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Pollen stratigraphy of Late Quaternary cores from Marmara Sea: land–sea correlation and paleoclimatic history

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Abstract

Marine pollen analysis is an important tool for paleoclimatic reconstruction of regions like the eastern Mediterranean and Near East where few onshore sites provide long pollen records. First, a compilation was made of core-top data from the eastern Mediterranean to Black Seas to map regional variations in modern marine pollen-spore concentrations. These data show a strong link between pollen-spore concentrations and sea surface salinity, with minima of 5 grains/g in the southern Mediterranean and maxima of 160 000 grains/g in the Black Sea. Despite under-representation of some forest and herbaceous vegetation indicators, e.g. *Fagus* and *Pistacia*, variations in species composition of the marine assemblages correspond closely with the distribution of regional vegetation zones and can be used as proxies for spatial differences in seasonal and total temperature and rainfall. Pollen-spore assemblages in five cores from the Marmara Sea with multiple ages ranging from 33 550 to 1990 yr BP and one Holocene core from southeastern Black Sea were used to compile a Late Quaternary marine pollen stratigraphy. These data were then compared with eastern Mediterranean onshore reference sites in order to reconstruct a vegetation and paleoclimate history for the Black Sea–Aegean corridor from the Pleniglacial interval to present. Five marine pollen zones are recognized. PZ-5 (∼33.6–24 ka) corresponds to the late Würm Pleniglacial; PZ-4 (∼24–13 ka) spans the Late Glacial Maximum (LGM); PZ-3 (∼13–10.2 ka) includes the Alleröd–Younger Dryas glacial–interglacial transition; PZ-2 (10.2–4 ka) marks the early Holocene interglacial warm, wet interval; and PZ-1 covers the latest Holocene colonization phase, which may also have been cooler and drier. Using the steppe–forest index of Traverse (1975), it is shown that the only intervals of severely dry conditions occurred briefly during the LGM and its transition; during most of the Pleniglacial and all of the Postglacial time, precipitation versus evaporation rates were sufficiently high to permit persistence of oro-Mediterranean forest vegetation. Furthermore, there is no evidence for environmental conditions in the Black Sea–Marmara region that would have encouraged pastoral or agricultural settlement in the littoral region prior to the Bronze Age, commencing 4600 years ago.

Keywords: pollen zone; paleoclimate; vegetation history; archeology; Marmara Sea; Black Sea

1. Introduction

Detailed knowledge of the Late Quaternary vegetation and climatic history in continental re-

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gions is primarily based on the results of palynological research (Van Zeist and Bottema, 1982; Roberts and Wright, 1993; Prentice et al., 1996). Previous studies show that pollen-spore assemblages in surface sediments from nearshore and continental margin areas are strongly correlated with regional vegetation zones (e.g. Heusser and Balsam, 1977; Mudie, 1982; Rossignol-Strick and Pastoret, 1971; Rochon and de Vernal, 1994; Rossignol-Strick, 1995) and thus can be used as paleoclimate proxies in marine sediment studies. High-resolution pollen sequences also show greater climate sensitivity than the Holocene interglacial oxygen isotopic records (Tzedakis et al., 1997). Marine pollen analysis is particularly useful for relative dating and climate reconstruction of the semi-enclosed Black and Aegean seas (Koreneva and Kartashova, 1975; Traverse, 1975; Aksu et al., 1995a), which adjoin a semi-arid region with few radiocarbon-dated palynostratigraphic sites onshore (see Fig. 1; also Van Zeist and Bottema, 1982; Bottema et al., 1995). The location of the eastern Mediterranean seas between steppe lands to the southeast and temperate forests to the northwest makes it an area of critical importance for reconstruction of the regional rainfall history and its impact on the origins of agriculture and migrations of Neolithic farmers (Farrand, 1971; Ryan et al., 1997; Bogucki, 1996). Pollen-spore assemblages are also a valuable tool for backtracking of past changes in runoff from the major rivers draining into the Black Sea (Komarov, 1989) and overflowing through the Marmara gateway (Aksu et al., 1995a, 1999).

There have been several previous studies of Late Quaternary pollen-spore assemblages in cores from the Black Sea using low-resolution sampling of long Neogene sequences (Traverse, 1974, 1975; Koreneva and Kartashova, 1975). Roman (1974) made detailed palynological studies of four cores from the Danube Delta in the northwest Black Sea, but no radiocarbon ages were given. Koreneva (1971) also studied an undated core from the western Marmara Sea, and concluded that the abundances of *Quercus* and other broad-leaved trees indicated a warm, wet interval of mid-Holocene age for the base of the core. The only published high-resolution studies of dated Black Sea cores are for Holocene sediments from the Dnieper Delta area (Kremenetski, 1995).

The purpose of the work reported here is to reconstruct a detailed paleoclimatic and vegetation history of the Marmara–Black Sea region from the Pleniglacial Würm glacial interval to the present. Here, we present the first high-resolution study of pollen-spore assemblages in the Marmara Sea, using radiocarbon-dated cores spanning the past 33 550 years. First, we compile the pollen-spore assemblages from published data and 10 new core-top surface samples from the Aegean–Black Sea corridor. Then we describe the assemblages in five cores from the Marmara Sea which have multiple absolute ages ranging from 33 550 to 1990 yr BP (uncorrected radiocarbon dates). Results of a study of one Black Sea core are also reported here. These primary data are then used to compile a Late Quaternary marine pollen stratigraphy that can be compared with the eastern Mediterranean onshore reference sites (see Fig. 1). Finally, this framework is used to interpret the regional climatic history, with special emphasis on the question of precipitation versus evaporation rates (P–E) during the Pleniglacial, Late Glacial Maximum (LGM), late glacial transition (Older–Younger Dryas), and latest interglacial (Holocene/Flandrian) time intervals. In separate papers (Abrajano et al., 2002; Mudie et al., 2002), this history of excess runoff is also related to intervals of high terrigenous carbon input, pollen and dinoflagellate cyst concentrations and preservation in order to understand the origin of sapropelic layers in the Marmara Sea.

2. Environmental setting

2.1. Physiography and climate

Marmara Sea (Fig. 1) is a 275-km long × 80-km wide epicontinental sea with three deep fault basins on the north side and a wide shallow continental shelf to the south. This semi-enclosed sea is connected to the Aegean Sea in the west via the 70-m-deep Dardanelles Strait, and it is linked to the Black Sea in the east via the 40-m-deep Bos-

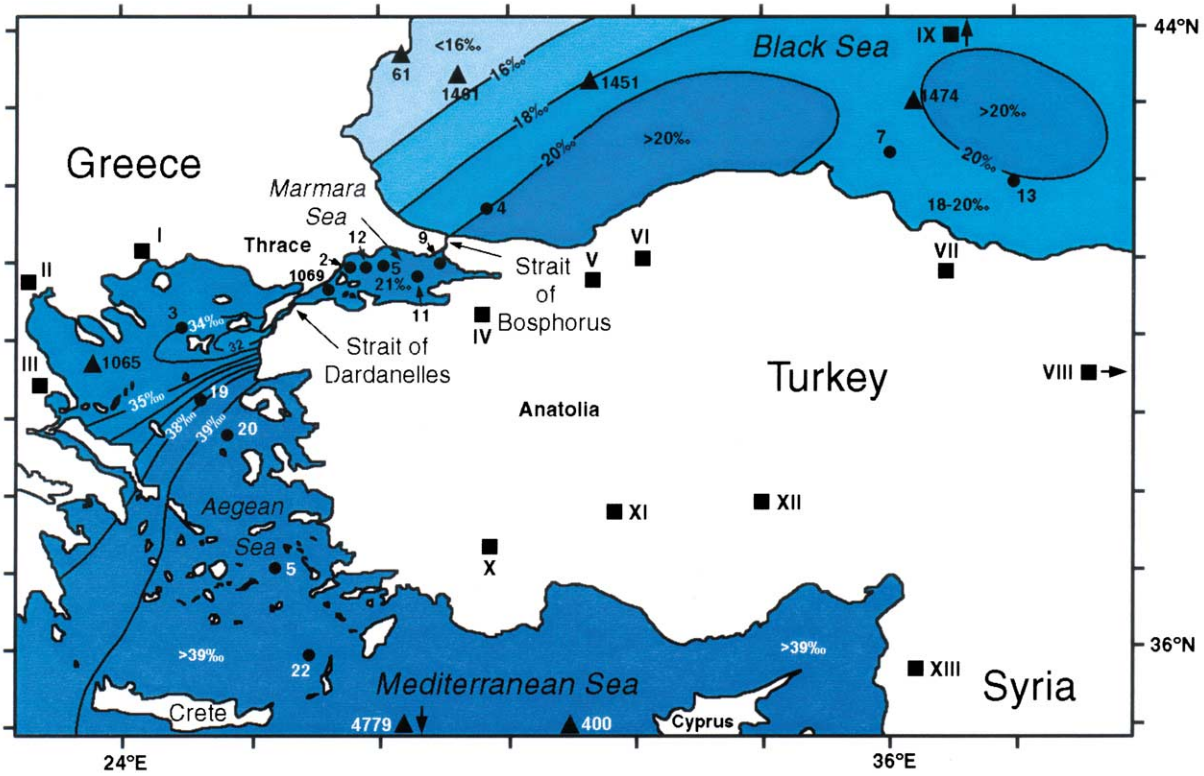

Fig. 1. Map of the study area showing sea surface salinity (where ‰ indicates psu), locations of marine cores and onshore lake reference sites (black squares; see Table 2 for corresponding names). Large black dots are new sites; triangles are published sites.

phorus Strait. Surface water salinity in the Marmara Sea (20.1–24.6 psu) is controlled by mixing of inflowing saline (38.8 psu) Aegean Sea water beneath low-salinity Black Sea surface water (16–17 psu) which overflows through Bosphorus Strait (Özsoy et al., 1995).

Most of the region is dominated by mountainous relief, with a mean altitude of >1 km and with less than 9% level or gently sloping land along the coast (Goetz, 1988). The Aegean–Pontic and Taurus ranges (elevation >3 km) flank the central plateau of Anatolia on the north and south, respectively. Three rivers flow into the southern Marmara Sea (see Aksu et al., 1995b), and three others drain into the Black Sea east of Bosphorus Strait (see Bottema et al., 1995). North of Marmara Sea, the average relief of Thrace is lower than Anatolia, and one river flowing into the Aegean Sea drains this region. Northeast of Thrace, the Danube, Dnieper, Dniester, and Don rivers drain into the Black Sea, contributing two-thirds of the total runoff to this basin (Hay, 1987).

The Marmara–Black Sea study area lies on the northern border of the Mediterranean climatic region which extends from ∼30 to 40°N and is thus generally influenced by seasonal shifts in the latitude of the subtropical anticyclonic belt (Rossignol-Strick, 1995). Moisture is primarily derived from evaporation of the Atlantic and Mediterranean seas, followed by orographic cooling that largely controls the distribution of this moisture as rain. The present climate therefore varies in accord with geographic relief, ranging from relatively humid coastal areas to a semi-arid interior (Goetz, 1988). The northern Marmara and Black Sea coasts have a relatively warm mild climate (mean 14°C, range 7–23°C) and rainfall of ∼700–2400 mm, spread throughout the year. At high elevations in the northeast, summers are also warm and rainy (18°C, ~200/600 total mm) but winters are very cold (−12°C). The southern Marmara, western and south coasts of Anatolia have a Mediterranean climate, with hot (29°C), dry summers and mild (11°C), wet winters (~400–600 mm/yr). The semi-arid interior plateau has slightly cooler (23°C), dry summers and cold (0°C), moist winters (~250–400 mm).

2.2. Modern vegetation

The distribution of main vegetation types in the study region is shown in Fig. 2. Five major types are present on the coastal plains and mountains fringing the Marmara, Aegean and Black seas (Roberts and Wright, 1993). The plant names are those used by Zohary (1973) who documents the authorship of the names.

2.2.1. Mesic euxinian forest

This is a deciduous, broadleaf forest associated with >600 mm of year-round precipitation. Dominant trees are *Fagus orientalis*, *Fagus sylvatica*, *Carpinus betula*, *Carpinus orientalis*, and deciduous oaks, e.g. *Quercus petraea*, *Quercus robur* and *Quercus cerris* (Dr. Y. Gemici, Ege University, Izmir, personal communication, 2000). *Pinus* and *Abies* are also present, as well as *Fraxinus* spp., *Alnus glutinosa*, *Populus tremula*, *Acer campestre*, *Ulmus* spp., and near the coast, *Rhododendron ponticum*. In Thrace, much of the *Fagus–Quercus* forest has been cleared from the Black Sea area, being replaced by *Alnus*, *Fraxinus ornus*, *Ulmus* spp., *Acer campestre* and *Salix alba*. Most of the central plateau is under agriculture and land around Istanbul is in urban use. Surface pollen assemblages from this region contain 50% or

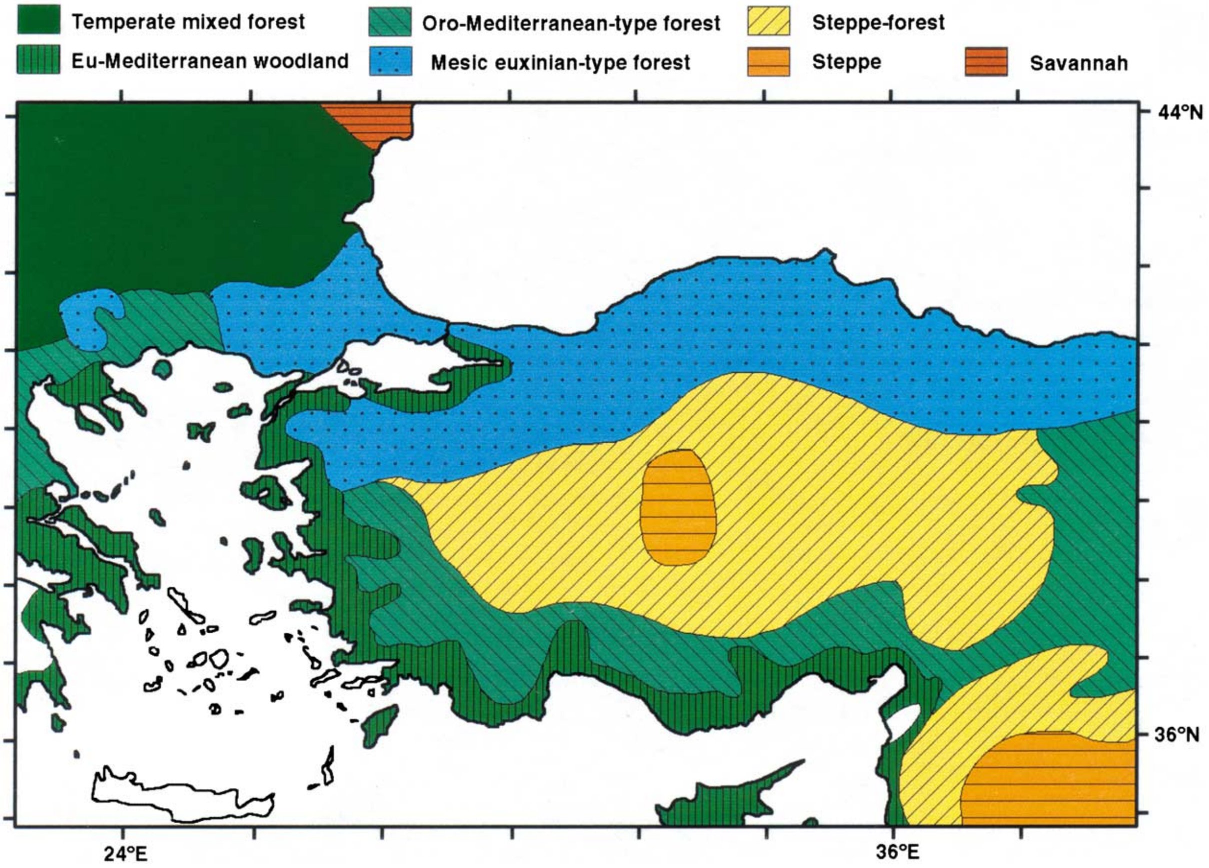

Fig. 2. General distribution of main vegetation zones (modified from Roberts and Wright, 1993).

more AP (arboreal pollen) and ~20–40% NAP (non-arboreal pollen) (Roberts and Wright, 1993; Bottema et al., 1995).

2.2.2. *Eu-Mediterranean woodland*

This is a drought-resistant evergreen xeric coastal woodland or macchi associated with a mean rainfall of 300–1000 mm, falling mainly in winter. The dominant trees are evergreen oaks (*Quercus ilex*, *Quercus coccifera*, and *Quercus infectoria*), *Pinus halapensis* and *Pinus brutia*, *Pistacia lentiscus*, *Olea oleaster*, *Arbutus andrachne* and *Ceratonia siliqua*, with *Sarcopoterium spinosum* (Rosaceae) phrygana replacing the macchi in eroded or cleared areas (Roberts and Wright, 1993; Dr. Y. Gemici, Ege University, Izmir, personal communication, 2000). The terrestrial pollen assemblages are > 30% AP, excluding oak, and 20% evergreen oak plus *Olea* and *Pistacia*.

2.2.3. *Oro-Mediterranean forest*

This is forest found at elevations of ~400–2000 m along the NW Aegean Sea and on the southern and western slopes of the Taurus mountains, associated with > 600 mm annual precipitation falling mainly in winter. Beug (1967) describes a similar sub-Mediterranean black pine forest for the upper slopes of the ranges bordering the Black and Marmara seas. In most Mediterranean areas, this forest has been severely altered by human occupation so that not much is known about the original composition (Bottema and Barkoudah, 1978). In less disturbed parts of Anatolia, however, species of *Pinus* and *Cedrus* dominate, with shrubby (from animal browsing) oaks in the undergrowth, whereas deciduous oaks are predominant in Greece, and may possibly have dominated earlier in Turkey. The oaks include the deciduous species *Quercus cerris, Quercus boissieri* and *Quercus libani*. *Ostrya*, *Acer*, *Fraxinus*, *Pyrus* and *Juniperus* may also be present. On colder, drier slopes, *Cedrus*, *Abies* and *Juniperus* are more common, accompanied by deciduous *Quercus* spp., *Pistacia*, *Acer*, *Sorbus*, *Ostrya* and *Carpinus*. Surface pollen assemblages are marked by > 50% AP, dominated by *Pinus* and *Quercus*, with less than 20% eu-Mediterranean elements present (Roberts and Wright, 1993).

2.2.4. *Steppe–forest*

This is a mixture of open xeric woodland and steppe grassland, which is found in the interior of Anatolia, and in northern Syria, where mean annual precipitation is 300–600 mm, mostly in winter. The woodlands are composed mainly of deciduous oaks, *Pinus*, *Pistacia*, *Juniperus* and *Amygdalus scoparia* (Rosaceae). The steppe vegetation is dominated by *Artemisia herba-alba*, diverse Leguminoseae, Compositae (= Asteraceae), Gramineae (= Poaceae) and isolated occurrences of Mediterranean shrubs, including *Amygdalus communis*, *Sarcopoterium spinosum*, *Cistus salvaefolia*, and a few trees such as *Quercus ithaburensis* and *Pistacia atlantica*. Surface pollen assemblages have 15–50% AP and less than 20% eu-Mediterranean elements.

2.2.5. *Steppe*

This is dwarf shrub grassland, treeless except along watercourses, which is presently found only in the interior of Anatolia and in southern Syria where mean annual precipitation is either < 100 mm in winter or 100–200 mm in summer. Chenopodiaceae dominate in the driest areas, where *Ephedra* shrubs are also present. *Artemisia* is the dominant dwarf shrub in areas of slightly moister semi-steppe vegetation, together with Gramineae (grasses), Compositae, *Plantago* (plantain) and other herbs. Compositae tend to dominate in areas with dry hot summers. This vegetation has surface pollen assemblages containing < 15% AP.

Northwest of the Marmara Sea, in the headwaters of the Danube River, is an extensive region of temperate mixed forest (Fig. 2), with a mean annual precipitation of > 1000 mm, falling year-round. This woodland is similar to the mesic euxinian-type forest, but with a higher proportion of coniferous forest, including *Picea* (spruce) and *Abies* (fir), fewer *Quercus* and *Acer* (maple) but more *Betula* (birch), and less *Carpinus* (hornbeam). *Tilia* (linden), *Ulmus* (elm) and *Corylus* (hazel) have recently been eliminated from the vegetation by human activities (Kremenetski, 1995). In the eastern Danube lowlands and surrounding the northern Black and Azov seacoasts are savannah grasslands with less than 600 mm/yr of precipitation, falling mostly in summer. In the past, the river valleys contained gallery forest dominated by *Alnus glutinosa* and *Salix* (willow), with *Quercus robur*, *Tilia cordata*, and *Ulmus* species also present (Kremenetski, 1995).

3. Methods

The cores used in this study (Fig. 1) were collected from the Turkish ship RV *Koca Piri Reis* using a 4-m long wide-diameter gravity corer. All cores were stored at ∼4°C until they were split, described and sampled for micropaleontological studies. The sedimentology of the cores is described in detail by Hiscott and Aksu (2002) who also illustrate the Marmara core lithology and list the radiocarbon ages and sedimentation rates. All lithofacies are further illustrated in Mudie et al. (2002) and the Black Sea core is described in detail by Duman (1992).

Palynomorphs were extracted from samples of 2–5 cm^3 volume, using standard methods for Quaternary marine sediments (Mudie, 1982): sieving at 15- and 125-μm mesh sizes, digestion in HCl and HF, and adding *Lycopodium* spores to obtain estimates of palynomorph concentration per cm^3. These concentrations include both pollen, fern and moss spores.

Palynomorph preservation is good in most sections of the cores, but sandy intervals often contain many oxidized and abraded grains, while other intervals include abundant pyrite-infilled grains. Some levels also contain common reworked pre-Quaternary (mainly Pliocene) pollen or spores and more rarely, reworked dinoflagellates. These reworked palynomorphs were primarily recognized by their distinctive morphology, but flattened and/or yellowish grains of extant pollen types were also scored as reworked. The positions of these reworked levels and the sandy intervals are noted in the figures. Most samples contained common to abundant dinoflagellate cysts, acritarchs, algal and fungal spores: these assemblages are reported elsewhere (Mudie et al., 2002).

One or two slides of each processed sample were counted at ×25 magnification, until a minimum of 300 *Lycopodium* spores was reached. This yielded counts of 100–200 for total pollen, fern and moss spores for most samples; however, in the oxidized sandy intervals, pollen counts were as low as 25–50 for two slides although >1000 *Lycopodium* spores were counted. The intervals of counts less than 50 are noted in the diagrams. A list of the number of pollen+spore counted for each sample can be obtained from the authors. Identification of unfamiliar eastern Mediterranean pollen types was based mainly on illustrations of Koreneva and Kartashova (1975) and Haddad (1969). The pollen sum used here includes all known tree, shrub and herb species, as well as the rare aquatics, but excluding fern and moss spores. Percentages of AP include all conifers, deciduous trees (including *Alnus*, *Betula*, *Salix* and all warm temperate species) and large (>30-μm) *Quercus* grains, most of which represent deciduous species. *Carpinus* and *Ostrya* pollen were grouped together because of difficulty in distinguishing between these grains. *Pistacia* was not included in the AP because we were unable to distinguish among tree and shrub species on a routine basis. NAP here includes small shrubby perennials, e.g. *Artemisia*, various Chenopodiaceae, *Sarcopoterium* and other Rosaceae, and all Compositae, in addition to Gramineae, Caryophyllaceae, and other identifiable herbs, e.g. *Plantago*, *Thalictrum*. In addition, unknown small (<30-μm) tricolpate/tricolporate pollen were included in the NAP because they cannot be matched with any of the common tree and shrub pollen species. Rare aquatics ($<5\%$ of total), e.g. *Typha*, *Nuphar*, were also included in the NAP.

4. Results

4.1. Core-top assemblage distribution

Table 1 lists the amounts and percentage abundances of dominant taxa and main climate-proxy species in core-top assemblages, including data from previous studies (Koreneva, 1971; Rossignol-Strick, 1995; Roman, 1974; Aksu et al., 1995a) and from 10 new samples (see Fig. 1). The pollen-spore concentrations (Fig. 3) range

Table 1

Core-top data used for Fig. 3, list of the water salinity, number of pollen+spores counted, pollen-spore concentrations, percentages of AP and NAP, and relative abundances of dominant and selected paleoclimatic pollen and spore indicators

Core number	GC22	GB5	GS20	KS19	GB13	KC3	1065	97-2	1069	98-12	94-5	97-11	98-9	98-4	1461	1474	BS7	BS13	400	4779	61
Surface salinity (psu)	39.5	39.3	39.1	38.4	34.5	34.0	34.5	24.0	24.0	23.0	22.0	22.0	20.1	17.6	17.0	20.0	22.0	22.0	39.5	> 39	15.0
Pollen and spores (grains/g)	103	56	209	784	49	262	5	578	60	3200	2730	5780	3890	3100	6000	160 000	42 300	55 941	10	< 5	10 000
Number of grains counted	34	50	123	80	100	107	nd	186	nd	208	100	101	70	90	200	nd	210	228	nd	nd	500
Pinus+Cedrus	56	40	6	69	20	42	90	31	70	55	55	72	71	39	20	12	17	18	44	10	5
Picea	6	7		6				1	+	2		1	1	5	2		1				1
Abies							+							3			3	1.7			
Taxaceae+Cupressaceae	13	13	6		20			2						1			6	1.7			
Quercus coccifera type	6	7	18	6	10	8	+	2	10	3	4	6	3	9	12	7	8	1.7	25	12	7
Quercus cerrus type					20	33				5	2	1	1	8				6			
Castanea			12					+	+	1								0.86			
Pistacia			18	3							2	3	1	1			1	6			
Betula			6				+		+					3	2		5	3.4	+	+	2
Alnus							+	1	+				3	5	7	26	16	16	+		11
Carpinus							+								5		12	4.3			2
Tilia+Ulmus+Fagus								+	+		2	1		2	2		2	12			2
Pterocarya+Carya+Juglans								2					3	1		3		11			3
Salix															2						5
Ephedra														1			1		+	+	
Corylus						8								1	2		1				2
Rosaceae			6					1		2				2			3				
Artemisia				3		8		2	2	3	7				10	2	2	1	5	3	6
Chenopodiaceae-Am	6			3				8	9	1	4	1	4	6	17	3	2	5.2	20	10	20
Compositae	6		18	3			+	3	8	2	2	3		2	5				15	15	12
Gramineae			6	6			+			1	2	3	1	3	3		6	5	1	50	10
Plantago				6				2		1		1		1							
Pteridium	6	13		20				10	+	4	4		4		10						6
Polypodiaceae				10							2		1	5							
AP	81	100	63	78	100	75	85	43	70	71	73	75	83	72	50	80	78	81	70	22	46
NAP	12		24	21		8	10	21	25	22	2	10	8	16	35	10	16	15	30	78	48

Geographic co-ordinates and data sources are shown in Appendix 1.

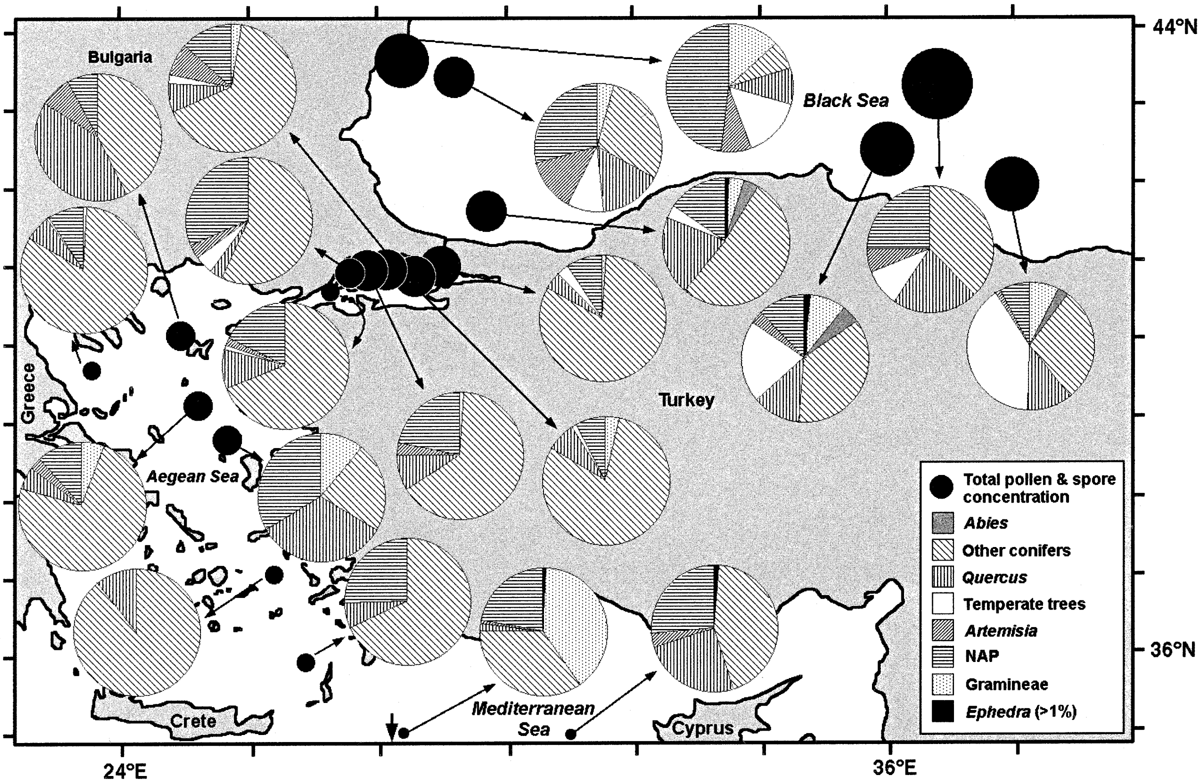

Fig. 3. Variations in core-top pollen-spore concentrations (black circles) and percentage abundance of selected arboreal and herb taxa listed in Table 1. Size of black circles is proportional to a log 10 with the smallest value $<10^{-1}$ and the largest $>10^{5}$ grains/g.

from less than 5/g in the eastern Mediterranean Sea to 160 000 grains/g in the eastern Black Sea, with an average of 178 (5–784) in the Aegean Sea, 2706 (60–3890) in Marmara Sea and 80 000 (3105–160 000) in the Black Sea.

Relative abundances of the main AP types and selected indicator NAP taxa are depicted in Fig. 3. In general, the AP is dominated by bisaccate grains of the conifers *Pinus*+*Cedrus* (40–90%; Table 1) as expected for offshore marine pollen assemblages (Mudie and McCarthy, 1994). Lower values (12–20%) of *Pinus*+*Cedrus* occur in the eastern Black Sea and at some sites in the southern Aegean (GC22, GS20) and the Mediterranean (4779, 400) where percentages of *Juniperus* and NAP (>20%) are also higher (Table 1). Relatively high percentages (~5–20%) of desert herbs/small shrubs (*Artemisia*, Chenopodiaceae, Compositae, Gramineae and *Ephedra*) characterize the sites bordering steppe and desert regions in the eastern Mediterranean, as noted by Koreneva (1971). Relatively high values (5–17%) of *Artemisia*+Chenopodiaceae, or Chenopodiaceae+Compositae+Gramineae, and presence of *Ephedra*, also mark the modern assemblages in some Marmara and Black sea samples. Very high amounts of Gramineae (50%), absence of *Abies* and warm temperate trees distinguish the marine spectrum of the desert region from that of the steppeland.

Small amounts of *Picea* conifer pollen (Table 1) are present in most samples except those from the eastern Mediterranean and eastern Aegean sites. This taxon is the clearest indicator of long-distance transport by air or water because the closest location of *Picea* is the European temperate forest. In contrast, *Abies* conifer pollen occurs only in the Black Sea and at one site off northeast Greece, indicating that it is not transported far from its source area in montane forests of northern Anatolia and Greece.

Hardwood tree and shrub pollen are mostly dominated by *Quercus*, with small grains of *Quercus coccifera*-type scrub oak (Table 1) prevailing in the Mediterranean Sea and increased representation of larger *Quercus cerris*-type deciduous oak pollen in northern Aegean and Marmara seas that are bordered by oro-Mediterranean or mesic forest. Pollen of *Fagus*, *Ulmus* and other trees requiring warm, moist conditions (*Carya*, *Juglans* and *Pterocarya*) have approximately the same distribution as the deciduous oak pollen and they are virtually absent in core tops outside the Black and Marmara seas. Pollen of more cold-tolerant but moisture-demanding trees, *Betula* and *Alnus*, show a similar pattern but increase in percent abundance in the Black Sea.

Fern percentages are not plotted in Fig. 3 because no numerical data are available for many of the older records. The data in Table 1, however, show a very wide distribution of 4–20% *Pteridium*-type trilete spores in contrast to mostly low percentages of *Polypodium*/*Dryopteris*-type spores which are concentrated in the Marmara Sea area. Koreneva (1971) did not list the fern spore genera found in her core-top samples but she shows up to 10% of fern+moss spores for all her sites in the Mediterranean and Aegean Seas, including those off the north African deserts. This widespread distribution also indicates that fern spores may be transported very large distances by air and water. Rossignol-Strick (1995) also notes that fern spores are highly resistant to oxidation in bottom sediments.

4.2. Marmara Sea cores

Three cores, MAR97-02, MAR98-12 and MAR94-05, were studied from the northwestern Marmara Sea, ∼25–50 km from the Aegean seawater entrance. Summer surface salinity in this area is about 25 psu (Özsoy et al., 1995), reflecting more mixing with Mediterranean water ($>$34 psu) than in the eastern Marmara Sea. Two cores were also studied from shelf areas of the eastern Marmara Sea. MAR98-11 is from the south margin beneath the core of the inflowing Aegean Sea water. MAR98-9 is from 20 km west of the Bosphorus Strait where the salinity is lower (∼22.5 psu; Özsoy et al., 1995) because of outflowing Black Sea surface water.

4.2.1. Core MAR94-05 (Fig. 4)

The oldest sediments are found in core MAR94-05 (Fig. 4) from the deep central basin of Marmara Sea (850 m water depth). At the base of this is ∼120 cm of laminated sapropelic light gray mud (sediments older than allounit C of Hiscott and Aksu, 2002). Above this sapropel is 40 cm of brown sandy mud that is unconformably overlain by 40 cm of a reddish silty clay (allounits B and A1 of Hiscott and Aksu 2002). The sandy mud has a Late Glacial age of 21 950 yr BP at the top. A radiocarbon age of 29 540 yr BP at 210 cm shows that the sapropel was rapidly deposited (21.5 cm/kyr) at the end of the Pleniglacial Würm interval (oxygen isotopic stage 3). Total pollen-spore concentrations range from an average of ∼10 000/g in allounits A1–B to 50 000/g in the laminated sediments of lower allounit C.

Three pollen assemblage zones are recognized. From the base to 80 cm core depth, *Pinus* pollen increases while both *Quercus* deciduous tree-type and *Artemisia* pollen decrease. Relatively low AP values ($<$60%) suggest a steppe–forest vegetation. However, the NAP does not exceed 50% (mostly *Artemisia*) and notable amounts of Cyperaceae indicate the presence of extensive wetlands. The persistence of *Quercus* and presence of *Fagus*, *Alnus* and *Pistacia* also point to a woodland vegetation more like the present oro-Mediterranean forest, which is associated with relatively high precipitation, at least in winter. The extraordinarily high pollen concentrations (today matched only in the upper Holocene sediments of the Black Sea) also indicate a dense vegetation cover surrounding a lake-like sea. This Pleniglacial pollen assemblage zone is designated PZ-5 and has an age of 29.54 to ∼24 ka. Similar assemblages are found at the base of MAR98-04 east of Bosphorus Strait which has a radiocarbon age of 33 550 yr BP (see Aksu et al., 2002).

The interval from 90 to 40 cm has an age of

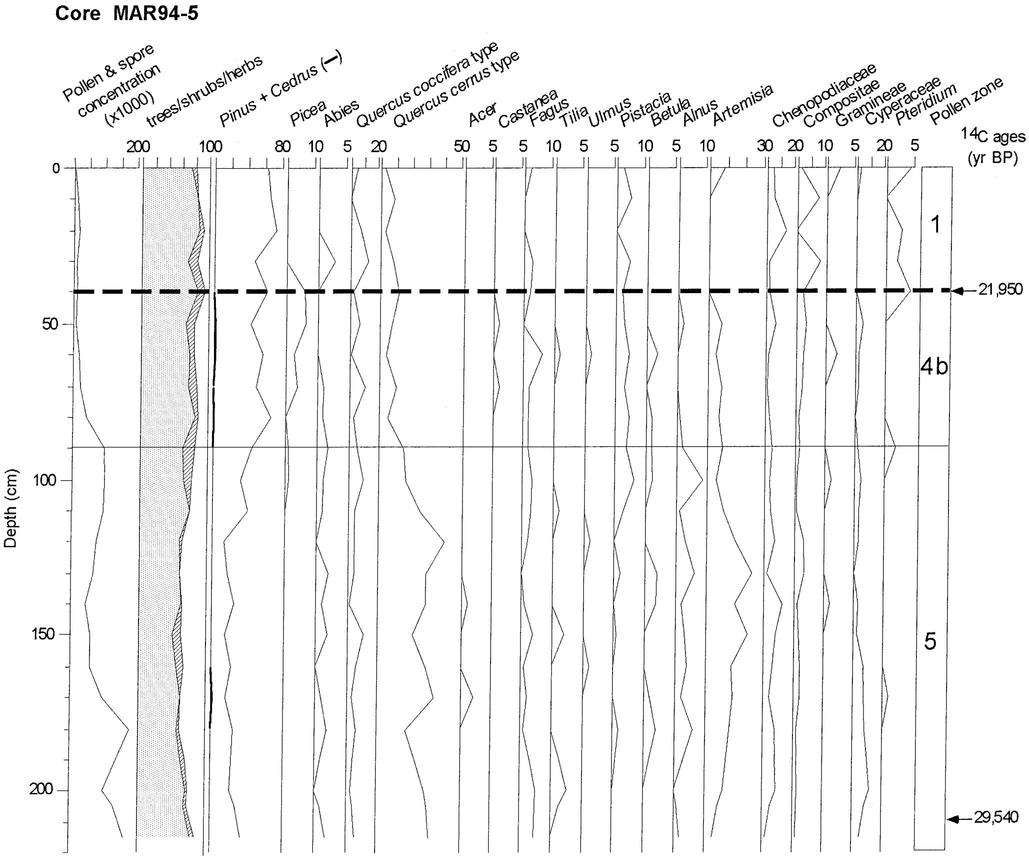

Fig. 4. Pollen diagram for MAR94-05 showing downcore changes in pollen-spore concentrations in grains $\times 10^3$/g, percentage of AP and NAP and percentage abundance of the dominant pollen types and main indicator taxa.

~24–21.95 ka, with common *Artemisia*, Chenopodiaceae and Gramineae and with relatively high percentages of *Pinus*, *Cedrus* and *Picea*. Some *Quercus* and other hardwood tree pollen are also present, notably *Fagus* which requires > 800 mm/yr (Bottema et al., 1995) and *Pistacia* which requires a minimum of 5°C in winter. This Late Glacial zone preceding the LGM from ~22 to 17 ka is designated PZ-4b.

The assemblages from 40 to 0 cm in this core are dominated by *Pinus*, and *Quercus* abundance is relatively low. *Fagus* is present, *Centaurea* pollen is common and *Artemisia* is absent. This interval is tentatively assigned to a late Holocene zone PZ-1 although it lacks typical markers like *Olea* and *Juglans* that delimit the start of permanent agriculture in the other Marmara and lake cores.

4.2.2. Core MAR98-12 (Fig. 5)

This core is from 550 m water depth on a saddle between the western and central basins of the Marmara Sea (Fig. 1). The core consists of a basal unit of light gray sandy mud with pyrite streaks (allounit B of Hiscott and Aksu, 2002), about 80 cm of olive gray laminated sapropelic mud in the center (allounit A2) and 60 cm of the reddish-brown allounit A1 at the top. Radiocarbon ages establish that the unit B/A2 boundary has an age of 10 660 yr BP, giving a lower sedimentation rate of 11.9 cm/kyr for the Holocene and late glacial sediments at this site (Aksu et al., 2002; Hiscott and Aksu, 2002). Average pollen-spore concentrations in MAR98-12 (~10 000 grains/g) are also lower than in the basin core MAR94-5, despite the slower sedimentation and excellent preservation in the sapropel.

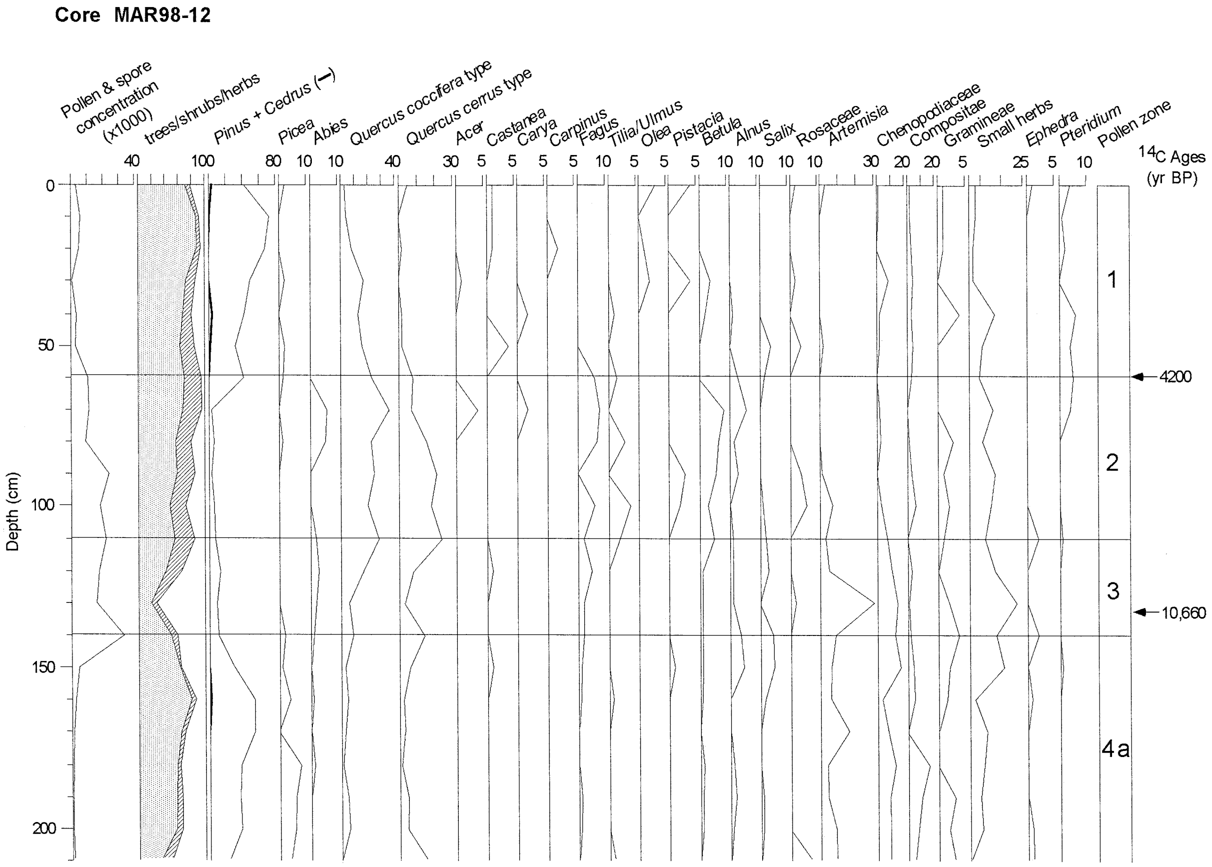

Fig. 5. Pollen diagram for MAR98-12 showing downcore changes in pollen-spore concentrations in grains $\times 10^3$/g, percentage of AP and NAP and percentage abundance of the dominant pollen types and main indicator taxa. Note that counts are >25 and <50 for levels 170–200 cm.

Four pollen assemblage zones are recognized, based primarily on major changes in concentration and large shifts in percentages of *Pinus*, *Quercus*, *Fagus*, *Artemisia* and Chenopodiaceae. Pollen concentrations at the base of the core (210–140 cm) are lower than in PZ-4b of MAR94-05. *Pinus* and *Cedrus* again dominate, but temperate hardwoods are absent and *Quercus* is rare, generally indicating colder conditions. The abundance of *Artemisia*, Chenopodiaceae and herbs (mainly Gramineae and Compositae) also suggests much drier conditions, probably corresponding to a steppe–forest landscape. The presence of *Abies*, *Fagus* and *Betula*, however, indicates that pockets of forest vegetation persisted, at least on the warmer lower slopes. Up to 10% *Picea* pollen suggests transport by strong winds from southern Europe (see 5.1. Core-top assemblage distribution). This pollen assemblage zone is designated PZ-4a and has a Late Glacial age of ~17–13 ka by cross-correlation with the ^{14}C-dated core MAR97-11.

From 150 to 140 cm, pollen-spore concentrations increase and remain high to 90 cm, with a major peak (30 000/g) occurring just above a shell horizon with an age of 10 660 yr BP. Pyrite-infilled grains are high in this sapropelic interval. There is a large increase in NAP, with a peak in *Artemisia*, increased Chenopodiaceae and 'small herb' pollen, accompanied by small amounts of *Pinus*, *Cedrus*, *Quercus*, *Betula* and *Alnus*. *Picea* is absent but *Abies* pollen is present. Peaks in *Ephedra* pollen indicate very cold, dry conditions. This pollen assemblage zone is designated PZ-3 and has an age of ~13–9 ka, encompassing the Younger Dryas cold event. The lower *Quercus* percentages in this sapropelic unit, together with the decline in *Quercus* seen in the sapropel of MAR94-5, establish that the fluctuations in this oxidation-sensitive pollen type reflect changes in vegetation cover, not improved preservation conditions (cf. Rossignol-Strick, 1995).

From 110 to 60 cm, pollen-spore concentrations decrease from an average of ~20 000 to 10 000/g although there is no significant change in sedimentation rate (see Aksu et al., 2002). Many pollen grains are infilled with pyrite, indicating strongly reducing bottom conditions. The pollen zone is marked by low % *Pinus* and increased % *Quercus*, including both *Quercus cerris*- and *Quercus coccifera*-type grains. Moisture-demanding temperate tree species *Fagus*, *Betula*, *Tilia* and *Ulmus* are also present. There is a notable peak in *Pistacia* just above the top of PZ-3. This *Pistacia* maximum has an age of about 9000 yr BP based on a shell date of 10 660 yr BP at 130 cm. This glacial–interglacial transition zone is designated PZ-2.

PZ-1 occurs from 60 to 0 cm and has a shell ^{14}C age of 4200 yr BP at the base. This age corresponds closely to the start of the post-Atlantic zone 3 at the Yeniçaga and Abant Lake sites (Van Zeist and Bottema, 1982; Bottema et al., 1995). PZ-1 is marked by a succession of co-dominance by *Quercus* and *Pinus*, followed by a rise in *Pinus* (>50% in most samples) and corresponding decline in *Quercus* pollen, particularly the deciduous tree type. There are fluctuating amounts of temperate hardwood pollen (*Carpinus*, *Castanea*, *Carya*, *Ulmus*), particularly in the lower section, before ~3000 yr BP, and with common *Pteridium* throughout. At the top, *Olea, Castanea* and *Pistacia* are present, marking the start of orchard farming and corresponding to zone PZ-1a found in the high-sedimentation core MAR97-02.

4.2.3. Core MAR97-02 (Fig. 6)

This core consists of 2.2 m of reddish silty clay (allounit A1 of Hiscott and Aksu, 2002) from the deep western basin (at 1080 m water depth), where sedimentation rates are high. Three radiocarbon ages show that the sediment in MAR97-02 was deposited continuously during the past ~3600 years, i.e. from about 2000 calendar years BCE to the present. Total pollen-spore concentrations range from 462/g near the base to a minimum of 84/g in the center. The average of ~250/g corresponds to an influx of ~30 grains per year, assuming a sedimentation rate of 67.2 cm/kyr (Aksu et al., 2002; Hiscott and Aksu, 2002).

The assemblages throughout this high sedimentation core are dominated by *Pinus* and *Quercus* spp. (>50% in most samples), with pollen from temperate hardwoods (*Juglans*, *Carpinus*/*Ostrya*, *Tilia* and *Castanea*) making up about 10% of the total AP (Fig. 6). These assemblages are essentially the same as those in PZ-1 of MAR98-12. However, three subzones are evident in MAR97-02. PZ-1c (210–160 cm) is marked by relatively high pollen concentrations (average ~500 grains/g, with peaks of ~1000), by the presence of *Cedrus* and >5% *Abies* conifer pollen in addition to *Pinus*, and with rare occurrences of Compositae and Gramineae. These features are consistent with a mesic euxinian forest landscape prior to major clearance, as expected for the pre-Greco/Roman settlement time at ~3000 yr BP (Van Zeist and Bottema, 1982). Peaks of *Pteridium* and Chenopodiaceae, however, suggest that some forest clearance and agriculture had already begun during the early Bronze Age settlement of Northern Anatolia at ~4600 yr BP. Subzone PZ-1c has an interpolated upper age of about 2800 yr BP or 1100 cal. yr BC (assuming a ^{14}C age of 3810 at 150 cm is too old as indicated by the presence of reworked Neogene dinoflagellates).

Subzone PZ-1b (160–60 cm) is marked by low pollen concentrations, including major decreases in *Pinus*, disappearance of *Abies* and, later, *Quercus* pollen. *Tilia* also disappears temporarily, while Gramineae and Compositae pollen become frequent, notably *Centaurea*- and *Taraxacum*-type pollen, which commonly invade orchards and pastures (Bottema et al., 1995). The interpolated age at the top of this subzone is 1500 yr BP (462 AD). Subzone PZ-1a (60–0 cm) is marked by the reappearance of *Abies* and *Quercus* and increased *Pinus* and *Pteridium* (bracken fern). *Juglans* (walnut) and *Olea* (olive) are continuously present

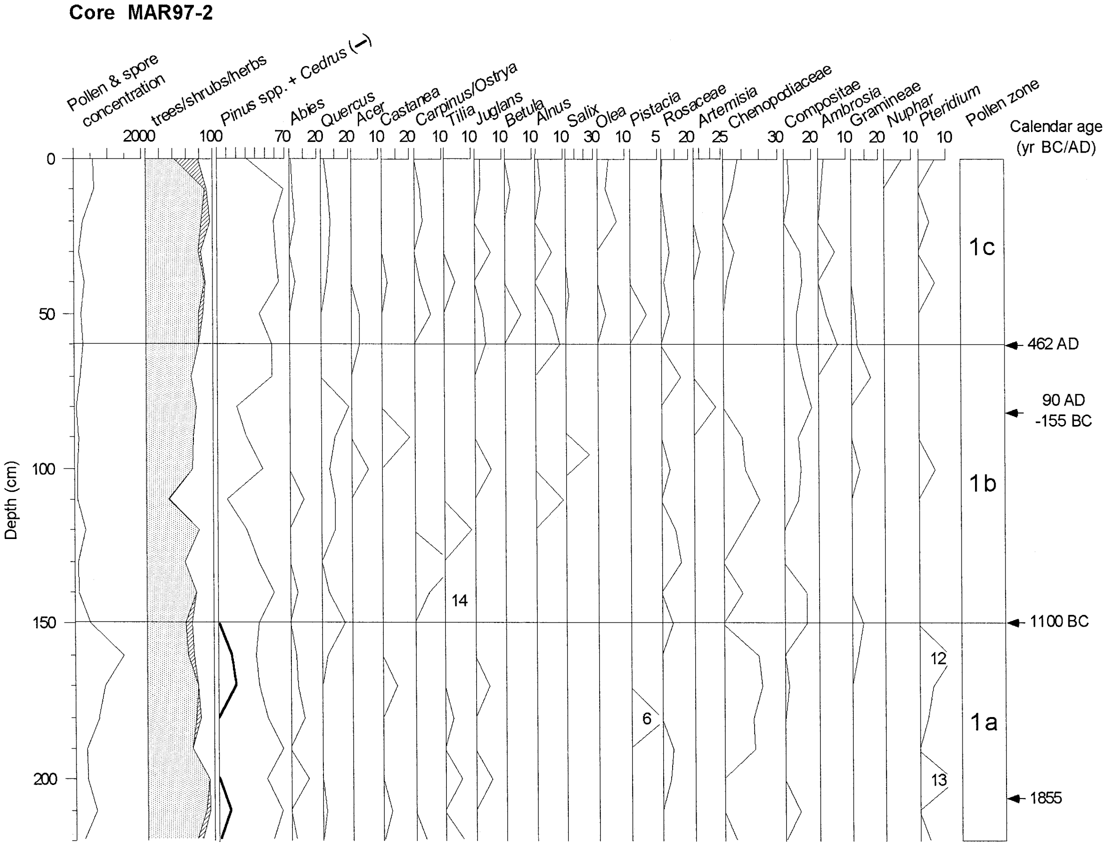

Fig. 6. Pollen diagram for MAR97-02 showing downcore changes in pollen-spore concentrations in grains/g, percentage of AP and NAP and percentage abundance of the dominant pollen types and the main indicator taxa.

and *Alnus* (alder) increases. The surface sample is marked by the presence of *Nuphar* (waterlily) pollen, which is a very recent introduction to lakes in northern Turkey.

4.2.4. Core MAR97-11 (Fig. 7)

This core is from ~20 km north of the mouth of the Simav River and it contains a continuous sequence of mud deposited since the LGM. The base is a gray mud with charcoal and mottles (allounit B; Hiscott and Aksu, 2002). Above this is ~90 cm of yellowish sandy mud which is overlain by ~80 cm of Late Glacial–Postglacial olive gray mud with a basal age of 10 790 yr BP.

At the base of the core (230–80 cm), both PZ-4b and 4a are present. PZ-4b (230–190 cm) is distinguished by relatively low NAP, common *Pinus*+*Cedrus*, and pollen of *Abies* and *Quercus* are present. This LGM interval has a shell age of >15 590 yr BP near the base and ~15 000 yr BP at the top. From 190 to 80 cm, *Pinus* decreases and *Picea*, *Betula* and *Alnus* are present, although *Quercus* and other deciduous hardwoods are absent. Herb pollen predominate, with *Artemisia*, Chenopodiaceae and Compositae as dominants, together with common Caryophyllaceae and Gramineae. Cyperaceae pollen suggest the proximity of freshwater marshland similar to the modern Danube Delta. These PZ-4a assemblages indicate that much colder, drier steppe–forest conditions prevailed, possibly with trees being confined to the watercourses. There is a shell age of 14 940 yr BP just above the base of this subzone.

From 90 to 70 cm (~11–10 000 yr BP), pollen

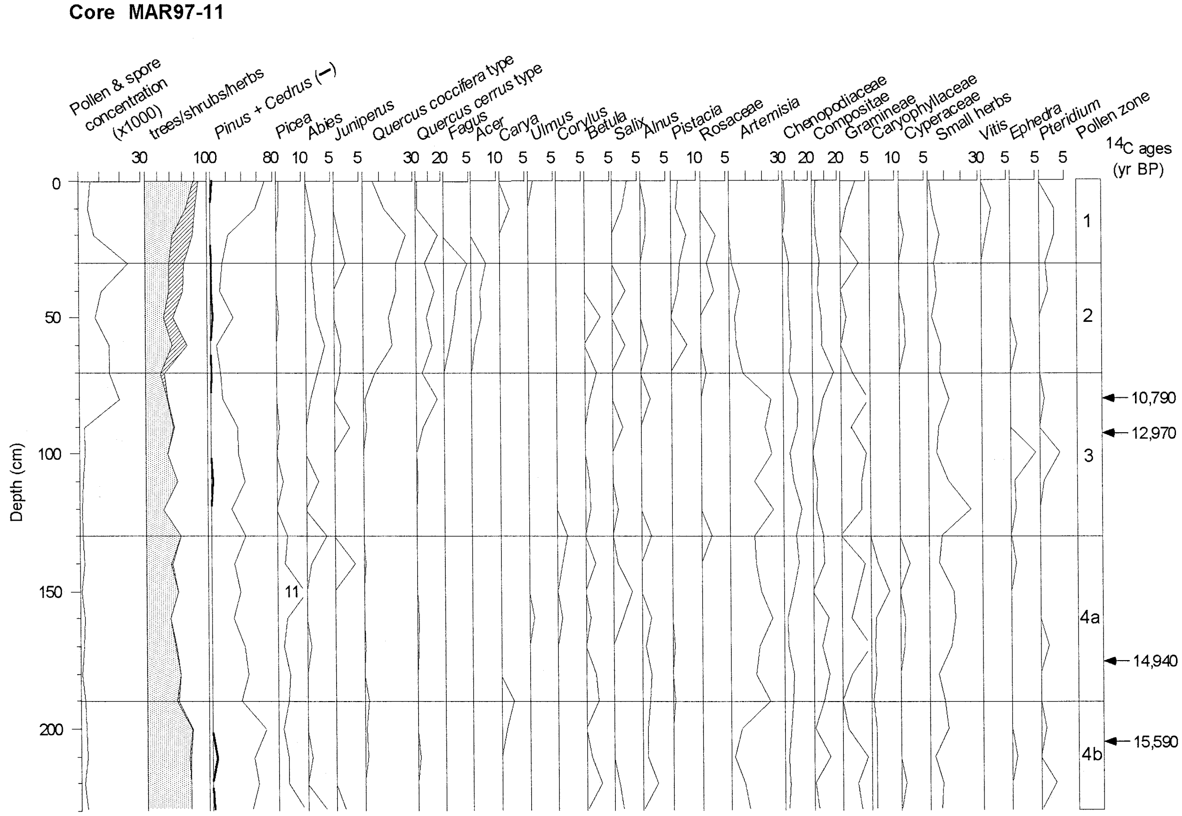

Fig. 7. Pollen diagram for MAR97-11 showing downcore changes in pollen-spore concentrations in grains$\times10^3$/g, percentage of AP and NAP and percentage abundance of the dominant pollen types and main indicator taxa. Note that counts are >25 and <50 for levels 150–180 cm.

influxes increase by a factor of ~2 and large peaks of *Artemisia* (30%), *Ephedra* and herb pollen mark the Younger Dryas event at the top of PZ-3. Below 90 cm ($>$12 900 yr BP), concentrations decrease but high sedimentation rates (~41–46 cm/kyr) mean that influx rates remain high (~300 grains/yr).

Above ~70 cm, pollen-spore concentrations are high (~5000/g) but sedimentation rates are slow (~7 cm/kyr), therefore influx rates are actually quite low (~17 grains/yr). The dominance of *Pinus* and the presence of *Vitis* (grape) and waterlily pollen (not shown here) from 10 to 0 cm confirm the presence of PZ-1 (30–0 cm). The decline in *Pinus* and concomitant rise in *Quercus* and other temperate hardwoods, e.g. *Carya*, *Ulmus*, the peak in *Pistacia* and the absence of *Artemisia* characterize PZ-2 from 70 to 30 cm.

4.3. Core MAR98-09 (Fig. 8)

This 1.2-m-long core of sandy gray mud from the shelf west of the Bosphorus Strait has an age of 10 220 yr BP at 110 cm and provides an expanded Holocene section. Sedimentation at the base is rapid (~60 cm/kyr) but there is a lower rate of ~7.8 cm/kyr above 60 cm (9070 yr BP). Pollen-spore concentrations increase from ~1000/g at the base to an average of ~4000/g above 90 cm core depth (~9840 yr BP).

The early Postglacial interval below 60 cm shows two peaks in *Quercus*, *Betula* and *Alnus*, while *Pinus* and *Cedrus* percentages are relatively low. At 90 cm, there is a notable peak in *Pistacia* pollen, which corresponds to a shell age of 9800 yr BP. Below this, herb pollen is higher although the near absence of *Artemisia* indicates that climate

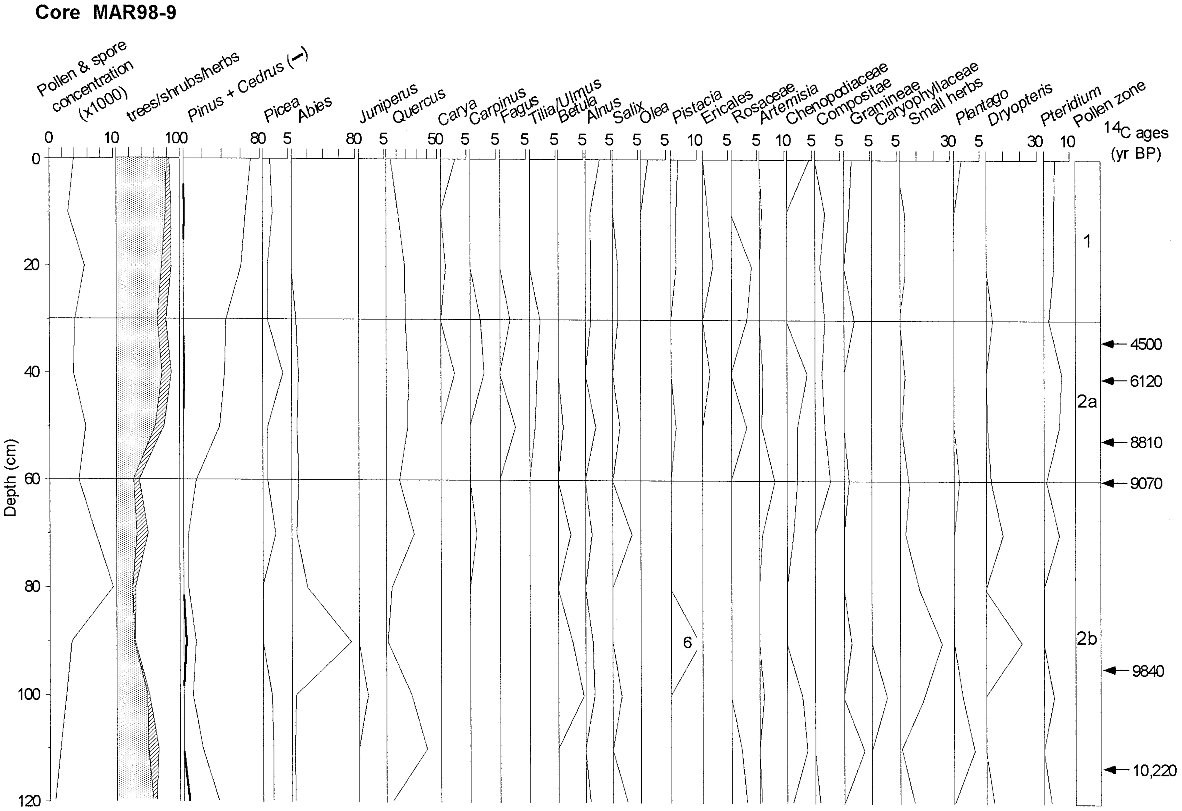

Fig. 8. Pollen diagram for MAR98-09 showing downcore changes in pollen-spore concentrations in grains $\times 10^3$/g, percentage of AP and NAP and percentage abundance of the dominant pollen types and main indicator taxa.

conditions were not as cold and dry as in PZ-3. The predominance of Gramineae, together with Caryophyllaceae pollen and *Dryopteris* spores, suggest the proximity of local marshland. There is a shell age of 10 220 yr BP just above the base.

An increase in percent *Pinus*, common *Quercus* pollen and presence of temperate tree pollen species delimit a PZ-2 zone from 60 to 30 cm, which has shell ages of 9070 yr BP near the base and 4500 yr BP at the top. These assemblages indicate that mesic euxinian forest and year-round precipitation prevailed during this time. At 60 cm, however, the sharp decline in temperate tree pollen and concomitant peaks of *Artemisia* and Compositae may mark a brief interval of somewhat colder drier conditions that is found in many parts of the world around 8000 yr BP (e.g. Ryan et al., 1997).

These pollen assemblages in MAR98-09 broadly correspond to those of early Holocene zone PZ-2 in the other Marmara cores. The relatively high sedimentation rate of MAR98-09, however, allows subdivision into two subzones. PZ-2b (120–60 cm) marks the earliest Holocene (10–9 ka) interval of *Quercus* expansion in the eastern Mediterranean and Near East (Rossignol-Strick, 1995; Bottema et al., 1995). The *Pistacia* peak in PZ-2a (60–30 cm) corresponds to the warm, wet Holocene climatic optimum as determined by Rossignol-Strick (1995).

The dominance of *Pinus*, common presence of *Quercus* and temperate tree pollen and near-absence of *Artemisia* mark PZ-1 at the top of the core (30–0 cm). Ericales pollen are also common in this unit, perhaps reflecting a greater proximity to the Black Sea (see also 4.4. Black Sea core B-7). *Olea* and *Pistacia* pollen confirm that the surface sediment layer is present. The base of PZ-1 at this site is about 4200 yr BP.

4.4. Black Sea core B-7 (Fig. 9)

Core B-7 is from a water depth of 2120 m (Fig. 1), about 100 km east of the core site 1474 studied by Wall and Dale (1973, 1974). Core B-7 contains three lithofacies (Mudie et al., 2002), which correspond closely to facies 1–3 at Wall and Dale's site. Two intervals in core 1474 were radiocarbon-dated and the sediments in this core were cross-correlated with ^{14}C-dated lithofacies in core 1462. Reported ages for these facies boundaries vary by up to 2000 years (see Jones and Gagnon, 1994). However, we show here that ^{14}C ages of about 7000–3000 yr BP for unit 2 are consistent with the regional pollen stratigraphy and with a corrected carbonate carbon age of 7540 ± 130 yr BP for the base of unit 2 (Jones and Gagnon, 1994).

From 120 to 70 cm (unit 3, banded lutite), pollen-spore concentrations are low. The low abundance may partly reflect higher rates of sedimentation but the correlation with large changes in composition of other aquatic sporomorphs such as marine dinocysts and acritarchs (Mudie et al., 2002) indicates a major paleoclimatic difference from units 1 and 2. The large decline in *Pinus* and *Cedrus*, increase in *Quercus*, presence of warm temperate trees and the peak in *Pistacia* are all characteristic of PZ-2b in the Marmara Sea and occur in the corresponding time interval (~9–6 ka) in NW Anatolian lakes (Bottema et al., 1995). The Black Sea core differs, however, in showing a concomitant increase in the pollen of cold and drought-tolerant desert shrub/herb species, including *Artemisia*, Chenopodiaceae, *Ephedra* and Compositae. Fern spores also increase suggesting more open forest vegetation and/or disturbed soils. This interval was correlated with the European Boreal and Late Prebor-

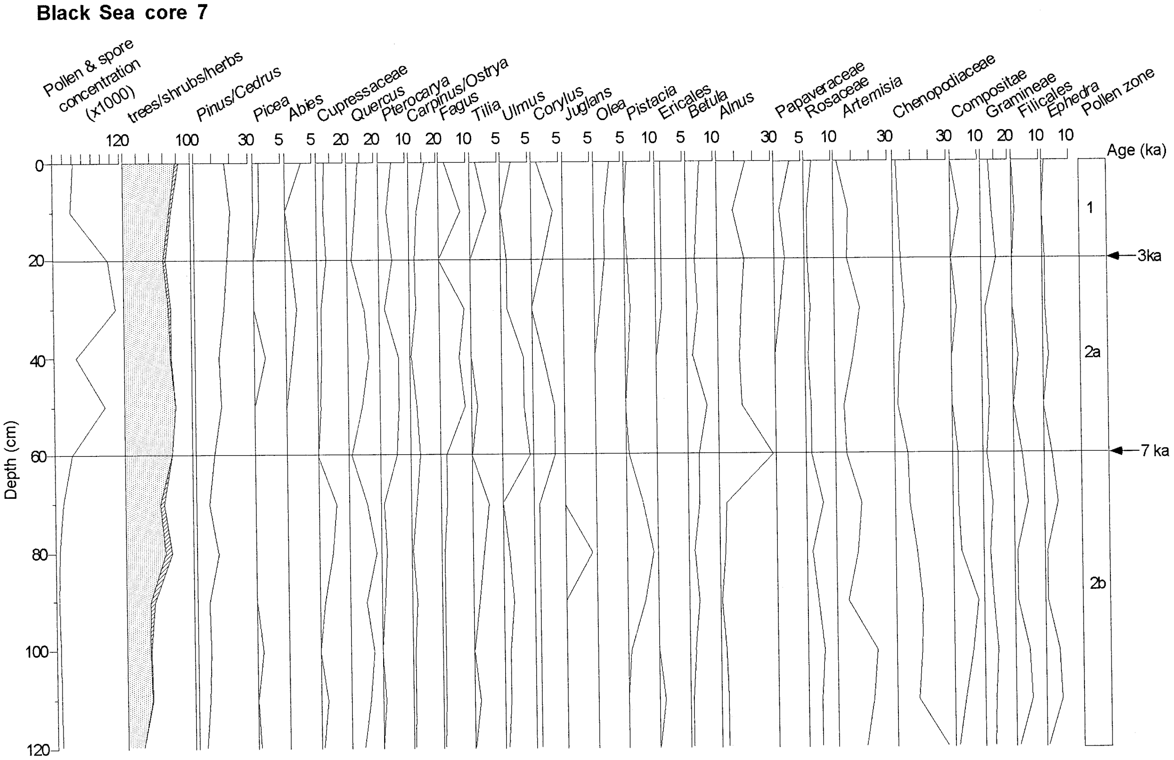

Fig. 9. Pollen diagram for B-7 showing downcore changes in pollen-spore concentrations in grains × 10^3/g, percentage of AP and NAP and percentage abundance of the dominant pollen types and main indicator taxa.

eal zones by Wall and Dale (1974), with a basal age of 9 ka being close to an age of 8600 ± 150 yr BP reported by Ross and Degens (1974) in the Alboran Sea and Mediterranean region. Common *Pediastrum coenobia* (a freshwater alga) in this unit also indicate the presence of large river plumes and salinity much lower than present (see Matthiessen et al., 2000).

From 60 to 20 cm, higher pollen-spore concentrations, increased *Quercus*, *Fagus* and other temperate tree pollen correspond to PZ-2a, and indicate warm, moist conditions typical of the middle Holocene and consistent with the age assignment of 7 ka at 60 cm. This Black Sea subzone contains a peak of *Pterocarya* which is a subtropical relict now confined to the eastern Anatolian slopes (Bottema et al., 1995).

Above 60 cm, pollen-spore concentrations and amorphogen flocs are extremely high, indicating very high terrigenous sediment influx. Pollen assemblages throughout this interval are marked by dominance of *Pinus* and *Cedrus* pollen, *Alnus* and moisture-demanding tree/shrub pollen of temperate-climate hardwoods, including *Carpinus*, *Pterocarya*, *Fagus* and *Ulmus*. From 20 to 0 cm, however, there is a steep decrease in pollen-spore concentrations, which together with the rise in *Olea*, presence of Papaveraceae pollen and relatively low percentage *Quercus* indicates the presence of a zone corresponding to PZ-1 in Marmara cores.

5. Discussion

5.1. Core-top assemblage distribution

Our eastern Mediterranean pollen-spore concentrations provide insight into the importance of drainage basin structure in determining marine pollen concentrations. In our data set, the 10-fold difference between pollen-spore concentrations in the deep basins of the Black Sea and the Marmara Sea is only partly explained by the two-fold differences in sedimentation rate, which Traverse (1974) considered to be the main reason for the high Black Sea concentrations. Shipboard aerosol sampling (Komarov, 1989) shows that pollen-spore inputs to the Black Sea average 398 grains/cm^2, in contrast to values of < 6/cm^2 for North Atlantic air samples. However, this aerial input of < 400 grains/cm^2 can account for less than 10% of the pollen/cm^2 ($\sim$4000–16 000 grains/cm^2) in the Black Sea core tops. Therefore, most of the Black Sea pollen input must be derived from the river discharge, which is an order of magnitude larger than in the Marmara Sea. Part of this enrichment of terrigenous particulate organic matter in the deep basins of the Black Sea is the result of sediment focussing (e.g. Hay et al., 1990), but this same process operates in the Marmara Sea where pollen influxes are much lower. Throughout the region, a broad correlation between salinity and pollen concentration is evident. Areas with sea surface salinities greater than 33 psu (Fig. 2) have a mean of 165 grains/g; intermediate salinities of the Marmara Sea have a mean of 2706, while the brackish waters of the Black Sea have a mean of 462 235.

Overall, the estimated high fluvial pollen component in the Black Sea is consistent with the fact that the surface sediment unit contains 27% terrigenous matter (Hay et al., 1990), with rivers contributing about a third of the total input of 4% organic carbon (Tissot and Welte, 1978). This interpretation agrees with other studies (e.g. Cross et al., 1966; Heusser and Balsam, 1977) showing that river discharge is the main pollen transport path to the ocean in subtropical/tropical regions and off western North America, in contrast to the importance of wind transport off eastern Canada (Mudie and McCarthy, 1994) and northwest Africa (Melia, 1984). Zonneveld (1995) also interpreted increased late glacial pollen concentrations in the Adriatic Sea as indicating intervals of greater discharge from the Po River.

In general, there is reasonable correspondence between marine pollen assemblages and vegetation zones in the eastern Mediterranean region despite the under-representation of some important indicator taxa. Notably, the marine surface samples show a paucity of *Acer*, *Fagus*, *Ulmus* and *Tilia* relative to the lakes, therefore, the presence of even small amounts of these pollen types in marine cores is probably significant. *Pistacia* is also under-represented in the marine samples, but Rossignol-Strick (1995) notes that this is also true for lakes, so that the onshore–offshore signals are roughly equal.

Koreneva (1971) claimed that high percentages (5–20%) of desert herbs/small shrubs (*Artemisia*, Chenopodiaceae, Compositae, Gramineae and *Ephedra*) characterize the sites bordering steppe and desert regions in the eastern Mediterranean. However, her data are variable and our results show that similar assemblages are also found in parts of the Marmara and Black seas. Very high amounts of Gramineae (50%), absence of *Abies* and warm temperate trees are the signals that clearly distinguish between the spectra of the desert and steppe regions.

The problem of over-representation of *Picea* in the Mediterranean is noteworthy and requires further study to resolve entirely. It is interesting, however, that the Black Sea aerosol samples of Komarov (1989) included *Picea orientalis* as part of the Crimean–Northern Caucasus and euxinian assemblages, thereby pointing to the importance of transport in northerly winds. *Picea abies* pollen is present in Greek lakes (Van Zeist and Bottema, 1982) and the Danube Delta (Roman, 1974), but not in lakes of the Turkish mountains; therefore, runoff from southern Europe may also be important. *Pterocarya* and *Cedrus* appear to be over-represented in both the marine core B-7 and lake sediments of the Black Sea region because these trees are presently rare in northern Anatolia and it is uncertain if they have been widespread at any time during the late Quaternary (Bottema et al., 1995). *Betula* also appears to be over-represented in the late Holocene marine sediments of the Marmara and Black seas because it is presently rare in western Anatolia and in modern lake sediments. This pollen type is not normally transported very far by wind and its prevalence in modern marine sediments seems to mark high runoff from western Europe. During the Late Glacial and early Holocene, however, *Betula* is common in Anatolian lake sediments, indicating that its distribution expanded westwards (Bottema et al., 1995) and accounting for the high values in PZ-2.

5.2. Comparison of marine and regional palynostratigraphies

Despite the above-mentioned problems of over- and under-representation, the downcore distributions of the marine pollen assemblages (Fig. 10) show major changes in indicator species that are clearly correlated with the generalized pollen zones established for lakes of northern Turkey for the past 14 ka (Table 2). In addition, the marine cores extend the high-resolution regional stratigraphy through most of the Late Glacial and the late Würm Pleniglacial to ~33 ka.

The vegetation and climatic interpretations of the main lake pollen zones found in ^{14}C-dated cores from the eastern Mediterranean are shown in Table 2. For direct onshore–offshore correlation with our marine cores, the most important onshore sites are those on the north slopes of the Pontic range. Here, lake sequences from Abant and Yeniçaga near the Sakarya River provide a ~14 000-year reference section for the western Black Sea, while Kaz and Ladik provide comparable sections for the eastern Black Sea (Beug, 1967; Bottema et al., 1995; Bottema, 1995). Five other cores from this northern region are undated but they provide detailed information (Bottema et al., 1995) covering the post-clearance phase (past ~4000 years). Published data are available for only one core site adjacent to the Marmara Sea, at Yenişehir (Bottema, 1995), southeast of core MAR97-11. This core has no radiocarbon dates but correlation of pollen zones with the Yeniçaga site shows that it is of late glacial to mid-Holocene age.

There are no ^{14}C-dated LGM (~21–17 ka) or Pleniglacial (~60–22 ka) lake palynostratigraphies for the Marmara, western Black Sea and south Anatolia regions (Table 2). The only onshore cores with data for comparison of the Pleniglacial and LGM intervals are far removed from the study area, e.g. at Lake Zeribar, western Iran, and at Tenaghi Philippon in Greece. In a previous palynological review, Van Zeist and Bottema (1982) concluded that dry steppe conditions prevailed during the LGM from ~24 to 14 ka, following a period (in the Levant) of moister open forest conditions from ~30 to 24 ka. In contrast,

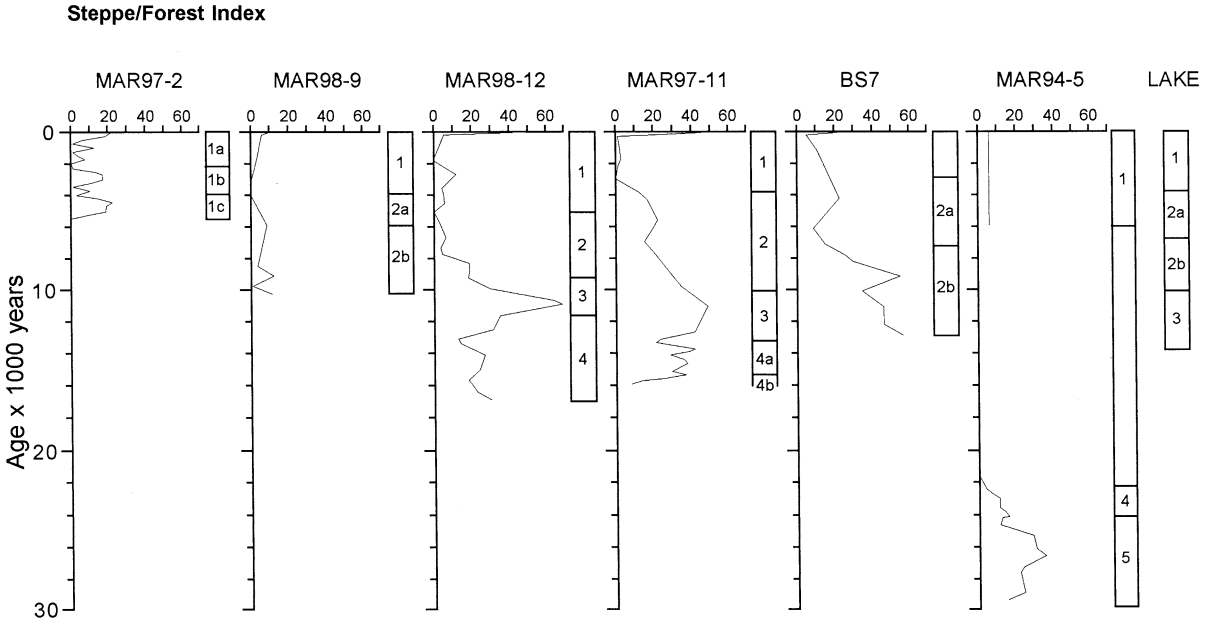

Fig. 10. Variations in the steppe–forest index (SFI), indicating changes in aridity with time and the correlation with marine and lake pollen zones described in the text.

Farrand (1971) studied the palynological, mammal and lake level records of the Mediterranean maritime littoral region for the past 70 ka and concluded that all evidence pointed towards a climate that was colder (5–7°C) and wetter than now. This interpretation agrees with data showing that lake levels in central Anatolia were higher than now, with the large pluvial lake Konya occurring on the plateau (Roberts, 1983; Erinç, 1978). Overall, the combined lake, timber line and archeological data indicate a temperature decrease of 4–5°C, slightly higher precipitation and longer duration of snowfall (Erinç, 1978).

The Black Sea–Marmara regional vegetation history broadly shows the following features that can be correlated with the marine cores.

(i) Late Pleniglacial assemblage zone

The PZ-5 marine pollen zone in MAR94-05 and MAR98-04 (see Aksu et al., 2002) extends from ~33 to 24 ka. During this time, there is a relatively low amount of *Pinus* (~20%) and both *Quercus cerrus*-type and *Artemisia* pollen are common. Moderately low AP values (50–60%) suggest steppe–forest vegetation although the NAP does not exceed 50%. However, the pollen of deciduous *Quercus* trees, the presence of *Fagus*, *Alnus*, *Pistacia* and common Cyperaceae point to relatively warm, wet conditions, perhaps like the present oro-Mediterranean forest which requires winter precipitation of > 600 mm. The very high pollen concentrations (today matched only in the upper Holocene sediments of the Black Sea) also indicate a dense vegetation cover surrounding a lake-like sea.

These marine assemblages are most similar to those described for Huleh in the southern Levant where open forest was present from > 29 to 24 ka, followed by an increase of *Artemisia* and Chenopodiaceae (Van Zeist and Bottema, 1982). In the Dead Sea region, the upper Würm was also a wet pluvial interval according to Farrand (1971). We therefore interpret both the Pleniglacial marine assemblages and the Near East lake assemblages as indicating relatively moist open forest conditions from ~30 to 24 ka.

(ii) LGM and Late Glacial assemblage zones

The marine pollen subzone PZ-4b covers the LGM interval from ~24 to 14 ka and shows a predominance of conifer tree pollen (~60%), with variable percentages of *Artemisia*, Chenopodiaceae and Compositae suggesting fluctuating moister and drier conditions. A rise in Cyperaceae pollen in MAR97-11 also indicates presence of freshwater marshland. The increase of *Pinus* and presence of *Betula* and *Alnus*, despite the decrease of *Quercus* and other deciduous hardwood trees, show that although temperatures were lower than in the Pleniglacial, precipitation was still sufficient (600 mm/yr) to support forest at lower altitudes. The presence of *Pistacia* also suggests a minimum of 5°C in winter. The combined pollen indicators suggest that conditions were moister and warmer in winter than during the Late Glacial–Interglacial transition, with pollen assemblages similar to those marking the Pleniglacial–Late Glacial mountain forest–steppe vegetation at Ioannina and Tenaghi Philippon.

The Late Glacial assemblages in PZ-4a and PZ-3 of MAR97-11 and MAR98-12 occur in the interval from ~15 to 10 ka. In PZ-4a, from ~15 to 13 ka, *Pinus* decreases and herb pollen increase, with *Artemisia*, Chenopodiaceae and Compositae as dominants, together with common Caryophyllaceae and Gramineae. These PZ-4a assemblages suggest much colder, drier steppe–forest conditions prevailed, possibly with trees being confined to the watercourses. Cyperaceae pollen indicate local presence of freshwater marshland. In zone PZ-3 from ~13 to 10 ka, pollen influxes increase by a factor of ~2 and large peaks of *Artemisia* (30%), *Ephedra* and herb pollen mark the Younger Dryas event at the top of this cold dry interval.

The corresponding Turkish lake zone 1, ~14–

Table 2

Pollen zones from lakes shown in Fig. 1, with inferred vegetation and climate changes in the eastern Mediterranean and Near East (from Van Zeist and Bottema, 1982; Rossignol-Strick, 1995, Bottema et al., 1995)

Age	I - III Greece (Ioannina, Philippon)	IV - VI Northwest Turkey (Yeniçaga, Abant)	VII, VIII Northeast Turkey (Van,Ladik)	X - XII SouthernTurkey (Sogut,Beysehir)	XIII NW Syria	Western Iran (Zeribar)
0 2000 4000 6000 8000 10,000 12,000 14,000 16,000 18,000 20,000	Increased human disturbance & decline of AP, possibly also drier	**Pollen Zone 3** Increased *Pinus*, retreat of *Betula-Abies* forest. Drier or man-made changes: high % Ericaceae shows forest clearing	**Pollen zones 7 & 8** AP decline, mostly *Quercus*; NAP increase reflects human activity, not dryness **Pollen zone 6** *Quercus* maximum Humidity as today	Man-altered *Pinus* forest Humidity reaches modern levels	Forest vegetation decreases from Man's activity *Juglans, Olea* and *Vitis* maxima	Pollen zone 7 Zagros *Quercus* forest, humidity as today
	Pinus-Quercus forest	Increase in *Pinus*, *Fagus*	**Pollen zone 4 and 5** AP gradually increases, replacing desert steppe humidity increase, probably more precipitation	*Cedrus* gives way to *Pinus* Increased humidity present day vegetation pattern is established	Forest maximum Humidity maximum	Zone 6 *Quercus* expands, P-E increase
	Quercus expansion, *Pistacia* maximum	Pollen Zone 2 Stable *Quercus-Pinus*-deciduous forest	**Pollen zone 1 to 3** Dryness prevented the expansion of trees Zone 2 *Ephedra* desert-steppe extremely arid	Increased AP, *Quercus-Juniperus* forest with *Cedrus* replace steppe vegetation Increased humidity	Forest with *Quercus, Pistacia Olea* and *Ostrya/Carpinus*	Pollen zone 5 Slow increase in AP, NAP high *Quercus-Pistacia* forest-steppe Relatively warm and dry, low P-E still limiting tree growth
	Increase in *Quercus, Tilia Ostrya-Carpinus, Ulmus*	Lower NAP, *Quercus-Juniperus* open forest		Herbaceous pollen dominate before 9180 BP, but no date is available prior to that age	High NAP coinciding with the Late-glacial European Würm-glacial Chronology Temperature did not limit tree growth Low P-E and extremely dry ↓ ~25,000 yrs BP	Pollen zone 4 Slight increase in AP Warmer but aridity is still limiting for trees
	Artemisia & Chenopodiaceae maximum	**Pollen Zone 1** NAP 80%, with *Artemisia*, Chenopodiaceae				Pollen zone 3 Steppe and desert-steppe vegetation. Almost no AP Climate colder and much drier than now ↓ 35,000 yrs BP
	Pinus-Betula-Juniperus woodland	*Pinus-Juniperus-Abies* open forest				
	AP <20%, *Artemisia* & *Chenopodium* dominate Steppe vegetation, *Quercus* and *Pinus* in areas with higher rainfall Colder and drier than now ↓ ~26,000 yrs BP	Compositae maximum, 25% *Pinus+Betula*				
		Pinus-Juniperus-Abies open forest				
		Maximum *Artemisia*-Chenopodiaceae				

10 ka, shows a dominance of either *Artemisia* or Chenopodiaceae and Compositae which mark wetter and drier steppe grassland, respectively. These steppe plants were interspersed with woodland in edaphically favorable areas, as indicated by about 25% *Pinus* pollen, initially together with *Betula*, *Juniper* and rare *Ostrya*, followed by a warmer interval with *Quercus*-*Pinus*-*Juniperus* forest, including *Abies*, *Betula* and rare hardwoods, then a maximum of *Artemisia* (up to 80%) and Chenopodiaceae from ~11 to 10.2 ka. This Late Glacial interval and its subphases are correlated with the European Older Dryas, Alleröd–Bölling and Younger Dryas events, respectively (Bottema et al., 1995); these authors also interpreted the climate as prevailingly cold and dry, with maximum dryness during the Older Dryas and with warmer, wetter conditions during the Alleröd–Bölling event.

Although the sequences in the marine cores are more compressed than in the lakes, the same succession of events is evident as two peaks of *Artemisia*, centered at ~14 ka and 10.66 ka, which are bracketed by intervals of high Chenopodiaceae or, during the Older Dryas, by high percentage Compositae pollen, and presence of *Ephedra*. Cold-tolerant conifers, *Pinus*, *Cedrus* and *Picea* (MAR98-12) or *Abies* (MAR97-11) are the main arboreal species, with small peaks of *Quercus*, *Alnus*, *Salix* and *Betula* (core 97-11 only) corresponding to the Alleröd–Bölling event. The only conspicuous difference between the onshore and marine Late Glacial assemblages is the presence of *Picea* in the northeastern Marmara cores, which may reflect a greater pollen influx from the southern European mountains to Marmara Sea.

(iii) Early Postglacial assemblage zones

Pollen zone 2 in the regional lakes spans the interval from ~10 200 to 3980 yr BP and is generally marked by a decrease of NAP to <40% because of the decline of *Artemisia* and Chenopodiaceae and corresponding rise in AP (Bottema et al., 1995). From ~9.88 to 8.7 ka, deciduous *Quercus*, *Juniperus* and *Betula*, *Ulmus*, *Acer* and *Tilia* form an open forest, with *Fagus* increasing towards the top of the zone. This early postglacial interval (10–7 ka) is interpreted as a time of rapid reforestation when pioneer *Betula* forests are replaced by *Acer*, followed by *Quercus* and *Abies*, and later by *Fagus*. *Pistacia* also shows a peak in this interval. The establishment of these oro-Mediterranean and mesic euxinic forests indicates that temperature and summer precipitation increased rapidly after ~10 ka on the north slopes of the Anatolian mountains, although these changes only occurred 2000–4000 years later in the northern Black Sea (see Kremenetski, 1995) and at Lake Zeribar in western Iran (see Table 2). From 7 to ~4 ka, this forest cover persists in a quasi-stable condition, with the main change being the dominance of *Pinus* over hardwoods. It is also notable that this long (6500-yr) interval does not show subzones corresponding to the European Preboreal, Boreal and Atlantic intervals (Bottema et al., 1995).

In the marine cores, zone PZ-2 (~10–4 ka) shows a similar sequence of initial afforestation by deciduous *Quercus* and *Pistacia* in PZ-2b, followed by other hardwoods, particularly the rise of the moisture-demanding tree, *Fagus* in PZ-2a. There is a clear correspondence with the early Holocene succession of *Quercus* and *Pistacia* peaks in lakes of the eastern Mediterranean (Rossignol-Strick, 1995), and most of the marine radiocarbon ages are synchronous with age assignment of 10–9 and 9–6 ka for these markers. The only notable differences from the lake sequence are the relatively low representation of *Pinus* (<20%) in the Marmara cores and the persistence of relatively high percentage *Artemisia* in the eastern Black Sea core. The absence of a detailed onshore reference section near the Marmara Sea makes it difficult to interpret the relatively low *Pinus* values at this time. However, the simplest explanation would be that warmer winters and wetter summers along the slopes below the lake sites (i.e. <500 m) favored the hardwoods (see Rossignol-Strick for limiting conditions of *Pinus* vs. *Quercus*). In the eastern Black Sea, the higher *Artemisia* and Chenopodiaceae values in PZ-2b presumably reflect long-distance transport in rivers draining the retreating Siberian ice sheet and the colder eastern Anatolian mountains, e.g. around Lake Van. Wind-borne influx from the dry Hungarian loess fields may also have contributed to the relatively high NAP values, but modern aerosol data (Komarov, 1989) show that wind only contributes a small fraction of the total pollen influx to the Black Sea. The anomalous presence of these steppe indicators within normal warm temperate–subtropical forest assemblages strongly suggests that year-round rainfall and fluvial transport to the Black Sea was high (>800 mm) during most of this time, despite the aridity of the Hungarian Plains to the northwest of the region (cf. Ryan et al., 1997).

(iv) Late Postglacial–recent assemblage zones

The regional lake pollen zone 3 spans the time interval of ~3880 to present. The lake assemblages record the onset of more unstable forest composition, with an initial increase in *Pinus* to ~45% and disappearance of *Tilia* and *Ulmus*. There is also a notable rise in Gramineae (especially the Cerealia subgroup), and in pollen of the weeds *Plantago* and Compositae which mark the start of human occupation on the northern Anatolian slopes. During the Beyşehir (Greco-Roman) Occupation phase from ~2990 to 1300 yr BP, *Quercus* and *Fagus* expanded and *Juglans* appeared, probably as a result of cultivation for food on the lower slopes (at present, *Olea* does not grow at the altitude of the lakes according to Bottema et al., 1995). After 1300 yr BP, there was some recovery of deciduous forest vegetation, accompanied by a rise in spores of the *Pteridium* fern, which today dominates the forest undergrowth. There is also a recent rise in NAP (primarily Compositae, but including *Artemisia* and Chenopodiaceae in the more eastern regions), and *Olea* and *Juglans* are consistently present.

The marine zone PZ-1 corresponds closely to the upper Holocene assemblages of zone 3 in the Abant and Yeniçaga sites in northwestern Anatolia (Beug, 1967; Van Zeist and Bottema, 1982; Bottema et al., 1995) which have an estimated radiocarbon age of less than 4000 yr BP. In PZ-2, forest clearance is manifest as a ~10-fold decrease in pollen-spore concentrations beginning at 2800 yr BP, and there is a selective reduction of conifers (*Pinus*, *Abies*, *Cedrus*) over the more useful *Quercus*. *Tilia* and *Ulmus* disappear, as at all European Neolithic sites, but the edible *Olea* and *Juglans* remain, and the Gramineae and Compositae become common (Fig. 6). The last two taxa include large Cerealia-type grains and increases in *Taraxacum*-type (dandelion) weed pollen, respectively.

Comparison of the records in MAR97-2 and zone 3 in the lakes shows that even small-scale cultural changes are recorded in high-sedimentation marine cores of the inland eastern Mediterranean seas, and it establishes that the radiocarbon ages for the youngest marine sediments are reliable. For example, the appearance of *Olea* also agrees with an age of ~1500–2000 yr BP when olive cultivation reached a peak in the western Mediterranean (Sheehan, 1979) and the continuous presence of *Juglans* (walnut) and *Olea* (olive) coincides with the establishment of orchards during the Byzantine era. We note here that the corresponding rise in *Alnus* pollen may also mark the start of forest clearance of the Black Sea slope.

5.3. Late Glacial radiocarbon ages

Precise correlation between marine zones PZ-4a, PZ-3 and the Late Glacial zone 1 in northern Turkish lakes is hampered by differences in the pollen zone age assignments of previous workers. Bottema et al. (1995) describe an *Artemisia*-Chenopodiaceae maximum in the Turkish lake zone 1a from ~14 to 12.3 ka, followed by an increase in AP with 25% *Pinus* and *Betula* corresponding to the Alleröd warm oscillation (zone 1b), then a second *Artemisia*-Chenopodiaceae peak (zone 1c) marking the Younger Dryas event between 12.3 and 10.2 ka. An almost identical sequence of events is present in MAR98-12 and MAR97-11, with the Late Glacial Older Dryas event occurring at ~13 ka and the Younger Dryas event having shell ages of 10.6 and 10.8 ka. According to Rossignol-Strick (1995), however, the first Chenopodiaceae maximum in lakes marks the Younger Dryas chronozone based on her correlation with the oxygen isotopic record in marine cores. If this interpretation is correct, it means that both the marine and lake shell ages in our study area are too old by several thousand years. The close agreement between the radiocarbon ages from the marine and lake depositional environments, however, makes it more likely that these concordant shell ages are valid for the northern Near East.

5.4. Paleoclimate reconstruction

Fig. 10 shows the chronostratigraphic succession of vegetation zones interpreted from the marine and lake palynozones and the changes in wetness and dryness provided by the steppe–forest index (SFI) of Traverse (1988; Traverse in Ross, 1975). This index is based on fluctuations in abundance of *Artemisia*, Chenopodiaceae and Amanthaceae pollen relative to AP. For DSDP Site 380-380A in the Black Sea, Traverse (1988) showed SFI ranges of 20–60% for the surface sediment and past interglacials, compared to 60–80% for conditions during the glacial oxygen isotopic stages 5a and 12 which he interpreted as extremely cold and dry periods.

The SFI indices for our higher-resolution records show that the late Pleniglacial has relatively low values of ~30%, which is in accord with our interpretation of open forest conditions as found in the Levant. The early LGM interval (PZ-4b) also has low SFI values of ~20%, increasing to 30–40% in PZ-4a. These low values are also consistent with our interpretation of the LGM assemblages indicating slightly warmer and much wetter montane forest conditions than during the Younger Dryas event, with the climate being like that presently found at high elevations in NW Greece.

In contrast, PZ-3 shows very large fluctuations in SFI from ~30 to 80%, with peaks of 60–80% marking the Younger Dryas event and supporting our interpretation of steppe–forest conditions with < 600 mm/yr. Most of the Holocene has SFI values of < 30%, except for one anomalous spike of 60% at about 9 ka in the Black Sea. These low Holocene values agree with our interpretation of mesic forest vegetation requiring more than about 800 mm/yr and winter temperatures of > 7°C. During the early Holocene *Pistacia* maximum, winter temperatures were 5–10°C.

Overall, it is very clear that climate conditions represented in our cores were never as severe as those recorded in the Black Sea during glacial isotopic stages 5a and 12. These low SFI values suggesting relatively warm, moist conditions for the LGM are in apparent conflict with previous interpretations of *Artemisia*–Chenopodiaceae steppe vegetation indicating cold dry conditions (Farrand, 1971; Van Zeist and Bottema, 1982). More recently, however, Prentice et al. (1992) tried to resolve the disparity between high Pleniglacial–LGM lake levels and the widespread occurrence of *Artemisia* steppe vegetation. A water balance model was proposed for Lake Ioannina in which winter temperatures were lower by ~6 ka but precipitation was not much different, so that winter runoff from saturated soils actually increased. This model is partly compatible with our late Pleniglacial data indicating oro-Mediterranean forest with deciduous trees that tolerate temperatures as low as −2°C in winter, but requiring P–E > 600 mm. The purported increase in westerly advection of air masses from the cold North Atlantic would also explain the presence of *Picea* pollen in the Marmara cores during the LGM. The *Picea* pollen must have been wind-transported from the European mountains because the Marmara Sea was isolated from the Black and Aegean seas at this time and *Picea* became extinct in Turkey early in the Quaternary. However, the summer rainfall requirement of deciduous trees is not satisfied by the Prentice model which proposes that the jet stream shifted south in winter but remained north of the Mediterranean in summer.

Despite the uncertainty regarding the nature and causes of changes in P–E during the Late Glacial in the eastern Mediterranean, the lake and marine palynological data both indicate that temperate deciduous forests requiring year-round rainfall of > 600 mm occupied the slopes of the Marmara and Black seas by 9 ka. Furthermore, the modern mesic forest requiring 700–2400 mm/yr was in place by 7 ka. This evidence for relatively warm, wet conditions in the region after 10 ka clearly contradicts the idea of Ryan et al. (1997) that cold dry conditions persisted in the early Holocene and sustained 150 m lower water levels in the Black Sea that allowed settlement of the shores by Neolithic farmers.

5.5. Archeological implications

Pollen assemblages from cores in small semi-enclosed seas reflect regional vegetation and land-use signals (see Traverse, 1988). In addition, large-scale changes in shoreline vegetation are evident. Because of their large size, the shoreline signals for the Black and Marmara seas are amplified relative to those of the smaller Anatolian mountain lakes. In all our marine cores, PZ-1 clearly shows palynological evidence of human occupation commencing after 4000 yr BP, which is strictly in accord with the archeological evidence for the earliest occupation of Troy and the southern Black Sea shores (Bottema et al., 1995). In contrast to the opinion of Ryan et al. (1997), there is no evidence for agricultural occupation of the Black Sea shores prior to this time. Nor do our cores show a large spike in pollen concentration at ~7000 yr BP when Ryan et al. (1997) postulate that the Mediterranean Sea flooded the Black Sea. The magnitude of this flood event, if real, would be manifest as a huge spike of Gramineae, Cyperaceae and Compositae pollen washed from the flooded savannah land and focussed into the deep basins.

In actual fact, the evidence for dense mesic forestland on the southern slopes of the Black and Marmara seas throughout the early Holocene clearly explains why the region was not suitable for agriculture and grazing (wool was an important commodity in Troy, ~3000 yr BP; see Barber, 1991). Prior to development of metal tools during the Bronze and Iron ages, this forested region was not suitable for the agricultural and pastoral practices that originated in the arid regions of southern and eastern Anatolia. The regional climate was too wet for grain crops, grassland was sparse and the land was good only for harvesting fruit trees and possibly, gathering salt, as suggested by abundant Chenopodiaceae pollen prior to ~7 ka.

6. Conclusions

(1) Pollen-spore data from published and new core-top samples in the Mediterranean–Aegean–Black Sea corridor establish meaningful regional proxy data signals for vegetation, and hence, climate changes. Concentrations show three orders of magnitude decrease with distance away from areas of highest river discharge. Changes in pollen composition mainly reflect proximity to regional vegetation zones: high Chenopodiaceae, Gramineae and *Ephedra* mark Mediterranean deserts; pollen of *Abies*, *Betula* and *Alnus* mark European and montane regions; mesic forests are dominated by *Pinus*, deciduous oaks and other hardwoods; eu- and oro-Mediterranean forests have more *Pinus*, *Cedrus*, evergreen oak and *Pistacia*.

(2) High-resolution studies (decadal to millennial scale) of pollen-spore assemblages in six cores from the Marmara and Black seas show the presence of five marine pollen zones with multiple ^{14}C ages establishing the following chronology: PZ-5 with a more extensive steppe–woodland forest vegetation including cold-tolerant and a few temperate hardwoods forming oro-Mediterranean forest on the lower slopes and *Artemisia* steppe–forest at higher elevations from 33.6 to ~24 ka; PZ-4b with steppe–forests including *Pinus*, *Cedrus* and *Quercus* marking the LGM from ~24 to 15 ka; PZ-3 *Artemisia* maximum marking the Younger Dryas event at ~10.6 ka; PZ-2b oak expansion and *Pistacia* maximum from ~10 to 7 ka; PZ-2a stable mesic forest phase from ~7 to 4 ka; and PZ-1 Late Holocene settlement phase (farms with *Olea*, *Juglans* and Papaveraceae) from 4000 to 0 yr BP.

(3) The marine zones are well correlated chronostratigraphically with dated pollen zones for Late Glacial–late Holocene zones in Northern Anatolian lakes so that a paleoclimatic history can be reconstructed from known requirements of vegetation marker species. This reveals a late LGM interval of relatively warm summers and cold, wet winters, a brief cold, dry Younger Dryas event, an early Holocene with >800 mm and winters >~7°C until ~7 ka, by which time modern mesic euxinian-type forest were fully established. Reconstructions of changes in P–E are also evaluated from the SFI of Traverse, which covers the entire Pleistocene, and allow interpretation of the new regional early LGM and the Late Pleniglacial pollen zones. Low SFI values

similar to the Holocene (< 40%) indicate relatively warm, moist conditions on the lower mountain slopes, and generally support water balance models and lake level estimates of P–E, but require that some moisture was available in summer.

(4) All the marine cores clearly show evidence of human occupation commencing after 4000 yr BP, in accord with archeological evidence for the earliest occupation of the southern shores. There is no evidence for major deforestation or agricultural occupation of the Black Sea shores prior to this time when dense mesic forestland would make the region unsuitable for agriculture prior to development of metal tools for land clearing.

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Appendix 1. Locations and references to core sites in Figs. 1 and 2

Map No.	Sample	Locality	Latitude (°N)	Longitude (°E)	Depth (m)	Reference
#1	GC 22	Cretan Trough	35.8	26.8	1050	This paper
#2	GB 13	S Aegean Sea	36.1	27.1	500	
#3	GB 5		37.4	26.2	510	
#4	GS 20	Central Aegean Sea	38.5	24.5	700	
#5	KS 19	N Aegean Sea	39.1	24.9	570	
#6	KC 3	NE Aegean Sea	40.2	24.9	560	
#7	K1065	NW Aegean Sea	39.2	24.0	1520	Koreneva, 1971
#8	M97-2	W Marmara Sea	40.9	27.6	1080	This paper
#9	K1069		40.9	28.0	1160	Koreneva, 1971
#10	M98-12		40.8	27.8	549	This paper
#11	M94-5	Central Marmara Sea	40.9	28.1	1008	
#12	M97-11	SE Marmara Sea	40.7	28.4	111	
#13	M98-9	E Marmara Sea	40.9	28.9	64	
#14	M98-4	SW Black Sea	41.5	29.3	112	
#15	K1474	W Black Sea	42.2	37.8	2117	Traverse, 1974
#16	K1461		43.0	30.0	1990	Roman, 1974
#17	K 61	NW Black Sea	44.5	29.0	200	
#18	BS-7	SE Black Sea	42.5	37.0	2120	This paper
#19	BS-13		42.0	37.9	2050	
#20	K400	E Mediterranean Sea	35.5	30.0	2500	Koreneva, 1971
#21	K4779		35.5	35.5	3090	
#I		Tenaghi Philippon				Rossignol-Strick, 1995
#II		Xinius				Van Zeist and Bottema, 1982

Appendix 1 (*Continued*).

Map No.	Sample	Locality	Latitude (°N)	Longitude (°E)	Depth (m)	Reference
#III		Ioannina				Rossignol-Strick, 1995
#IV		Yenişehir				Beug, 1967
#V		Abant				Bottema et al., 1995
#VI		Yeniçaga				Bottema et al., 1995
#VII		Ladik				Van Zeist and Bottema, 1982
#VIII		Van				Van Zeist and Bottema, 1982
#IX		W Ukraine				Kremenetski, 1995
#X		Sogut				Van Zeist and Bottema, 1982
#XI		Beyşehir				Van Zeist and Bottema, 1982
#XII		Konya				Van Zeist and Bottema, 1982
#XIII		Ghab				Van Zeist and Bottema, 1982

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