analyses. Adult valves of *C. torosa* were used throughout the core except for the interval 940 and 860 cm and the uppermost half of the core where, in the absence of *C. torosa*, adults of *Candona* sp. were analysed. Based on the differences in published vital effects on $\delta^{18}\text{O}$ of these two groups (Decrouy and Vennemann, 2013) a correction of (+0,9‰) is made to the *C. torosa* data to make them comparable to the *Candona* sp. In total, 44 samples were analysed for $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ using a Finnigan MAT253 mass spectrometer connected to an automated carbonate device (KIEL IV) at the GFZ Potsdam, Germany. They were automatically dissolved with 103% H_3PO_4 at a temperature of 72 °C and the isotopic composition of the released and cryogenic purified CO_2 determined. Replicate analysis of reference material (IAEA-NBS19, and internal C1) reported relative to VPDB yielded standard errors of 0.06‰ for both isotope ratios, $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$.

3.5. Sieve pore and body length analyses of *C. Torosa*

We measured the valve length of female left valves (FLV) of *C. torosa* and a couple of carapaces when there were no single FLVs valves present, in order to determine if changes in the valve sizes could be used to infer changes in water chemistry through time, following the work of Boomer et al. (2016). Also, the shape of 3–4 sieve pores for one FLV of at least one *C. torosa* per sample was recorded.

4. Results

4.1. Chronology

Ideally, establishing a chronology for the Sağlık II core should be based on ^{14}C dating. Unfortunately, it was difficult to obtain samples suitable for ^{14}C dating due to the often low abundance of organic carbon. Furthermore, the samples contained aquatic plants and are therefore subject to reservoir effects which need to be quantified. Indeed, the samples are depleted in the stable isotope ^{13}C , which is characteristic for aquatic plants. We were able to obtain only 5 AMS measurements for the complete core. They are shown in Table 1.

Because of unknown reservoir effects, the ^{14}C dates alone cannot provide an absolute chronology. But the core does contain anchor points visible in the proxy records (palynology and ostracod assemblage) discussed in this manuscript - such as the beginning and end of the YD with known absolute dates. The analysis of these anchor points and ^{14}C dates together yield a reasonable chronology which can be used in a pragmatic way. We are able to derive two different approximate sedimentation lines for the Holocene and Late Glacial parts of the core, as follows.

(a) Holocene part of the core

In the Holocene part of the core, we recognize two extreme climatic events. First, the end of the YD is located at a depth of 720 cm. This has a known absolute age of 11,500 calBP (Rasmussen et al., 2014), which

via the ^{14}C calibration curve (Reimer et al., 2013) corresponds to a ^{14}C age of approximately 10,150 BP.

Second, the ostracod record shows an extreme $\delta^{18}\text{O}$ event at a depth of 280 cm. The $\delta^{18}\text{O}$ value of the carbonate/water system is a proxy for evaporation, thus climate (Mook, 2006). This depth shows a negative $\delta^{18}\text{O}$, representing a wet phase. We can safely assume this corresponds to a large moist episode in the region, as observed in the Dead Sea level and Jordan River valley. This episode is dated to 7000 BP (Frumkin et al., 1991).

These 2 data points define a line $y = 0.14x - 700$ (y is depth in cm, x is ^{14}C age) which can be assumed to represent a rough age-depth model for this part of the core.

Applying this model to a depth of 614 cm, we obtain a ^{14}C age of 9385 years. This layer has been dated to 9990 BP (Beta-393636), which in turn means that the reservoir effect of the dated material (aquatic plant remains) must be 605 years.

Unfortunately, the top layer of the sediment of Sağlık-II has disappeared because of modern human activities. The youngest sample (GrA-63541) is anomalously young, very likely because of contamination from the surface. We rejected this measurement (indicated by * in Table 1). Our age-depth model would give a date of 6710 years for this level.

The top of the sediment (240 cm) would date to 6710 ^{14}C years according to our model. This is not inconsistent with results from another nearby core from the same lake, Sağlık-I which also yielded an, unpublished, near-surface ^{14}C date of 6700 BP. At this level, the Ostracod $\delta^{18}\text{O}$ signal suggests a dry climatic event. This is also consistent with observations from the Jordan River/Dead Sea region (Frumkin et al., 1991).

(b) Late Glacial part of the core

The beginning of the YD is observed at a depth of 822 cm. This has a known absolute age of 12,800 calBP (Rasmussen et al., 2014), which via the ^{14}C calibration curve (Reimer et al., 2013) corresponds to a ^{14}C age of approximately 11,000 BP.

We observe that our Holocene depositional model (described above) would yield 10,870 ^{14}C years for 822 cm depth, which is not unreasonable given the uncertainties.

The oldest anchor point is from a depth of 1300 cm. The ostracod record shows the end of the DO-2 warm phase marker as observed in Greenland ice cores (see Section 5.2.3). This is absolutely dated to 21,500 calBP (Rasmussen et al., 2014), which via the ^{14}C calibration curve (Reimer et al., 2013) corresponds to a ^{14}C age of approximately 17,800 BP.

These 2 data points define a line $y = 0.07x + 49$ (y is depth in cm, x is ^{14}C age) which can be assumed to represent a rough age-depth model for this part of the core.

For a depth of 1150 cm, we obtain a ^{14}C age of 15560 years. This is consistent with the observed climate signal from a *Botryococcus* in another record (Miebach et al., discussed below) and in the ostracod record (Section 5.2.3).

Applying this model to our sampling depths of 960–963 and 1238–1240 cm, the line yields dates of 13,000 and 16,930 ^{14}C years, respectively. For these depths we measured ^{14}C dates which are much older. Such is also the case for the ^{14}C date at 820–824 cm depth, marking the beginning of the YD. The reservoir effects for these three dates from the Glacial are millennia in size (see Table 1). This is not uncommon, as groundwater - and thus aquatic plants - in this region shows “recent” ^{14}C concentrations much lower than those of contemporaneous atmospheric and terrestrial organic material, this is generally the cause of reservoir effects (e.g. Olsson, 1983; Olsson, 1989; Philippsen 2013). For lacustrine sediments in the Levant region, this is often taken as low as 68% of the “recent value” in truly terrestrial samples (Stiller et al., 2001; Meadows, 2005; Roberts et al., 2016). This value will be determined by a range of factors such as lake chemistry,

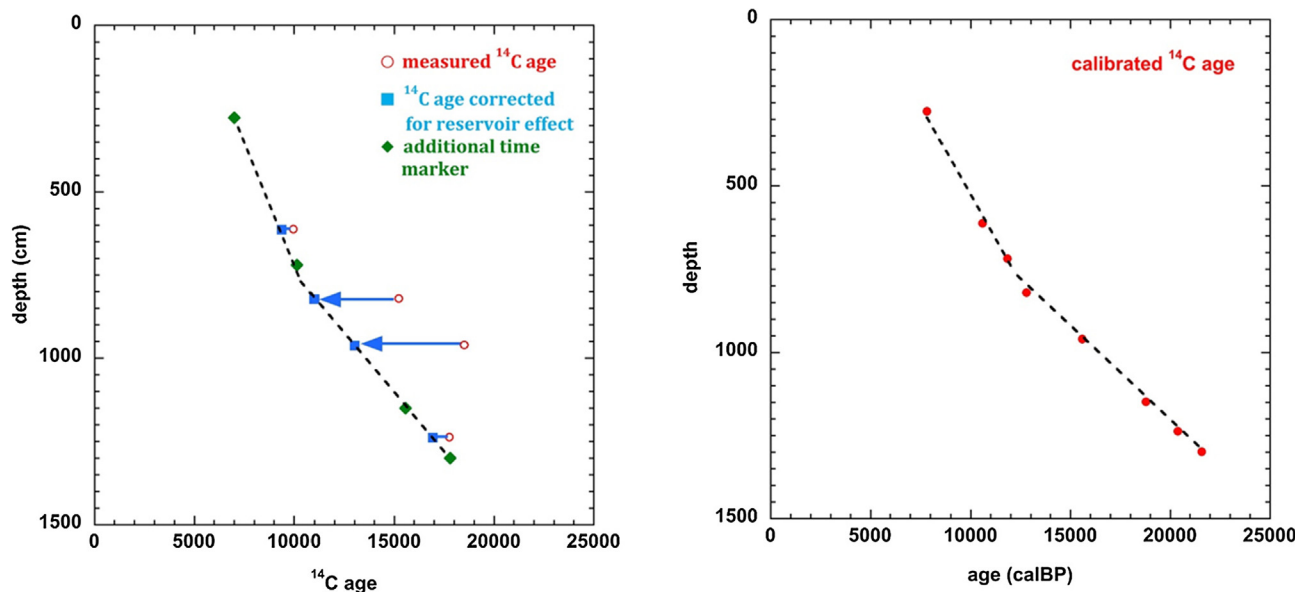


Fig. 2. Radiocarbon chronology for the Sağlık II core. (a) Expected and corrected ^{14}C dates and additional time markers (all in ^{14}C time) (b) Calibrated ^{14}C dates (shown in cal BP).

biota and other climate-related variables. The value of 68% corresponds to an age offset of 3100 ^{14}C years.

Table 1 summarizes our chronology as explained above. It shows the 5 measured dates (including $\delta^{13}\text{C}$ values and laboratory numbers), sampling depths, anchor points, final ^{14}C ages based on our age-depth model, reservoir effects (i.e. difference between measured ^{14}C date and age derived from deposition line), and calibrated dates (in calBP; calibrated using IntCal13, Reimer et al., 2013).

The uncertainties for the measured ^{14}C dates are indicated at 1-sigma level. The derived numbers are estimates, and uncertainties for these are difficult to assess.

The ^{14}C dates are plotted as a function of depth in Fig. 2. Fig. 2a shows the measured, corrected and additional ^{14}C dates (see Table 1), Fig. 2b shows the absolute dates in calBP. Both show a change in sedimentation rate around the Glacial/Holocene transition.

The youngest two dates (above 280 cm depth) are not plotted.

4.2. Ostracods

4.2.1. Faunal assemblages

The Late Glacial and early Holocene interval part of the Sağlık II core was analysed for ostracods. A total of eight species of podocopid (freshwater) ostracods were observed and identified throughout the core: *Darwinula stevensoni* (Brady and Robertson, 1870), *Plesiocypridopsis newtoni* (Brady and Robertson, 1870), *Ilyocypris* sp. (taxonomy is uncertain; Mazzini et al., 2014), *Candona angulata* G.W. Müller, 1900, *Candona neglecta* Sars, 1887, *Cyprideis torosa* (Jones, 1850) (both smooth and noded forms), *Prionocypris zenkeri* (Chyzer and Toth, 1858), and *Limnocythere inopinata* (Baird, 1843). Some of the key taxa recorded in the core are figured in Plate 1. Most of the specimens referred to *Candona* consisted of juveniles (Fig. 11).

A few adults of *C. neglecta* were observed during the Late Glacial interval (Fig. 3). This species prefers relatively cold waters, but tolerates higher temperatures temporarily (Meish 2000). Only at 600 cm depth, are adult specimens of *Candona angulata* abundant (Fig. 3). Both *C. neglecta* and *C. angulata* tolerate slightly saline water conditions (Meish, 2000).

Candona (mostly juveniles), *C. neglecta*, *C. torosa* (both noded and smooth forms), *D. stevensoni*, *Ilyocypris* sp. and *Prionocypris zenkeri* are present in the lower half of the core that covers the Late Glacial interval including the Younger Dryas, Allerød interstadial and Older Dryas

(Fig. 3). *Cyprideis torosa* and *Prionocypris zenkeri* were only found in the Late Glacial phase (Fig. 3). *P. zenkeri* is abundant at the bottom of the core during the Older Dryas and through to the end of the YD. *P. zenkeri* is strictly confined to freshwater conditions (Mischke et al., 2014). Its presence in lakes is often associated with significant input from nearby rivers and streams (Meisch, 2000). *P. zenkeri* has also been recorded in the modern fauna of high mountain lakes (glacial lakes) of the Kaçkar region in Turkey (Aygen et al., 2012).

C. torosa is almost absent between 860 and 940 cm, except for two noded juvenile valves observed at 900 cm depth. *C. torosa* produces one generation per year (Heip, 1976). The life cycle of *C. torosa* can be predicted with the changing temperature when mortality is constant (Heip, 1976). The number of adult *C. torosa* in a population increases once a year between the end of April and July, August, or October with the requirement of minimum water temperature of approximately 15 °C during this time (Heip, 1976). So, the absence of *C. torosa* during this time might have been due to colder water conditions in summer during the YD.

Both smooth and noded forms of *C. torosa* disappear after 740 cm and *Candona* (mostly unidentified juveniles and *C. angulata* at 600 cm depth) dominate during the early to mid-Holocene. Near this boundary (at 740 cm) many black coloured valves/carapaces (which is not the original colour) of all *Cyprideis torosa*, *Ilyocypris* sp. and *Candona* specimens were observed. This observation may relate to conditions bringing about bottom-water anoxia, possibly through eutrophication, with possible anoxia below the sediment-water interface, this could facilitate the production of pyrite or manganese imparting a black colouration to the valves.

Hydrological changes are also supported by pollen evidence dated to the last phase of the YD (see Section 4.3). The green alga *Pediastrum boreanum* shows very high abundances at 740 cm, this could also be linked to high productivity and low oxygen bottom waters. This boundary also registers the last presence of *C. torosa* and *P. zenkeri*.

C. torosa is a euryhaline species which can tolerate high salinity, up to 60‰ (Meisch, 2000), and is known to develop nodes in low salinity environments (Keyser, 2005). Noded forms commonly occur in waters with a salinity of less than 5‰ (Vesper, 1975; adopted from Mischke et al., 2014). The presence of both smooth and noded forms of *C. torosa* in the lower part of the core may indicate changing salinity levels at this time. This species is also observed in sediment records during the mid and late Holocene of coastal lakes on the Black Sea shore of Turkey

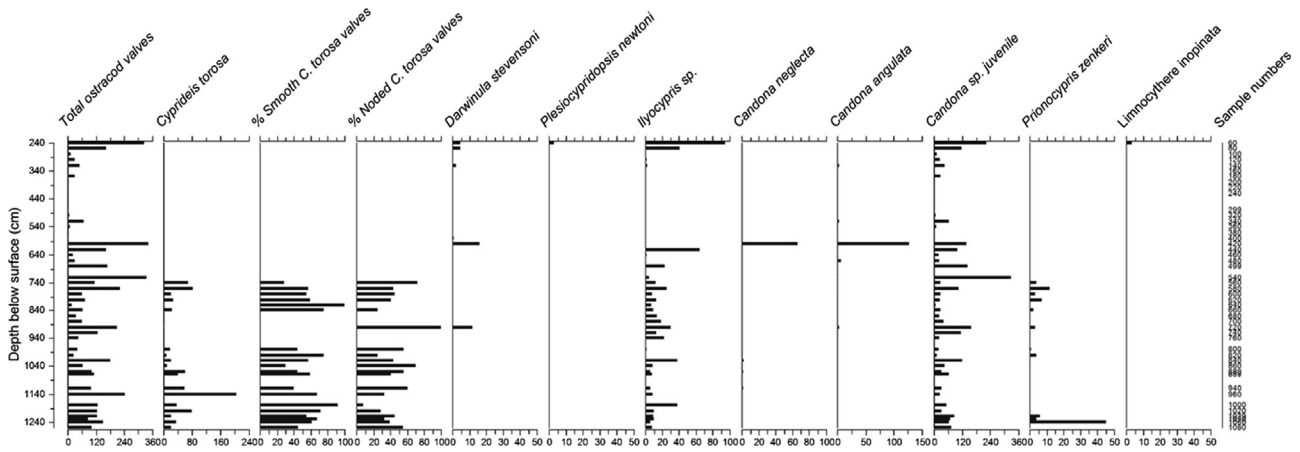


Fig. 3. The Sağlık II ostracod stratigraphy. Number of valves of ostracod species through depth below surface. Different x scale has been used for *Darwinula stvensoni*, *Plesioeypridopsis newtoni*, *Candona neglecta*, and *Prionocypris zenkeri* to visualize better these taxa in a same graph.

(Sekeryapan, 2011). *Cyprideis* is never found in ephemeral water bodies, requiring permanent waters (De Deckker and Lord, 2017). Colonization by *C. torosa* of inland water bodies requires permanent, brackish and shallow water bodies under relatively warm conditions (Pint et al., 2012). Semi-arid climates could stimulate the formation of such inland water bodies through evaporation. The occurrence of *C. torosa* far from marine influence can be used as an indication of relatively dry climate resulting in brackish water conditions (Fig. 3). Although it is assumed that nodding is indicative of low salinities (Keyser, 2005), it can occur at all salinities (Schonikov, 1973; adopted from De Deckker and Lord, 2017), but is more common in low salinity waters. Other important environmental parameters influencing ostracod abundance are bottom water dissolved oxygen and CO₂ concentrations (Martin-Rubio et al. 2005). Temporal dysoxic conditions usually cause a decline in ostracod assemblage diversity levels (Rieradevall and Roca, 1995). In addition to salinity, temperature, dissolved oxygen concentration, pH, nutrient level and depth of water all influence fresh water ostracod abundances (Ruiz et al., 2013).

Candona is present almost throughout the core except at a few depths (560, 420 and 340 cm), at these depth no ostracods were observed. At 600 cm depth, about 9300 ¹⁴C years ago, *Candona angulata* shows a maximum abundance (Fig. 3; Table 1). The abundance of adult *Candona angulata* and *C. neglecta* valves in the assemblage reaches 59% (Fig. 4). The large mortality of juveniles probably represents an in-situ death assemblage with little post-mortem transportation or disturbance (Whatley, 1983, adopted from Frenzel and Boomer, 2005). *Ilyocypris* sp. and *Darwinula stvensoni* were also observed (Fig. 3) at this depth.

The uppermost part of the core (240–380 cm depth below the surface) contains *Candona* juvenile and specimens of *Ilyocypris* sp., *D.*

stvensoni, *Plesioeypridopsis newtoni*, and *Limnocythere inopinata* with the latter two are restricted to this interval. *P. newtoni* prefers small stagnant water bodies such as ponds, littoral zones of lakes and even rice fields, on the other hand, *L. inopinata* is common in shallow open water and littoral areas of lakes (Meisch, 2000). Ostracod abundance is very low between 380 and 500 cm depth.

Ostracod assemblages reflect environmental conditions at the time of deposition. *C. torosa* population structure during the Late Glacial and *Candona* population structure can be seen in Fig. 4. Juvenile/adult ratio in *C. torosa* populations during the Late Glacial represents low-energy biocoenoses (Keatings et al., 2007; Heip, 1976), throughout much of the Sağlık II core. At 780 cm, however, the juvenile/adult ratio (21:1) indicates higher energy environments (Keatings et al., 2007). At the same depth, the valve/carapace ratio is also high. High valve/carapace ratios generally indicate post mortem disarticulation due to current activity, possibly in tandem with low sedimentation rate (suggesting post-mortem transportation or disturbance, Boomer et al., 2003). Through most of the core *Candona* only occurs as juvenile valves, representing a taphocoenosis (again suggesting post-mortem transportation or disturbance, Boomer et al., 2003). However, at 600 cm, the juvenile/adult ratio is 1 and adults occur mainly as carapaces, suggesting a low energy thanatocoenosis at this depth (in-situ, living population, Boomer et al. 2003).

4.2.2. Stable isotopes

Forty-five samples were prepared for δ¹⁸O and δ¹³C analysis on ostracod shells although one sample did not yield enough carbonate material (Fig. 5).

It is assumed that the δ¹⁸O of the water of the former Sağlık lake,

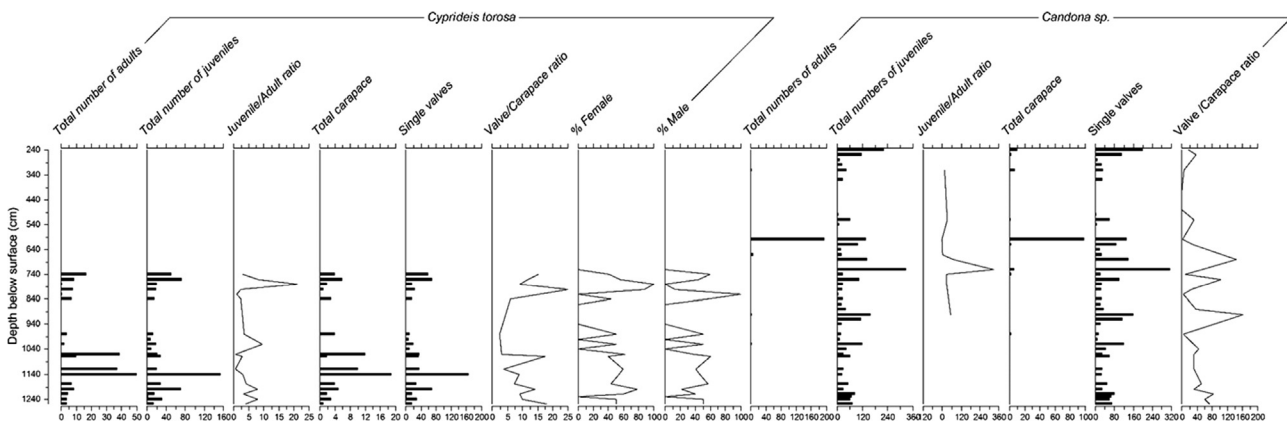


Fig. 4. Sağlık II population structure of *C. torosa* and *Candona* sp.

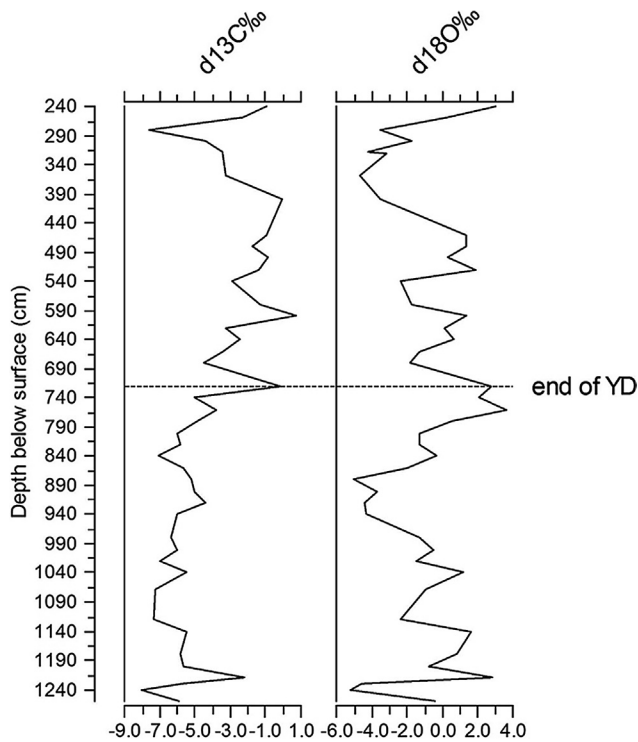


Fig. 5. $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ values from ostracod shells.

located in low-lying, undrained topography and a semi-arid region, primarily changed in response to the balance of precipitation/evaporation. The source of precipitation to the lake was probably both from the Atlantic Ocean and Mediterranean Sea. Higher values mean more evaporative/concentrated conditions (Leng and Marshall, 2004). In our records, it appears that the precipitation/evaporation ratios between Late Glacial, early and mid-Holocene were different. Evaporation was higher during the Allerød interstadial and most of the Holocene except for a wet phase during the mid-Holocene. The Older Dryas, Allerød interstadial, and YD are clearly distinguished in our $\delta^{18}\text{O}$ record.

According to the measured $\delta^{18}\text{O}$ values, higher precipitation climatic conditions prevailed at the bottom of the core (DO-2 and Older Dryas), during the YD, and in the mid-Holocene. Evaporation was higher during Allerød interstadial, early Holocene, and in the uppermost part of the core. The $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ isotope record of the uppermost part of the core indicates contrasting lake conditions, starting with high precipitation (wet) phase and ending with a higher evaporation phase through the top of the core (Fig. 5).

There is a gradual increase in $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ values through the onset of the Early Holocene. The higher $\delta^{13}\text{C}$ values observed during the early Holocene are possibly due to the high evaporation rates. According to the $\delta^{13}\text{C}$ values, conditions gradually shifted from oligotrophic to eutrophic near the start of the Holocene. This is also the case at the depth of 720 cm, where *C. torosa* disappears, and at 740 cm ostracod species where the dark coloured ostracod shells are recorded. This shift also corresponds to higher $\delta^{18}\text{O}$ values, suggesting higher temperatures driving increased evaporation.

4.2.3. Valve size in *C. Torosa*

Sieve-pore shape and valve length in *C. torosa* can be used to detect trends in paleosalinities (Frenzel and Boomer, 2005; Keatings et al., 2007; Boomer et al., 2016; Frenzel et al., 2016). In our study, valve length analyses of FLV (female left valves) of *C. torosa* shows a range of sizes between about 940–1025 μm . A comparison of these data with the multi-site study of Boomer et al. (2016) (see Fig. 6) suggests that they lived in waters that were most likely of a salinity higher than about 10

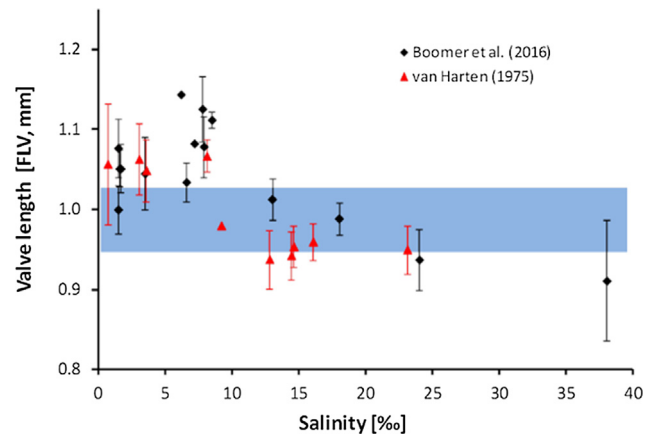


Fig. 6. The range of body lengths of FLV (female left valves) of *C. torosa* from the Sağlık core is denoted by the shaded box, this is plotted over the modern data sets of Van Harten (1975); Boomer et al. (2016).

PSU (Practical Salinity Units).

4.2.4. Sieve pore shape in *C. Torosa*

The relative abundance of different shapes of sieve-type pores in *C. torosa* has been observed to be related to the salinity of the water in which the individuals were living. Rosenfeld and Vesper (1977) demonstrated that at relatively low salinities these pores are relatively round but there is a relative increase in the abundance of elongate and subsequently irregularly shaped pores as salinity increases. Fig. 7 shows the length/height ratio for FLV *C. torosa* through the core. Perfectly circular sieve-type pores would return a value of 1, increasing elongation would reduce that value. The sieve-type pores on specimens from the Sağlık core were observed under scanning electron microscope in the relatively flat, mid-valve region to avoid distortion towards the margins. All are seen to be sub-round to slightly oval type and there is very little variation during the Late Glacial (see the examples shown in Fig. 8).

Taken together with the evidence from the valve length, it is suggested that the salinity of the waters in which these specimens lived was probably around 10–15 PSU.

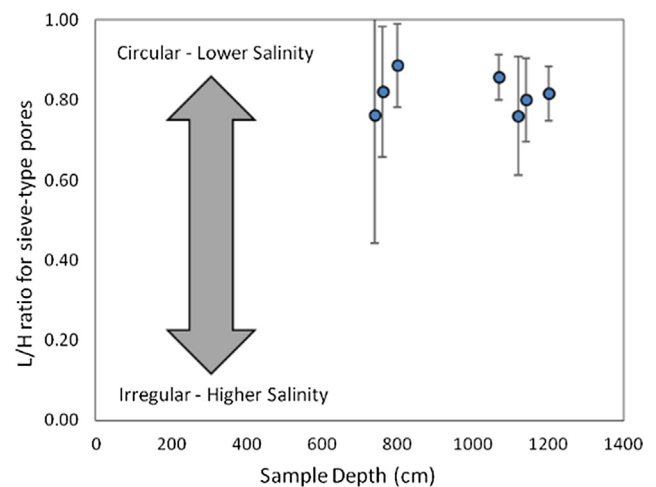


Fig. 7. Length/height ratio of sieve pore types of *C. torosa* in the Sağlık II core. Shaded dots indicate the mean value of 3 observations on each of 3 or 4 valves, the error bars indicate one standard deviation for each studied sample.

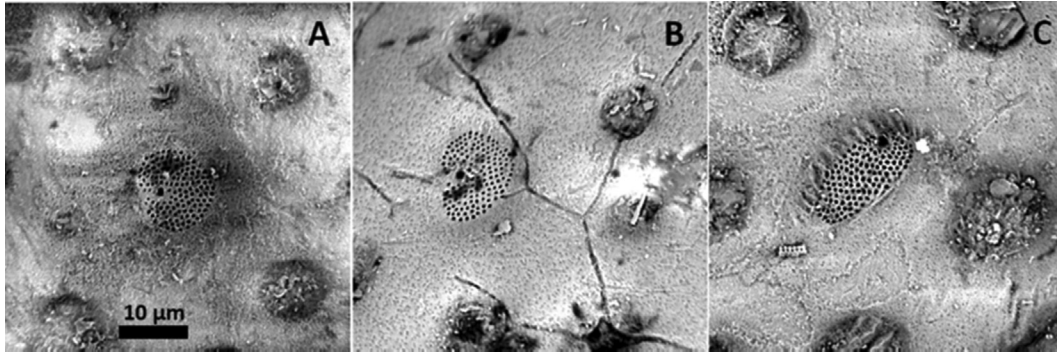


Fig. 8. Examples of sieve type pores measured during this study (A. Oval, B & C slightly elongate oval).

5. Discussion

5.1. Chronology

As discussed above (see Section 4.1), the Sağlık II core chronology is constructed from ¹⁴C dates and chronological anchor points that enable the construction of an age-depth model for the Holocene and (Late) Glacial part of the record (see Fig. 2).

We can link our record with that of Lake Iznik, in western Anatolia (Miebach et al., 2016) which yielded a comparable palynological signal, as well as a series of ¹⁴C dates for the Holocene and Late Glacial back to 28,000 BP based on a similar series of anchor points (Table 1). We interpret the *Artemisia*/Chenopodiaceae phase of zone 3 in the Sağlık II record (Fig. 9) as corresponding with the YD interval*. At about 16,000 ¹⁴C years, the Iznik record shows a distinct increase of *Botryococcus* around 1350 cm depth. This corresponds with our observation of high *Botryococcus* values in Sağlık II around 1150 cm depth (see below).

Summarizing, taking into account anchor points and reservoir effects we were able to obtain a chronology for the palynological record of the Sağlık II lake sediment (see Table 1).

* Miebach et al. assigned the YD phase in the Iznik pollen diagram to the top of pollen zone 5. In our opinion this time must be allocated to zone 6 of the diagram (Woldring et al., in press).

5.2. Terrestrial vegetation reconstruction: Palynology

5.2.1. Coring location, sediment and dating

In 2001, an earlier coring exercise in Sağlık Ovası (labcode Sağlık I) reached a depth of 9.10 m and recorded the Holocene up to ca. ~ 2700 BP. Since they did not reach the natural subsoil, a second coring was carried out at about the same location in 2003, with the aim of obtaining palynological data for the pre-Holocene period. This core (Sağlık II, discussed in this manuscript) reached a depth of 1270 cm below ground level. Again no clues were found indicating the close presence of the natural subsoil. The sediments entirely consist of

Sağlık II

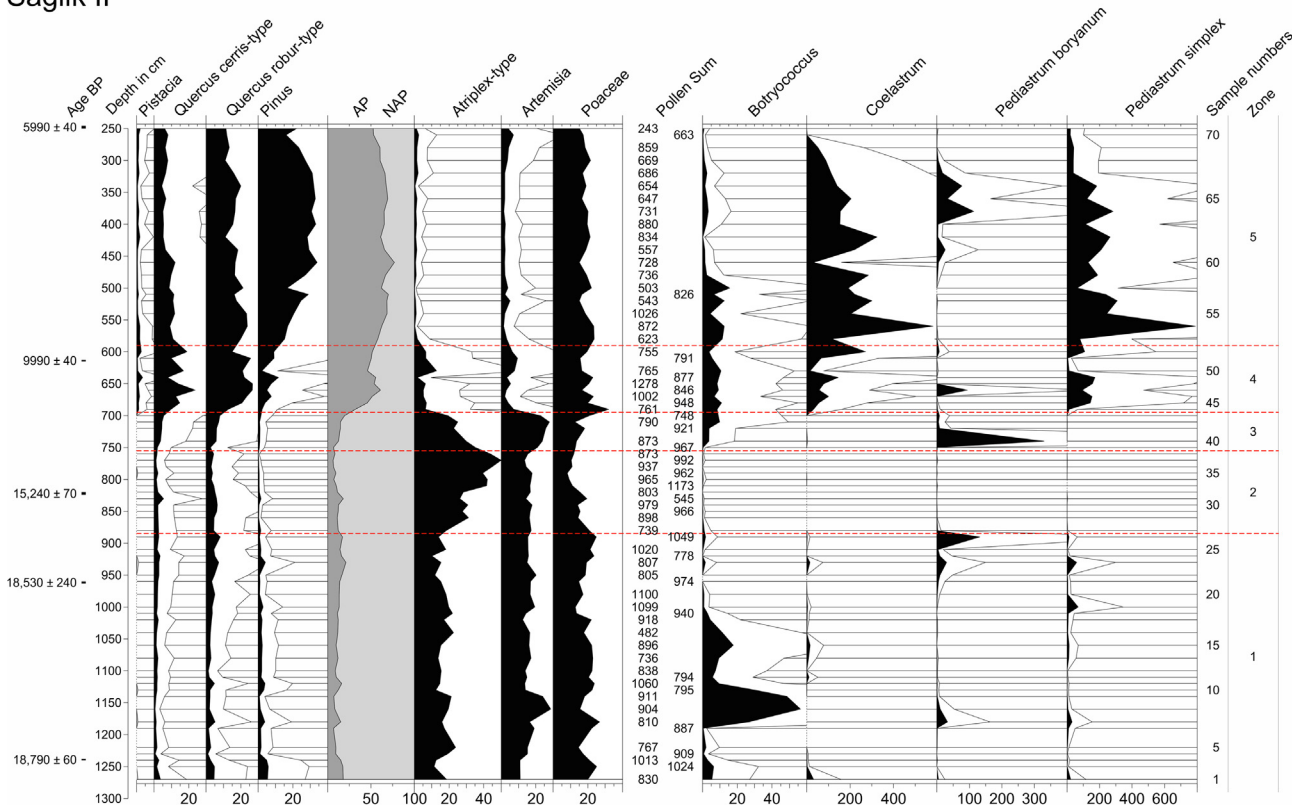


Fig. 9. Sağlık II summary pollen diagram, comprising a selection of pollen types, AP/NAP ratios and main aquatic algae.

Table 2
Depth and age of Pollen Assemblage Zones (PAZ) based on interpolation of ^{14}C dates, corrected for reservoir effect.

PAZ	Depth (cm)	^{14}C age (reservoir corrected)	Calibrated age (calBP)	Biostratigraphical zones
PAZ 1	1270–885	14.300–11.500	17.400–13.350	Oldest Dryas/ Bølling/Allerød
PAZ 2	885–755	11.500–10.500	13.350–12.500	Allerød /Younger Dryas
PAZ 3	755–695	10.500–10.000	12.500–11.400	Younger Dryas
PAZ 4	695–590	10.000–9300	11.400–10.500	Preboreal
PAZ 5	590–250	9300–6700	10.500–7570	Boreal/Atlantic

uniform, fine greyish silts (with mollusc remains present between depths of 1000 and 725 cm). Unfortunately, the (conventional, in BP) ^{14}C dates are not consistent with the pollen record. For example, the start of forest expansion in zone 4 can be dated to the beginning of the Holocene at ca. 10,000 BP. Without correcting, interpolation of these ^{14}C dates would date this depth to ca. 12,000 BP. Other important sites of the Levant, like Hula and Ghab also show ^{14}C dates which appear too old compared with the contemporaneous pollen record. Groundwater depleted in ^{14}C is the main cause for reservoir effects in the Levant. As explained in Section 4.1 we have developed a model to quantify the reservoir effect for Sağlık II. Accordingly, the pollen diagram (Fig. 9) is believed to cover the period from approximately 18,000 to 6700 BP (see Fig. 2 and Table 1).

Pollen sample treatment included heavy liquid separation with sodium polytungstate (e.g. Leipe et al., 2019) and subsequent chemical treatment following Faegri and Iversen (1989).

5.2.2. Pollen zone chronology

Five pollen assemblage zones have been distinguished in the summary diagram (see also Table 2. The dating of the zones is based on interpolation (see Table 1).

5.2.3. Interpretation

5.2.3.1. Late Glacial pollen record. Significant pollen values of *Artemisia*, *Atriplex*-type (chenopods) and Poaceae (grasses) in combination with low AP values (arboreal pollen) denote cold and dry conditions all through zones 1 to 3. The further increase of *Atriplex* (zone 2), *Artemisia* (zone 3), and decline of arboreal taxa and grasses even indicates semi-desert conditions (e.g. Van Zeist and Bottema, 1991; Rossignol-Strick, 1995). According to the chronology, zones 2 and 3 cover the last phase of the Allerød and the YD, respectively. The Allerød interstadial, generally considered as a relatively warm and moist climatic phase in the Late Glacial, is not recognized as such in the pollen record. It is possible that the zone 2 vegetation expanded as a result of extreme aridity which was brought about by a rise in temperature and evaporation not compensated for by an increase of moisture. During the time of zone 3, steppe vegetation, mainly composed of *Artemisia*, *Atriplex* and Poaceae, dominates the northern Levant. Zone 3 represents about the last half of the YD, a phase of global deterioration of climate.

5.2.3.2. Early Holocene pollen record. From the start of zone 4, the *Artemisia-Atriplex* steppe declines, whereas *Quercus* (deciduous oaks), *Pistacia* (pistacio, terebinth) and Poaceae (grasses) increase considerably. The spread of open oak-terebinth woodland and grasslands reflects a climatic improvement including a rapid rise of temperature and humidity. During zone 5, oak-pine woodland becomes dominant which may indicate a gradual decrease in moisture availability.

In palynological records a range of pollen types and fungal spores are indicative of human impact. The Sağlık II record shows little evidence of human presence, except for the occasional appearance of spores of coprophilous fungi in the uppermost half of zone 5 (not indicated in the pollen diagram). The increase of coprophilous fungi is often coupled with domestic livestock.

5.2.3.3. Late Glacial hydrological conditions. Green algae records are potentially useful habitat parameters of waterbodies, e.g. for water depth and temperature, trophy level and alkalinity. The algal record could also be relevant for comparison with the ostracod record. Unlike the noteworthy frequencies of ostracods (Fig. 3), green algae are mostly of little significance in the Late Glacial timespan. Of interest is the increase of *Botryococcus* in the middle part of zone 1. The species concerned is probably *B. braunii*, a widely distributed planktonic freshwater alga of various eutrophic to oligotrophic habitats (ditches, pools, ponds, lakes). *B. braunii* is known to tolerate seasonally cold climates (Batten and Grenfell, 1996) and blooms are even possible in the winter period (Labib et al., 2014). It has a wide tolerance, and there may even be a preference for habitats rich in humus and therefore is also found in bogs and moors (Barth, 2002).

Zone 1 shows a certain relationship in the curves of *Botryococcus* and isotope values (Fig. 5). $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values indicate cooler circumstances during most of this interval suggesting that a shallow, productive lake favored the growth of *Botryococcus*.

Pediastrum boreanum is a cosmopolitan green alga and the most frequent *Pediastrum* species identified in pollen analysis. In consequence of its wide ecological range the indicator value of this species is not very high (Komarek and Jankowska, 2001). As a regular component of eutrophic water bodies, it is expected that the peaks in its abundance point to higher nutrient levels. Large spikes (as in spectrum 40) imply strong, and probably sudden, natural or man-induced phases of eutrophication (Woldring and Bottema, 2003). The records of *Coelastrum* and *Pediastrum simplex* are discussed below.

5.2.3.4. Early Holocene hydrological conditions. *Coelastrum*, *P. simplex* and *Botryococcus* are the predominating green algal taxa in this timerange. *Pediastrum simplex* is considered slightly thermophilic, living in neutral to alkaline pH water and may occur in relatively deep water (Komarek and Jankowska, 2001). *Coelastrum* was identified at genus level only, which hinders ecological interpretation of the water biotope. Even so, we infer from the largely corresponding curves of *Coelastrum* and *P. simplex* that both taxa occupied ecologically comparable habitats. The general decline and disappearance of green algae in the upper part of zone 5 is associated with decreased lake levels resulting from a drier climate. There is ample evidence of a drier climate during the mid-Holocene in the Near East (e.g. Roberts et al., 2011).

5.3. Faunal reconstruction of the lake

Both increasing $\delta^{13}\text{C}$ values of ostracod shells (Fig. 5) and increasing green algae abundances (Fig. 10) indicate higher productivity during the Holocene, the result of which may have been temporally anoxic bottom water conditions, initially during the later YD, and this could have continued through the early and mid-Holocene. Anoxic bottom water conditions could explain the absence of *C. torosa*.

Abundant presence of *P. zenkeri* at the bottom of the core might indicate increased freshwater input to the lake during the Older Dryas (possibly relating to ice-melt), it is also relatively high during the YD (Fig. 3). Between 720 and 780 cm, the juvenile/adult and valve/carapace ratios of ostracod assemblages suggest high energy environments and slow sedimentation rates. High juvenile mortality in *C. torosa* and

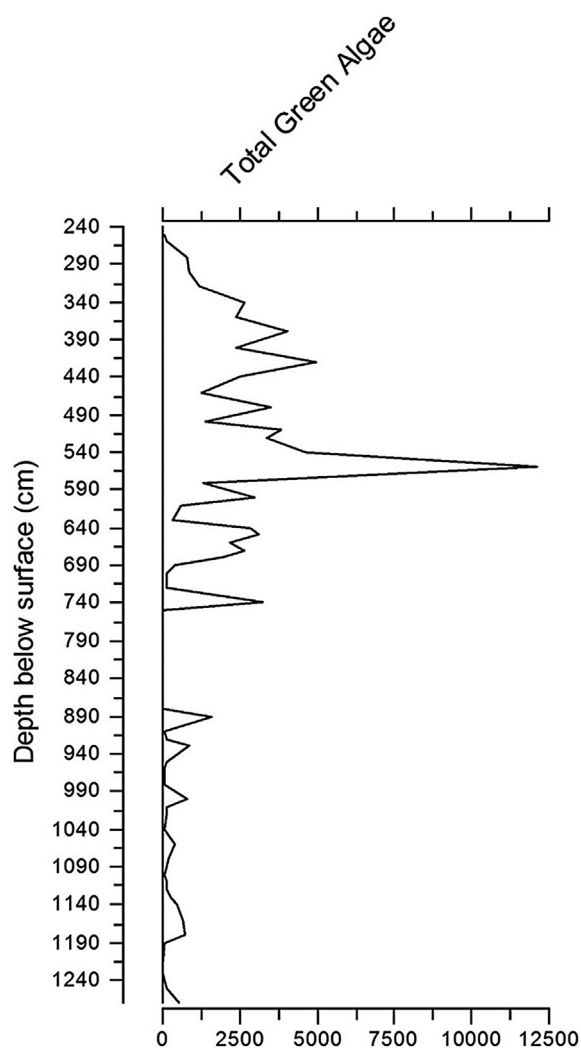


Fig. 10. Total Green Algae.

Candona around that time indicates unfavourable conditions. It occurs around the higher $\delta^{18}\text{O}$ values observed in the long core. Warmer lake waters and/or low water levels resulting from increased evaporation can also lead to eutrophic conditions. We do observe an inverse relationship between total green algae and total ostracods through the core (see Figs. 3 and 10). At around 740 cm green algae first become abundant while the $\delta^{13}\text{C}$ values begin to increase at this time. Anoxic bottom water conditions would also explain why we observed black coloured ostracod shells at the 740 cm. This might be caused by a chemical reaction with Iron, Sulphur and possibly carbonates present in anoxic conditions. Positive $\delta^{18}\text{O}$ values for ostracod carbonate were observed at these depths. Probable warmer climate conditions during the late summer and water shortages due to the higher evaporation can also lead to eutrophic conditions in the Mediterranean lake systems.

Between 380 and 560 cm the total ostracod abundance in the sediment is very low, in fact almost absent. That also coincides with the third wetter period (high precipitation) around 7500 ^{14}C years ago. *Ilyocypris* sp. specimens were observed together with *C. torosa* during the late glacial, and together with *Candona* juveniles during the mid-Holocene, with an interruption at around 7500 ^{14}C year ago. That might be due to the dilution of lake water during this time. *Darwinula stevensoni*, *Ilyocypris* sp. and *Candona* are once more present in the uppermost part of the core, but this time also together with *Plesiocypridopsis newtoni* and *Limnocythere inopinata* representing shallower water levels.

Lastly, we did not observe representatives of the genus

Gomphocythere in the Sağlık II core, although Boomer and Gearey (2010) record specimens in the samples from Domuztepe, a Late Neolithic wetland site located in the eastern part of the Kahramanmaraş valley (see Fig. 1)

5.4. Regional environmental change

During the Late Glacial, until the end of YD, there was a permanent and brackish lake in the Sağlık Basin. Near the end of the YD, high productivity conditions prevailed leading at times to anoxic bottom water. The lake may have been more transient or experience temporary bottom-water anoxia conditions during the Holocene. Both pollen (the spread of open oak-terebinth woodland and grasslands, and domination of oak-pine woodland during zone 5 suggesting high moisture) and green algae data (increase in total planktonic green algae suggesting relatively deep water and likely eutrophic conditions) reveal high moisture availability during the early Holocene, high evaporation rates during warm/hot summer conditions in semi-arid climates may have resulted in seasonal water shortages and/or eutrophication with anoxic bottom water conditions, especially during the late summer. Abundant green algae during the Holocene indicate a highly productive lake or eutrophic conditions (Wetzel, 1983; pp. 353).

Domuztepe is one of the largest known settlements, dating to the sixth millennium BC (Campbell et al., 1999; Carter et al. 2003; Atakuman, 2004), characterised by a trans-regional cultural network of people (Carter, 2010). The Halaf period (8100 to 7450 BP) is only partly represented in the Sağlık II core, starting from about 300 cm depth. Stable isotopes indicate wetter (high precipitation) conditions at its start, which was followed by warm to very warm (high evaporation) conditions (Fig. 5).

6. Conclusions

This study represents the first sequence of ostracod assemblages from a lacustrine sediment in Turkey, that extends into the Late Glacial (Özuluğ et al., 2018). It provides insights into past regional climate changes in the Eastern Mediterranean during the Late Glacial and early Holocene.

Our $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ measurements on ostracod calcite shows good agreement with other archives from the Eastern Mediterranean, representing climatic events in the Older Dryas, Allerød interstadial, YD, and early/mid-Holocene.

The former lake demonstrates brackish and oligotrophic conditions during the Late Glacial (except during the Allerød interstadial). It becomes drier and more productive (eutrophic), during the Holocene until a third wet (high precipitation) phase in the mid-Holocene. One of the wet (high precipitation) and oligotrophic phases in the lake's history occurs at around 7500 ^{14}C years ago (ca. 8300 cal BP). In the uppermost part of the core (240 and 260 cm; Fig. 5) conditions again switched to drier (high evaporation) and higher productivity (Fig. 5 and Fig. 3) that corresponds with the beginning of the Halaf period, indicating that Halaf occupation began in relatively wetter conditions, which became progressively drier in the later centuries. Our results show that the archaeological site at Göbeklitepe, which dates between 12,000 and 11,000 calBP (Schmidt, 2010), roughly corresponds to the time of the YD and a period of transition from a relatively wetter to progressively drier period (Fig. 5).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

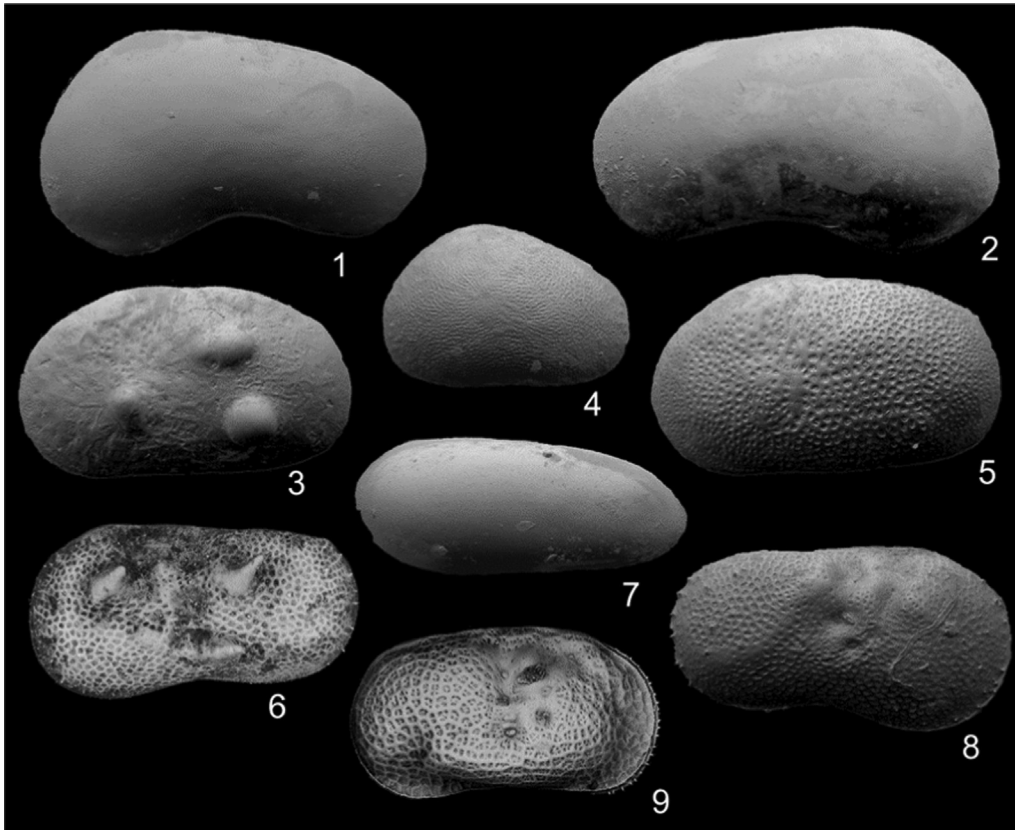


Fig. 11. (Plate 1) All specimens except number 4 are adult, external lateral views. **Figs. 1 and 2.** *Candona neglecta*, RV, from the depth of Sağlık II 840–841 cm. **Fig. 3.** *Cyprideis torosa*, LV, from the depth of Sağlık II 1000–1001 cm. **Fig. 4.** *Prionocypris zenkeri*, LV, juvenile, from the depth of Sağlık II 1060–1061 cm. **Fig. 5.** *Cyprideis torosa*, LV, from the depth of Sağlık II 1000–1001 cm. **Fig. 6.** *Ilyocypris* sp. LV, from the depth of Sağlık II 60–61 cm. **Fig. 7.** *Darwinula stevensoni*, RV, from the depth of Sağlık II 60–61 cm. **Fig. 8.** *Ilyocypris* sp. RV, from the depth of Sağlık II 60–61 cm. **Fig. 9.** *Limnocythere inopinata*, RV, from the depth of Sağlık II 60–61 cm.

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References

- Atakuman, C., 2004. Ritualisation of settlement: Conditioning Factors of Spatial Congruity and Temporal Continuity during the Late Neolithic of Southeastern Anatolia. University of California, Los Angeles Thesis.
- Aygen, C., Ozdemir, D., Ustaoglu, M.R., 2012. Discovering the Hidden Biodiversity of Crustacea (Branchiopoda, Maxillopoda, and Ostracoda) Assemblages in the High Mountain Lakes of Kackar Mountains (Turkey). *J. Animal Veterin. Adv.* 11, 67–73.
- Bar-Yosef, O., 2011. Fluctuations and Early Farming in West and East Asia. *Curr. Anthropol.* 52 (S4), S175–S193.
- Barth, E., 2002. Vegetations- und Nährstoffentwicklung eines nordwestdeutschen Stillgewässers unter dem Einfluss von Landschafts- und Siedlungsgeschichte. Paläoökologische Untersuchungen an dem Erdfallsee "Grosses Heiliges Meer". *Abhandlungen aus dem Westfälischen Museum für Naturkunde* 64. Jahrgang, Heft 2 (3), 1–216.
- Batten, D.J., Grenfell, H.R., 1996. Chapter 7D. Botryococcus. In: In: Jansonius, D., McGregor, D.C. (Eds.), *Palynology: principles and applications* Vol. 1. American Association of Stratigraphic Palynologists Foundation, pp. 205–214.
- Boomer, I., Eisenhauer, G., 2002. Ostracod faunas as palaeoenvironmental indicators in marginal marine environments. *Washington DC Am. Geophys. Union Geophys. Monograph Series* 131, 135–149.
- Boomer, I., Horne, D.J., Slipper, L.J., 2003. The use of ostracods in Palaeoenvironmental studies, or what can you do with an ostracod shell? *Paleontol. Soc. Papers* 9, 153–180.
- Boomer, I., Gearey, B., 2010. The occurrence of a new species of Gomphocythere (Ostracoda, Limnocytheridae) in the Holocene of SE Turkey: the northernmost record for the genus. *J. Micropalaeontol.* 29, 115–118.
- Boomer, I., Frenzel, P., Feike, M., 2016. Salinity-driven size variability in *Cyprideis torosa* (Ostracoda, Crustacea). *J. Micropalaeontol.* 36, 63–69.
- Bottema, S., Woldring, H., 1984. Late Quaternary vegetation and climate of Southwest Turkey II. *Palaeohistoria* 26, 123–149.
- Campbell, S., Carter, E., Healey, E., Anderson, S., Kennedy, A., Whitcher, S., 1999. Emerging Complexity on the Kahramanmara Plain, Turkey: The Domuztepe Project, 1995–1997. *Am. J. Archaeol.* 103 (3), 395–418.
- Carter, E., 2010. The Glyptic of the Middle-Late Halaf Period at Domuztepe, Turkey (ca 5755–5450 BC). *Paléorient* 36 (1), 159–177.
- Carter, E., Campbell, S., Gauld, S., 2003. Elusive Complexity: New Data from late Halaf Domuztepe in South Central Turkey. *Paleorient* 29, 117–134.
- Cobelas, M.A., Rojo, C., Angeler, D.G., 2005. Mediterranean limnology: current status, gaps and the future. *J. Limnol.* 64, 13–29.
- Cullen, H.M., deMenocal, P.B., Hemming, G., Brown, F.H., Guilderson, T., Sirocko, F., 2000. Climate change and the collapse of the Akkadian empire: evidence from the deep sea. *Geology* 28, 379–382.
- De Deckker, P., Lord, A., 2017. *Cyprideis torosa*: a model organism for the Ostracoda? *J. Micropalaeontol.* 36, 3–6.
- Dean, J.R., Jones, M.D., Leng, M.J., Noble, S.R., Metcalfe, S.E., Sloane, H.J., Sahy, D., Eastwood, W.J., Roberts, N.C., 2015. Eastern Mediterranean hydroclimate over the late glacial and Holocene, reconstructed from the sediments of Nar Lake, central Turkey, using stable isotopes and carbonate mineralogy. *Quat. Sci. Rev.* 124, 162–174.
- Decrouy, L., Vennemann, T.W., 2013. Potential influence of the chemical composition of water on the stable oxygen isotope composition of continental ostracods. *J. Paleolimnol.* 50, 577–582.
- deMenocal, P.B., 2000. Cultural responses to climate change during the late holocene. *Science* 292, 667–673.
- Eastwood, W.J., Roberts, N., Lamb, H.F., Tibby, J.C., 1999. Holocene environmental change in southwest Turkey: a palaeoecological record of lake and catchment-related changes. *Quat. Sci. Rev.* 18, 671–695.
- England, A., Eastwood, W.J., Roberts, C.N., Turner, R., Haldon, J.F., 2008. Historical landscape change in Cappadocia (central Turkey): a palaeoecological investigation of annually laminated sediments from Nar lake. *The Holocene* 18 (8), 1229–1245.
- Faegri, K., Iversen, J., 1989. *Textbook of Pollen Analysis*, 4th ed. Chichester.
- Flohr, P., Fleitmann, D., Matthews, R., Matthews, W., Black, S., 2015. Evidence of resilience to past climate change in Southwest Asia: Early farming communities and the 9.2 and 8.2 ka events. *Quat. Sci. Rev.* 136, 23–39.
- Frenzel, P., Ewald, J., Pint, A., 2016. Salinity-dependent sieve pore variability in *Cyprideis torosa*: an experiment. *J. Micropalaeontol.* 36, 63–69.
- Frenzel, P., Boomer, I., 2005. The use of ostracods from marginal marine, brackish waters as bioindicators of modern and Quaternary environmental change. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 225, 68–92.
- Frumkin, A., Magaritz, M., Carmi, I., Zak, I., 1991. The Holocene climatic record of the salt caves of Mount Sedom, Israel. *The Holocene* 1, 191–200.
- Heip, C., 1976. The Life-Cycle of *Cyprideis torosa* (Crustacea, Ostracoda). *Oecologia* 24 (3), 229–245.
- Jones, M.D., Roberts, C.N., Leng, M.J., Türkes, M., 2006. A high-resolution late Holocene lake isotope record from Turkey and links to North Atlantic and monsoon climate.

- Geology 34, 361–364.
- Kashima, K., Matsubara, H., Kuzucuoğlu, C., Karabiyiçoğlu, M., 1997. Diatom assemblages from inland saline lakes in the central part of Turkey – Their application for quantitative reconstruction of paleosalinity changes during the late Quaternary. *Japan Rev.* 8, 235–249.
- Kashima, K., 2002. Environmental and climatic changes during the last 20,000 years at Lake Tuz, central Turkey. *Catena* 48, 3–20.
- Kashima, K., 2003. The quantitative reconstruction of salinity changes using diatom assemblages in inland saline lakes in the central part of Turkey during the Late Quaternary. *Quaternary Int.* 105, 13–19.
- Kashima, K., 2011. Climatic Changes and their Influences for the Archaeological Events during the Holocene in Central Turkey and Northern Syria. *Trans., Japanese Geomorphol. Union* 32 (2), 108–114.
- Keatings, K.W., Hawkes, I., Holmes, J.A., Flower, R.J., Leng, M.J., Abu-Zied, R.H., Lord, A.R., 2007. Evaluation of ostracod-based palaeoenvironmental reconstruction with instrumental data from the arid Faiyum Depression, Egypt. *J. Paleolimnol.* 38, 261–283.
- Keyser, D., 2005. Histological peculiarities of the nodding process in *Cyprideis torosa* (Jones) (Crustacea, Ostracoda). *Hydrobiologia* 538, 95–106.
- Komarek, J., Jankowska, V., 2001. Review of the green algal genus *Pediastrum*; implication for pollen-analytical research. *Bibliotheca Phycologica*, Band. J. Kramer, Berlin.
- Korkmaz, H., 2008. Antakya-Kahramanmaraş graben alanında kurutulan sulak alanların (Amik Gölü, Emen Gölü ve Gâvur Gölü bataklığı) modellerinin oluşturulması. *Mustafa Kemal Üniversitesi Sosyal Bilimler Enstitüsü Dergisi* 5, 19–37.
- Labib, W., Mikhail, S.K., Kassem, A.M., Kassas, M.E., Ahmed, M.M., 2014. Blooms of the colonial green algae *Botryococcus braunii* Kützting associated with massive fish mortality in Nozha Lake, Alexandria, Egypt. In: Kim, H.G., Reguera, B., Hallegraeff, G.M., Lee, C.K., Han, M.S., Choi, J.K. (Eds.), *Harmful Algae 2012*, Proceedings of the 15th International Conference on Harmful Algae. International Society for the Study of Harmful Algae, pp. 188–191.
- Leipe, C., Kobe, F., Müller, S., 2019. Testing the performance of sodium polytungstate and lithium heteropolytungstate as non-toxic dense media for pollen extraction from lake and peat sediment samples. *Quat. Int.* 516, 207–214.
- Leng, M.J., Marshall, J.D., 2004. Paleoclimate interpretation of stable isotope data from lake sediment archives. *Quat. Sci. Rev.* 23, 811–831.
- Martin-Rubio, M., Rodriguez-Lazaro, J., Anadon, P., Robles, F., Utrilla, R., Vazquez, A., 2005. Factors affecting the distribution of recent lacustrine ostracoda from the Caicedo de Yuso-Arreo Lake (Western Ebro Basin, Spain). *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 225, 118–133.
- Mazzini, I., Gliozzi, E., Rossetti, G., Pieri, V., 2014. The Ilyocypris puzzle: A multi-disciplinary approach to the study of phenotypic variability. *Int. Rev. Hydrobiol.* 99, 395–408.
- Meadows, J., 2005. Younger Dryas episode and the radiocarbon chronologies of the Lake Huleh and Ghab Valley pollen diagrams, Israel and Syria. *The Holocene* 15, 631–636.
- Meisch, C., 2000. Crustacea: Ostracoda. *Spektrum Akademischer Verlag*, Heidelberg, Berlin.
- Miebach, A., Niethard, P., Roeser, P., Litt, T., 2016. Impacts of climate and humans on the vegetation in northwestern Turkey: palynological insights from Lake Iznik since the Last Glacial. *Clim. Past* 12, 575–593.
- Mischke, S., Zhang, C., Börner, A., 2008. Bias of ostracod stable isotope data caused by drying of sieve residues from water. *J. Paleolimnol.* 40, 567–575.
- Mischke, S., Almogi-Labin, A., Al-Saqarat, B., Rosenfeld, A., Elyashiv, H., Boomer, I., Stein, M., Lev, L., Ito, E., 2014. An expanded ostracod-based conductivity transfer function for climate reconstruction in the Levant. *Quat. Sci. Rev.* 93, 91–105.
- Mook, W.G., Streurman, H.J., 1983. Physical and chemical aspects of radiocarbon dating. *PACT Publications*, pp. 31–55.
- Mook, W.G., van der Plicht, J., 1999. Reporting ^{14}C activities and concentrations. *Radiocarbon* 41, 227–239.
- Mook, W.G., 2006. Introduction to Isotope Hydrology: Stable and Radioactive Isotopes of Hydrogen, Oxygen and Carbon. Taylor and Francis, The Netherlands.
- Olsson, I.U., 1983. Dating non-terrestrial materials. *PACT Publications*, pp. 277–293.
- Olsson, I.U., 1989. The ^{14}C method, its possibilities and some pitfalls. *PACT Publications*, pp. 161–177.
- Özuluğ, I., Kubanç, S.N., Kuban, C., Demirci, G.I., 2018. Checklist of Quaternary and Recent Ostracoda (Crustacea) species from Turkey with information on habitat preferences. *Turkish J. Biosci. Collect.* 2 (1), 51–100.
- Philippson, B., 2013. The freshwater reservoir effect in radiocarbon dating. *Heritage Sci.* 1, 24.
- Pickarski, N., Kwiecien, O., Langgut, D., Litt, T., 2015. Abrupt climate and vegetation variability of eastern Anatolia during the last glacial. *Clim. Past* 11, 1491–1505.
- Pint, A., Frenzel, P., Fuhrmann, R., Scharf, B., Wennrich, V., 2012. Distribution of *Cyprideis torosa* (Ostracoda) in Quaternary Athalassic Sediments in Germany and its Application for Palaeoecological Reconstructions. *Int. Rev. Hydrobiol.* 97, 330–355.
- Rasmussen, S.O., Bigler, M., Blockley, S.P., Blunier, T., Buchardt, S.L., Clausen, H.B., Cvijanovic, I., Dahl-Jensen, D., Johnsen, S.J., Fischer, H., Gkinis, V., Guillevic, M., Hoek, W.Z., Lowe, J.J., Pedro, J.B., Popp, T., Seierstad, I.K., Steffensen, J.P., Svensson, A., Vallelonga, P., Vinther, B.M., Walker, M.J.C., Wheatley, J.J., Winstrop, M., 2014. A stratigraphic framework for abrupt climate changes during the Last Glacial period based on three synchronized Greenland ice-core records: refining and extending the INTIMATE event stratigraphy. *Quat. Sci. Rev.* 106, 14–28.
- Reimer, P.J., Bard, E., Bayliss, A., Beck, J.W., Blackwell, P.G., Ramsey, C.B., Buck, C.E., Edwards, R.L., Friedrich, M., Grootes, P.M., Guilderson, T.P., Hafliadason, H., Hajdas, I., Hatté, C., Heaton, T.C., Hoffmann, D.L., Hogg, A.G., Hughen, K.A., Kaiser, K.F., Kromer, B., Manning, S.W., Niu, M., Reimer, R.W., Richards, D.A., Scott, E.M., Southon, J.R., Staff, R.A., Turney, J.S.M., van der Plicht, J., 2013. IntCal13 and Marine13 Radiocarbon age calibration curves 0–50,000 years cal BP. *Radiocarbon* 55, 1869–1887.
- Rieradevall, M., Roca, J.R., 1995. Distribution and population dynamics of ostracodes (Crustacea, Ostracoda) in a karstic lake: Lake Banyoles (Catalonia, Spain). *Hydrobiologia* 310, 189–196.
- Roberts, N., Reed, J., Leng, M.J., Kuzucuoğlu, C., Fontugne, M., Bertaux, J., Woldring, H., Bottema, S., Black, S., Hunt, E., Karabiyiçoğlu, M., 2001. The tempo of Holocene climatic change in the Eastern Mediterranean region: new high-resolution crater-lake sediment data from central Turkey. *Holocene* 11(7)–11(7)34.
- Roberts, N., Eastwood, W.J., Kuzucuoğlu, C., Fiorentino, G., Caracuta, V., 2011. Climatic, vegetation and cultural change in the eastern Mediterranean during the mid-Holocene environmental transition. *The Holocene* 21 (1), 147–162.
- Roberts, N., Alcock, S.L., Arnaud, F., Dean, J.R., Eastwood, W.J., Jones, M.D., Leng, M.J., Metcalfe, S.E., Malet, E., Woodbridge, J., Yiğitbaşıoğlu, H., 2016. A tale of two lakes: a multi-proxy comparison of Lateglacial and Holocene environmental change in Cappadocia, Turkey. *J. Quat. Sci.* 31, 348–362.
- Rosenfeld, A., Vesper, B., 1977. The variability of the sieve-pores in Recent and fossil species of *Cyprideis torosa* (Jones, 1850) as an indicator for salinity and palaeosalinity. In: Löffler, H., Danielopol, D. (Eds.), *Aspects of Ecology and Zoogeography of Recent and Fossil Ostracoda*. Junk, The Hague, pp. 55–67.
- Rossignol-Strick, M., 1995. Sea-land correlation of pollen records in the Eastern Mediterranean for the glacial-interglacial transition: biostratigraphy versus radiometric time-scale. *Quat. Sci. Rev.* 14, 893–915.
- Ruiz, F., Abad, M., Boderger, A.M., Carbonel, P., Rodriguez-Lazaro, J., Gonzalez-Regalado, M.L., Toscano, A., Garcia, E.X., Prenda, J., 2013. Freshwater ostracod environmental tracers. *Int. J. Environ. Sci. Technol.* 10, 1115–1128.
- Schmidt, K., 2010. Göbekli Tepe – the Stone Age Sanctuaries. New results of ongoing excavations with a special focus on sculptures and high reliefs. *Documenta Praehistorica VOL XXXVII Book Series: Documenta Praehistoria* 37, 239–256.
- Schonikov, E.I., 1973. Ostracoda of the Aral Sea. *Zool. Zh.* 52, 1304–1314.
- Sekeryapan, C., 2011. Paleolimnological Investigations from Modern Coastal Lakes on Thrace and Black Sea Coast of Turkey during the Mid-late Holocene. Ph.D. Thesis. Metu, Ankara.
- Stiller, M., Kaufmann, A., Carmi, I., Mintz, G., 2001. Calibration of lacustrine sediment ages using the relationship between ^{14}C levels in lake waters and in the atmosphere: the case of Lake Kinneret. *Radiocarbon* 43, 821–830.
- Türkeş, M., 1996. Spatial and temporal analyses of annual rainfall variations in Turkey. *Int. J. Climatol.* 16, 1057–1076.
- Van Harten, D., 1975. Size and environmental salinity in the modern euryhaline ostracod *Cyprideis torosa* (Jones 1850), a biometrical study. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 17, 35–48.
- Vesper, B., 1975. To the problem of nodding on *Cyprideis torosa* (Jones, 1850). *Bull. Am. Paleontol.* 65, 205–216.
- Wetzel, R.G., 1983. *Limnology*, 2nd ed. Saunders College Publishing, USA.
- Whitley, C., 1983. The application of Ostracoda to palaeoenvironmental analysis. In: Maddocks F.R. (Ed.), *Applications of Ostracoda*, Proceedings of the Eighth International Symposium on Ostracoda. University Houston Geoscience, Houston, pp. 51–77.
- Wick, L., Lemcke, G., Sturm, M., 2003. Evidence of late glacial and Holocene climatic change and human impact in eastern Anatolia: high-resolution pollen, charcoal, isotopic and geochemical records from the laminated sediments of Lake Van, Turkey. *The Holocene* 13, 665–675.
- Woldring, H., Bottema, S., 2003. The vegetation history of East-Central Anatolia in relation to archaeology: the Eski Acıgöl pollen evidence compared with the Near Eastern environment. *Palaeohistoria* 43 (44), 1–34.
- Woldring, H., Streurman, H.J., van der Veen, Y.R., van der Plicht, J., Cappers, R.T.J. in press. The Younger Dryas in the Eastern Mediterranean Revisited: Some Additional Notes on Late Glacial and Early Holocene Pollen and Radiocarbon Chronologies. In: Çaylı, P., Demirci, I., Eser, B. (Eds.), *Half a century dedicated to archaeology: a festschrift in honour of Sevil Gülcür*.
- Woodbridge, J., Roberts, N., 2011. Late Holocene climate of the Eastern Mediterranean inferred from diatom analysis of annually-laminated lake sediments. *Quat. Sci. Rev.* 30, 3381–3392.
- Zeist, W., Bottema, S., 1991. Late Quaternary Vegetation of the Near East. *Beihefte zum Tübinger Atlas des Vorderen Orients* 18, Wiesbaden, Germany: Reichert, pp. 156.