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Pollen, plant macrofossil and charcoal records for palaeovegetation reconstruction in the Mediterranean-Black Sea Corridor since the Last Glacial Maximum

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Abstract

New reconstructions of changing vegetation patterns in the Mediterranean-Black Sea Corridor since the Last Glacial Maximum are being produced by an improved biomisation scheme that uses both pollen and plant macrofossil data, in conjunction. Changes in fire regimes over the same interval will also be reconstructed using both microscopic and macroscopic charcoal remains. These reconstructions will allow a diagnosis of the interactions between climate, fire and vegetation on millennial timescales, and will also help to clarify the role of coastline and other geomorphic changes, salinity and impacts of human activities in this region. These new data sets are being produced as a result of collaboration between the Palynology Working Group (WG-2) within the IGCP-521 project and the international Palaeovegetation Mapping Project (BIOME 6000). The main objective of this paper is to present the goals of this cooperation, methodology, including limitations and planned improvements, and to show the initial results of some applications.

1. Introduction

The UNESCO-sponsored IGCP-521 program (Yanko-Hombach et al., 2005, 2007) is bringing diverse research groups together to provide cross-disciplinary and cross-regional correlation of geological, geophysical, oceanographic, biological and anthropological aspects of the Mediterranean-Black Sea Corridor. An important component of this work is the reconstruction of changing vegetation patterns over the past 30,000 yr BP, and this is the focus of the Palynology Working Group (WG-2) of the IGCP-521 program. Details of the WG2 mandate are shown at http://www.bridge.bris.ac.uk/projects/EMBSecBIO.

Changes in vegetation patterns over millennial timescales are primarily determined by changes in climate (Bartlein et al., 1986; Webb, 1986; Jackson and Overpeck, 2000; Davis and Shaw, 2001; Webb et al., 2003). However, climate changes also induce changes in disturbance regimes and most importantly in fire regimes (see e.g. Siegert et al., 2001; Girardin et al., 2004; Pausas, 2004; Flannigan et al., 2005; Thonicke et al., 2005) that themselves exert a profound influence on the vegetation. Furthermore, in areas with a long history of occupation, humans can modify the vegetation directly and through changing the disturbance regime (Berglund, 1991; Edwards and MacDonald, 1991; Redman, 1999; Ramrath et al., 2000). The use of fire as a method of land clearing, the harvesting of timber for building and/or fuel, and the introduction of agriculture therefore can have profound effects on the landscape and natural vegetation cover. Finally, the region

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around the Black Sea and Caspian Sea has to be considered as a geomorphically active area, given the large changes that have occurred in the extent of these water bodies, and the geomorphic and salinity adjustments that have occurred in response to these changes (Varushchenko et al., 1987; Kazanci et al., 2004; Chepalyga, 2006; Leroy et al., 2006; Major et al., 2006; Yanko-Hombach, 2005; Yanko-Hombach et al., 2007). These changes will also affect vegetation patterns, through their influence on the location of refugia during climate extremes and on migration pathways as vegetation responds to climate changes (see e.g. Caner and Algan, 2002; Cordova, 2007; Krebs et al., 2004; Leroy and Arpe, accepted for publication). To understand these complex influences on the regional vegetation, it is important to reconstruct changes in both vegetation and fire regime, and to explore the interaction between climate, vegetation and fire through the application of models and extensive comparisons of observed and simulated patterns of vegetation change.

This paper presents an overview of the data sources and methodology that have been selected to reconstruct changing vegetation and fire regimes in the Mediterranean-Black Sea Corridor, and discusses some potential problems and limitations of the approach that have arisen during the initial studies. The somewhat limited definition of this region as adopted by the IGCP 521 program in general has been expanded to include the regions around the Caspian and Aral Seas, the Levant, Mesopotamia, the Zagros and Elburs (= Alborz or Elburz) Mountains, and the Iranian Plateau (here referred to as the WG-2 region; Fig. 1). The inclusion of the Near East in this synthesis is expected to throw some light regarding the diffusion of agriculture into the Mediterranean-Black Sea Corridor. It is also important to consider this larger region in order to encompass potential refugia for natural vegetation.

2. Background

2.1. Modern climate and vegetation in the Mediterranean-Black Sea Corridor

The study region (Fig. 1), as defined by WG-2, extends over some 16° of latitude (from 33° to 49°N, ca 1780 km) and 40° of longitude from Greece eastward to Uzbekistan and Kazakhstan (from 20° to 60°E, ca 4440 km). This area is topographically diverse, including inland lake basins such as that of the Caspian Sea (ca −27 m a.s.l.), extensive lowland steppes, and the rugged ranges of the Caucasus (highest elevations >5000 m), Pontic (highest elevations >4000 m) and Carpathian (highest elevations >2500 m) Mountains. The region encompasses the transitions from Mediterranean climates northwards into mid-latitude temperate climates and eastwards into mid-continental arid climates. Thus, the Balkans, western Anatolia and the coastal region of Syria, Lebanon and Israel are characterized by winter rains and summer drought, and the natural vegetation is a mixture of warm-temperate broadleaf evergreen or open conifer woodlands and forests. In the mountains of the Balkans, western Carpathians, western Caucasus and northern Turkey, precipitation occurs throughout the year and the natural vegetation consists of dense forests of temperate broadleaf or conifer trees. Steppe vegetation occurs in the semi-arid continental regions of southern Ukraine, Russia and in central Asia. Steppe grasslands also occur in mountain regions of central

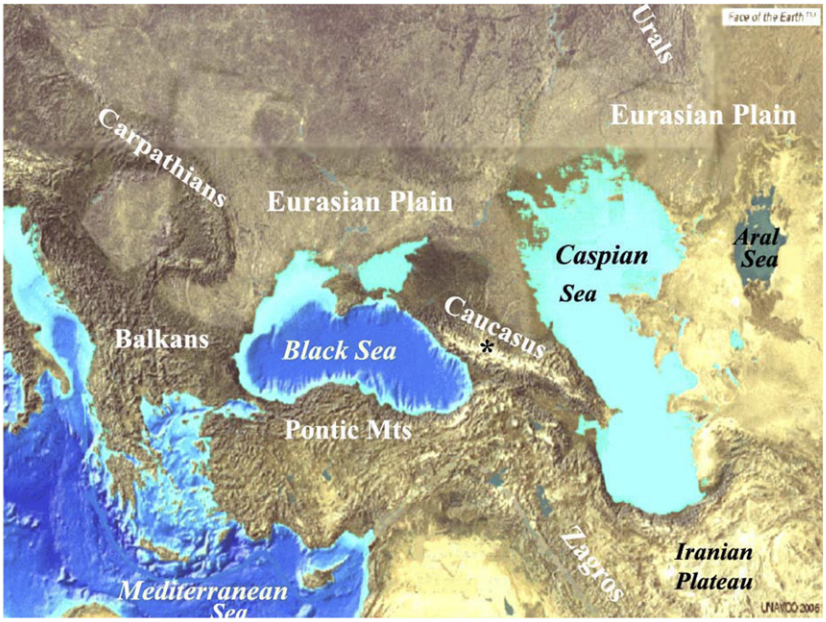

Fig. 1. Map of the study region, showing locations and relative sizes of the inland seas and the large variation in topography. Note that the Caspian Sea appears to be about two times larger than its modern size because the photo shows the area below sea level, not just the water surface area at 27 m b.s.l. *Elburs (= Alborz) Mountains.

Anatolia, and on the eastern side of the Syrian and Lebanese Mountains due to orographic effects. The combined effects of orographic rain shadow and continentality result in steppe and desert vegetation in Mesopotamia, the Iranian Plateau and Transcaucasia.

2.2. The regional context of Late Quaternary vegetation change in the Mediterranean-Black Sea Corridor

There are a large number of records documenting vegetation changes through time at individual sites within the study region (see summaries presented by e.g. Bottema et al., 1993; Roberts and Wright, 1993; Cordova and Lehman, 2005). There have also been attempts to use marine cores from the Black and Marmara Seas for reconstruction of vegetation changes (Atanassova and Stefanova, 2005; Caner and Algan, 2002; Filipova-Marinova, 2003; Mudie et al., 2002, 2007). Grichuk (1984) and Velichko et al. (1997) have produced palaeovegetation maps for key times in the Late Quaternary, but few of the available pollen and plant macrofossil records used in these syntheses were derived from the WG-2 study region. However, Van Zeist and Bottema (1991) created maps of the vegetation patterns at 18, 12 and 5 ka BP for the region comprising Turkey, The Levant and NW Iran. These reconstructions were based on a subjective interpretation of pollen records from the region and inferences based on distribution of modern vegetation, soils, topography and climate. More recently, Simakova (2006) has presented vegetation maps for the later Pleistocene, based on the use of indicator plant types, which encompass the western part of the study region and extend to the Black Sea.

The Mediterranean-Black Sea Corridor region was mapped as part of the Palaeovegetation Mapping Project (BIOME 6000: Prentice et al., 1996, 2000). This project developed a globally applicable method of reconstructing vegetation patterns through time using an objective methodology known as biomisation, which relies on the assignment of pollen taxa to plant functional types (PFTs) and the definition of major vegetation types (biomes) as assemblages of PFTs. This approach was applied on a region by region basis to produce maps of vegetation patterns at the Last Glacial Maximum (ca 21,000 ± 1000 yr BP) and the Mid-Holocene (ca 6000 ± 500 yr BP). The Mediterranean-Black Sea Corridor region was not treated as a single unit within the BIOME 6000 project; rather, parts of this region are dealt with as part of the Europe (Prentice et al., 1996; Elenga et al., 2000), Africa and the Middle East (Jolly et al., 1998; Elenga et al., 2000) and the Former Soviet Union (Tarasov et al., 1998, 2000) regions.

The Mediterranean-Black Sea Corridor is a complex region, where the influence of changes in climate is modulated by changes in the extent of the Black and Caspian Seas, and by human exploitation. A relatively high density of sites is required to document changes in vegetation cover in sufficient detail to be able to separate these different influences. There have been many new pollen studies carried out in this region since the BIOME 6000 compilation was completed (e.g. Vermoere et al., 2001; Filipova-Marinova, 2003; Wick et al., 2003; Atanassova and Stefanova, 2005; Filipova-Marinova and Atanassova, 2006; Leroy et al., 2006). The new working group (WG-2) that has been created as part of the IGCP-521 (*Black Sea-Mediterranean Corridor during the last* 30 *ky: Sea Level Change and Human Adaptation*) project, has the aim of synthesizing the data from the region. By combining this synthesis with the existing BIOME 6000 database, and with data being collected in the context of BIOME 6000 daughter projects such as PAIN and CiMBIO (e.g. Bigelow et al., 2003; http://www.bridge.bris.ac.uk/resources/databases), this should achieve a good coverage of this key region.

3. Sources of data

3.1. Pollen records

The pollen sequences used in this project are from a variety of sources. The majority of pollen sequences are from lake basins, but there are a number of sequences from wetlands, cave deposits, alluvial deposits and even sea bottom sediments, particularly from the Black Sea, Marmara Sea, Caspian Sea (Leroy et al., accepted for publication) and Aral Sea. A total of 99 pollen sequences are currently included in this project (Fig. 3b). Unfortunately, most of the pollen sequences are concentrated in Western Anatolia and the Balkans; extensive areas have no records. These empty areas are located mainly in the arid and hyperarid parts of southwestern and central Asia. Modern surface samples are available from several areas (Fig. 2a); these samples will be used for testing during the developmental phase of the biomisation procedure.

3.2. Plant macrofossils

Plant macrofossils can generally be identified to higher taxonomic resolution than pollen, which will be exploited in improving plant assignments in the biomisation procedure. Furthermore, in arid regions, plant macrofossils are often better preserved than pollen. In the study area, pollen records are not available over areas of Northern Syria and the Fertile Crescent, but these do provide abundant plant macrofossil records (Fig. 2b). This may allow extension of the vegetation reconstruction into areas which would otherwise have been unsampled (see e.g. Thompson and Anderson, 2000). Plant macrofossils are generally not transported long distances from their source; this is both an advantage and a disadvantage. On the one hand, they only provide a record of local vegetation and this record may not be compatible with the regional picture obtained from pollen. On the other hand, the presence of macrofossils provides definite evidence of the local presence of a particular plant. One of the common problems encoun-

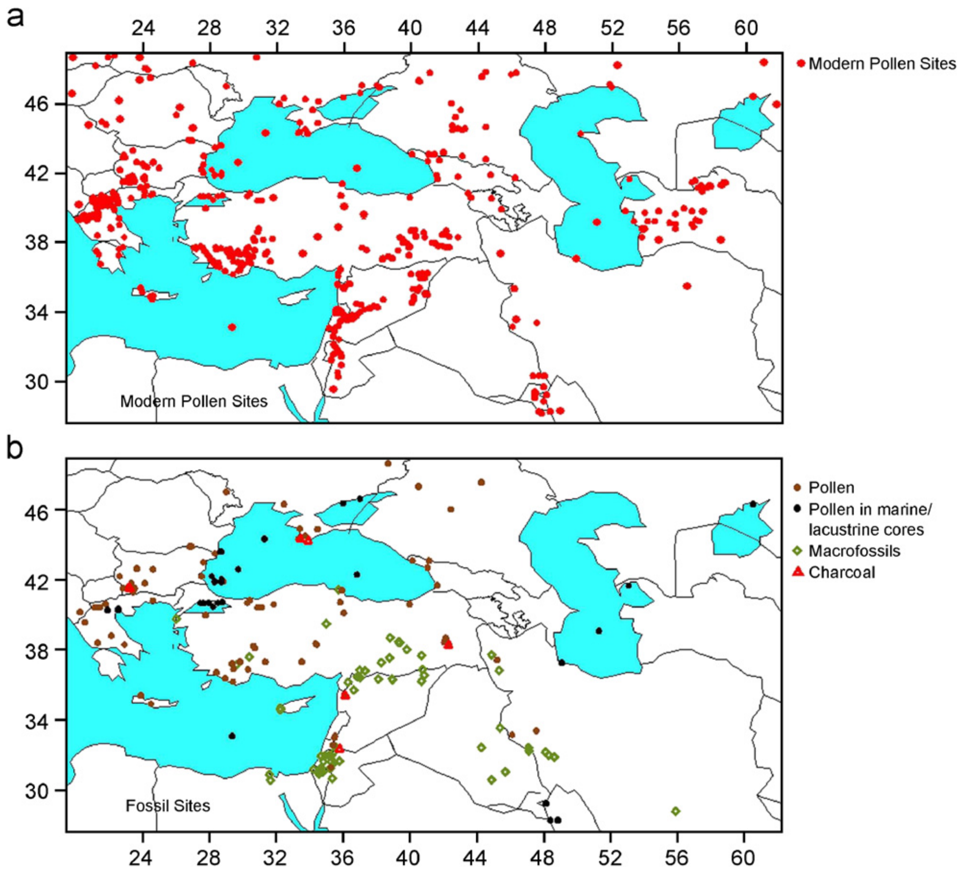

Fig. 2. Sites with (a) modern pollen and (b) with fossil records (pollen, pollen in marine cores, macrofossils, charcoal) within the WG-2 study region.

tered in using the biomisation procedure in regions characterized by non-forest vegetation is that contamination by long-distance transported pollen can yield unrealistic assignments of the fossil assemblages (see discussion in e.g. Yu et al., 2000; Bigelow et al., 2003). Plant macrofossils can be used to determine whether there are problems with contamination.

3.3. *Charcoal records*

The presence of charcoal or charred particles in sediment sequences provides evidence of the occurrence of fires, and changes in the abundance of charcoal through time have been interpreted as evidence of millennial-scale changes in fire regimes at a regional to continental scale (Haberle and Ledru, 2001; Carcaillet et al., 2002; Power et al., submitted for publication). Although macroscopic charcoal remains are generally thought to reflect fires within the catchment most reliably, changes in the abundance of microscopic charcoal can also provide at least a qualitative measure of changes in the background level of fire (e.g. Tolonen, 1986; Clark et al., 2002; Whitlock et al., 2003; Whitlock and Bartlein, 2004). Although records of microscopic charcoal are often presented in pollen diagrams, there are only six published sequences in the WG-2 study region (Fig. 3b), namely the Al-Ghab Basin in Syria (Yasuda et al., 2000), Lake Van (Wick et al., 2003), Lake Suho Brezhnisko and Lake Okadensko in Bulgaria (Atanassova and Stefanova, 2005), and the Chërnaya Valley and Yaila in Crimea (Cordova and Lehman, 2005; Cordova, unpublished data).

4. Reconstruction methodology

4.1. *Database construction*

Separate databases have been constructed for each of the data sources, i.e. for pollen, for charcoal and for plant macrofossils. The general structure of each database is similar. The databases contain original counts/measurements; in the case of pollen and plant macrofossils, the counts are recorded at the taxonomic resolution of the original study. In addition to the primary data (e.g. counts or measurements, as well as the name of the person who counted and the person who entered the data in the database), each database contains adequate data to allow in-depth analysis of the data, including information on the site itself (site metadata), on the sample (sample metadata), on the age model (dating information), and on the source of the information (publications). The types of supporting data available for each site and sample follow standard guidelines for the construction of palaeoenvironmental databases (see e.g. Kohfeld and Harrison, 2000; Anderson

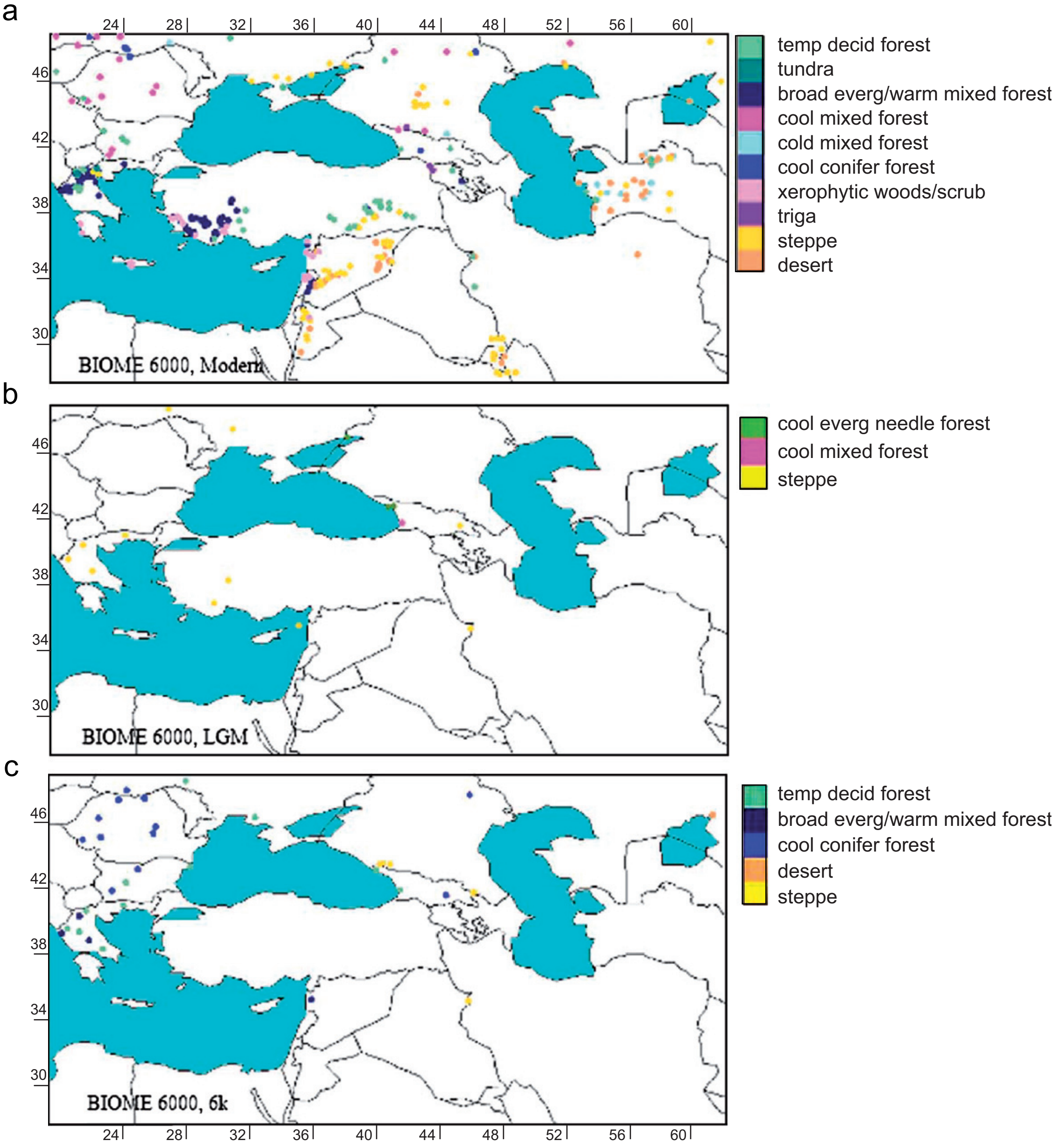

Fig. 3. Site-based reconstructions of vegetation patterns (a) today, (b) at the Last Glacial Maximum, ca 21,000 cal yr BP and (c) in the mid-Holocene, at 6000 cal yr BP obtained by an objective biomisation procedure. Data derived from the BIOME 6000 database (Prentice et al., 2000).

and Webb, 2001; Harrison, 2003, 2006); the choice of fields is based on previous experience in the BIOME 6000 project. A complete listing of the fields is given in Table 1. Collecting this amount of supporting data for each site/sample is time-consuming, but it enhances the long-term usefulness of the database as well as ensuring that subsequent reconstructions using these data are adequately documented and transparent with respect to the primary data.

4.2. Taxonomy

One major problem in constructing databases of palaeobotanical information, and particularly if these databases are to include information from different regions and from individual studies made at different times, is the lack of taxonomic standardization. The problem is compounded because the level of taxonomic resolution differs between data sources, with macrofossils generally being identified at much higher taxonomic resolution than is possible with pollen. The BIOME 6000 project did not impose a standardized taxonomy but dealt with the lack of standardization by the assignment of all synonymous taxa to the same PFT; thus, e.g. Labiatae (old nomenclature) and Lamiaceae (new nomenclature) were both accepted in the taxon list but were always assigned identically in the biomisation procedure. This pragmatic decision can cause data-handling problems through the artificial expansion of the taxon list. BIOME 6000 also allowed composite taxa to exist and be assigned to PFTs. For example, when the

Table 1
Information contained in the pollen database

Worksheet	Contents
Site metadata	Site name, latitude, longitude, elevation, site type, water depth, basin size, catchment size, landscape description, local vegetation, regional vegetation, inflow, outflow, publication number
Sample metadata	Site name, sample name, sample depth, depositional context, collector, pollen analyst, synthesis contact, count type, sample type, publication number
Publications	Listed by publication reference number
Dating information	Site name, depth, lab number, material dated, age, positive error, positive error, type of date, comments
Pollen data	Alphabetical list of taxa against columns containing site name, sample name and depth

original analysts had lumped together aquatic taxa for reporting because they were only present in low numbers, BIOME 6000 recognized both composite taxa such as *Sparganium*/*Typha* where pollen morphology is similar and *Cyperus*/*Typha* that includes grains of very different morphology. When the composite taxa included species from very different PFTs, this resulted in a significant down-weighting of the usefulness of the "composite taxon" in the reconstruction procedure. The current project uses a standard taxonomy for the data compilation, specifically Czerepanov's (1995) "Vascular Plants of Russia and Adjacent States (the Former USSR)". An electronic version of this flora was provided by Czerepanov and has been incorporated into the data-entry spreadsheets. Wherever possible, older published records are being translated to conform to this taxonomy. The use of composite taxa, or the grouping together of species/genera represented in low numbers into families, is being minimized through contact with the original author(s) of individual studies.

4.3. Age modelling

A variety of different approaches have been used to erect chronologies for sites in the Mediterranean-Black Sea Corridor region. There are considerable differences in the quality of available age models, depending on the number and type of dates available. In particular, many of the older records from the region have relatively few radiocarbon dates and/or dates based on bulk sediments, or were dated by correlation with other nearby sites. Very few of the records are presented in terms of calibrated calendar years. The reliability of the existing age models will be assessed before the record is used in the reconstructions; it may be necessary to erect new age models based on up-to-date calibration techniques (e.g. Stuiver et al., 1998). To facilitate this, the database contains information about the radiometric dates available for each site (see Table 1) and allows for the construction and preservation of multiple age models. The selection of records or parts of records for subsequent inclusion in the reconstructions can then be made on the basis of detailed analyses of the available dating and age models, and cross-comparison between sites.

4.4. Biomisation

Biomisation is an objective way of determining the major vegetation type (i.e. biome) represented by a given pollen assemblage (Prentice et al., 1996). Unlike other methods of assigning pollen assemblages to vegetation types, it makes no assumption about the importance of individual species—it does not rely on the use of dominant or indicator species. Furthermore, it does not assume that species that characterize a given vegetation type today necessarily co-occurred in the past. Thus, it is capable of recognizing major vegetation types even though they are defined by different combinations of species from today or are characterized by shifts in the relative importance of co-occurring species (see e.g. Edwards et al., 2000). In principle, therefore, it is also capable of identifying biomes that do not occur on the present landscape or, if present, are confined to small areas and therefore generally recognized as azonal/intrazonal vegetation types (see e.g. Bigelow et al., 2003). In order to achieve this flexibility, biomisation uses a three-step procedure: (a) the assignment of pollen taxa to PFTs, (b) the definition of major vegetation types (biomes) as assemblages of PFTs and (c) the use of a quantitative approach based on calculating the affinity score of each pollen sample to each biome. Pollen taxa are assigned to PFTs on the basis of physiological and ecological information about the species within the taxon. The taxonomic discrimination of pollen is limited and as a result some pollen taxa are necessarily assigned to more than one PFT. However, as Jackson et al. (1997) have shown, plant macrofossil records from a given site can be used to determine which species are present locally and this information can be used to improve the pollen-based discrimination of PFTs. Major vegetation types (biomes) are conceptualized as assemblages of different PFTs. The number of different biomes recognized is not fixed but can be adapted to the regional scale or problem being addressed. In practice, the number of reconstructed biomes has tended to increase to reflect the increasing levels of discrimination used by state-of-the-art vegetation models to facilitate model-data comparisons (see e.g. Prentice et al., 1996, 2000; Bigelow et al., 2003; Pickett et al., 2004).

4.5. Inter-relations between vegetation and fire

Previous studies within the BIOME 6000 project have focused on explaining reconstructed changes in vegetation patterns in terms of climate changes. However, changes in the disturbance regime (and in particular in the incidence of fire) can be an important trigger for biotic reorganizations (e.g. Lloret and Vila, 2003; Heisler et al., 2004). The situation is complex because the fire regime (i.e. the characteristic frequency, intensity, and area of fire during a particular period) itself responds to changes in climate and changes in vegetation on multiple temporal and spatial scales and at the same time can cause changes in vegetation and climate (e.g. through changing trace gas emissions). Thus, comparison of reconstructed changes in fire regimes (based on sedimentary charcoal records) and reconstructed vegetation patterns (based on plant macrofossil and pollen data) can be used to investigate the regional linkages between climate, fire and ecosystem response.

5. Initial results

5.1. Site-based reconstructions of palaeovegetation

The BIOME 6000 database currently includes 449 modern samples, 35 Mid-Holocene sites and 13 sites for the Last Glacial Maximum from Mediterranean-Black Sea Corridor region. Reconstructions based on these records (Fig. 3) suggest rather large changes in vegetation within the region. At the Last Glacial Maximum, most of the lowland sites north of the Black Sea were characterized by steppe vegetation (Fig. 3b), while coastal areas of the eastern Black Sea (Fig. 3b) indicate cool evergreen or mixed forests, in agreement with previously published marine pollen records (Mudie et al., 2002, 2007). During the Mid-Holocene (Fig. 3c), there was a marked expansion of broad-leaved evergreen/warm mixed forests in the western part of the region at the expense of temperate deciduous forests.

5.2. Macrofossils from archaeological sites

Plant macrofossils can be recovered from natural sections (e.g. lakes and peatbogs), but most of the records in the WG-2 region are from archaeological sites (see e.g. Riehl, 1999; Riehl and Kümmel, 2005). These samples represent those plants from the immediate vicinity (usually less than 10 km from the archaeological site) that reached the sites mostly by human action and domestic animals, e.g. in dung pellets used for fuel (Yanushevich, 1976). It is not clear whether such data will be useful in the biomisation procedure, in part because the preserved macrofossils may not correspond with the dominant taxa in the natural vegetation and in part because the archaeological sites may not be co-located with the pollen cores. Nevertheless, documentation of the changing distribution and abundance of crop macrofossils (including cereals and legumes) in archaeological sites through time will provide useful information about both human activities and climate changes (Kremenetski, 1997; Kremenetski et al., 1999; Dönmez, 2005; Riehl and Bryson, 2007). The changing distribution of einkorn can be used as an example of the use of crop macrofossils to infer climate changes. Einkorn is considered to be susceptible to drought (Oleinikova, 1976; Kishitani and Tsunoda, 1981; Zhao et al., 2005). Changes in the abundance of einkorn in sites from different stages during the Bronze Age (Fig. 4), and specifically its absence from sites in the Levant during the Middle Bronze Age, may indicate a significant increase in aridity at this time—an increase that should also be registered in the natural vegetation of this region. This trend in plant macrofossil distributions is generally evident in all drought-susceptible crop species of the sub-region (Riehl and Bryson, 2007), and it is further reflected by changes in the proportions of selected wood taxa at some sites (Fig. 5).

For example, from the Early to Middle Bronze Age, there seems to be a decrease in wood species richness, and an increase in more drought- and salinity-adapted species. This is particularly notable in the northeastern (Khabur) and southwestern (Damascus) basins of the Euphrates. In these areas further away from the large river, *Fraxinus* and *Quercus* species are numerous during the Early Bronze Age, but in the Middle Bronze Age, Chenopodiaceae increase strongly in the Damascus area, and *Quercus* decreases in the few continuing sites of the Khabur area. Along the Euphrates, there are many sites around modern Lake Assad, including Emar (Fig. 5) where the ratio of *Tamarix* (salt tolerant) to *Populus* increases in the Middle Bronze Age, suggesting increased salinity in this area, despite the proximity to the river. At Umbashi, there is also a notable increase in Chenopod wood over the salt-sensitive *Pistacia*. The inclusion of macrofossils from archaeological sites in the WG-2 synthesis thus allows detailed exploration of the nature and magnitude of human impact on the vegetation.

5.3. Marine versus terrestrial cores

BIOME 6000 and its daughter projects previously have only used pollen data from terrestrial cores. However, pollen records from marine cores have been shown to be useful for land–sea correlation and climate reconstruction (e.g. Rossignol-Strick, 1995; Traverse, 1988; Hooghiemstra et al., 2006; Mudie et al., 2002, 2004; Mudie and McCarthy, 2006). In the almost land-locked setting of the sea in the WG-2 study area, pollen from marine cores may provide a good record of vegetation changes in nearby coastal zones. These marine-core records are particularly useful because they provide almost uninterrupted sequences covering the whole of the time period of interest and, because they contain calcareous material (e.g. molluscs), they are generally well dated. Marine records also include other microfossil (e.g. foraminifera, ostracods, dinocysts) and geochemical records (e.g. oxygen and stable carbon isotopes: Lyle et al., 2001; Mudie et al., 2001; Robinson et al., 2006) that can be used to derive an independent record of regional climate change and aid in the interpretation of the reconstructed vegetation changes. WG-2 will therefore include pollen records from marine

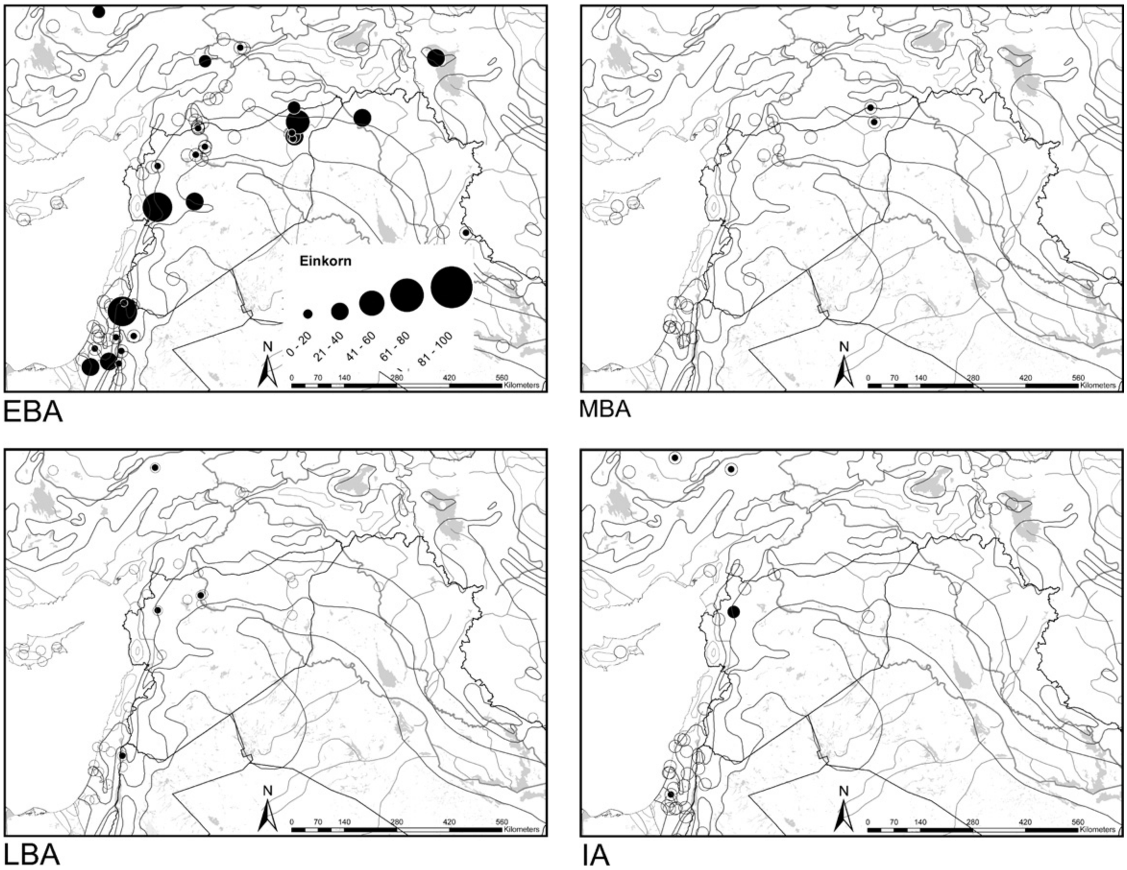

Fig. 4. Changes in abundance of einkorn cereal grains during the Bronze Age in the Levant. EBA, Early Bronze Age; MBA, Middle Bronze Age; LBA, Late Bronze Age.

cores in the database; there are presently 12 marine cores from the region (Fig. 2b).

The inclusion of pollen records from marine cores poses its own problems. First, the relationship between regional marine and land pollen signals needs to be investigated using surface samples collected on the continental shelf and continental slope adjacent to the study region (e.g. Mudie, 1982; Traverse, 1988; Hooghiemstra et al., 2006). Maps of the distribution of the most abundant pollen species in the marine sediments of the North Atlantic Ocean show a close relationship to that of the vegetation zones on the adjacent continents. Mudie and McCarthy (2006) found correlation coefficients of 0.6–0.9 between the eastern North American shelf assemblage percentages and average regional pollen percentages for adjoining vegetation zones. Nevertheless, this relationship needs to be re-examined in the context of the records from the Black Sea and the Marmara Sea. A second issue is the possibility of over-representation of anemophilous pollen species in marine sediments. It has been noted that *Pinus* and *Artemisia* are over-represented in the sediments of Marmara Sea (Caner and Algan, 2002; Mudie et al., 2002) but it is evident that the major late glacial and postglacial pollen zones reported for the Turkish lakes are present in low-resolution (millennial-scale) marine cores (Mudie et al., 2002). This is consistent with the finding that pollen input to continental shelf basins is primarily from aerial transport (Mudie and McCarthy, 1994; Hooghiemstra et al., 2006) rather than fluvial transport or runoff. In humid regions, ~90% of the airborne pollen is washed out of the lower atmosphere within 50 km of the coastline, and pollen settles rapidly to the seabed by flocculation and as faecal pellets (Mudie and McCarthy, 1994; Mudie and Head, 1996). In dry regions such as northwest Africa, the wind transport is the main source of pollen in marine sediments in the belt beyond the immediate coastal zone up to >1200 km offshore. Vertical transport through the water column is believed to be very rapid, facilitated by aggregation into faecal pellets. The assemblages in the sediment at the bottom of the ocean directly represent the pollen in the air above the water body (Hooghiemstra et al., 2006), except where there are turbidites that may resuspend and redeposit shelf pollen sediments (McCarthy and Mudie, 1998).

The fidelity with which the marine assemblages in the WG-2 study area can reproduce a sub-regional vegetation history can be illustrated by comparing summary diagrams (Fig. 6) of the results of pollen studies made independently in Lake Manyas (Leroy et al., 2002) and the central Marmara Sea (Mudie et al., 2002), i.e. at ~50 km away from each other. The summary pollen diagrams show the percentage abundances of the 14 most abundant taxa among the totals of 36 and 80 taxa found in the marine and

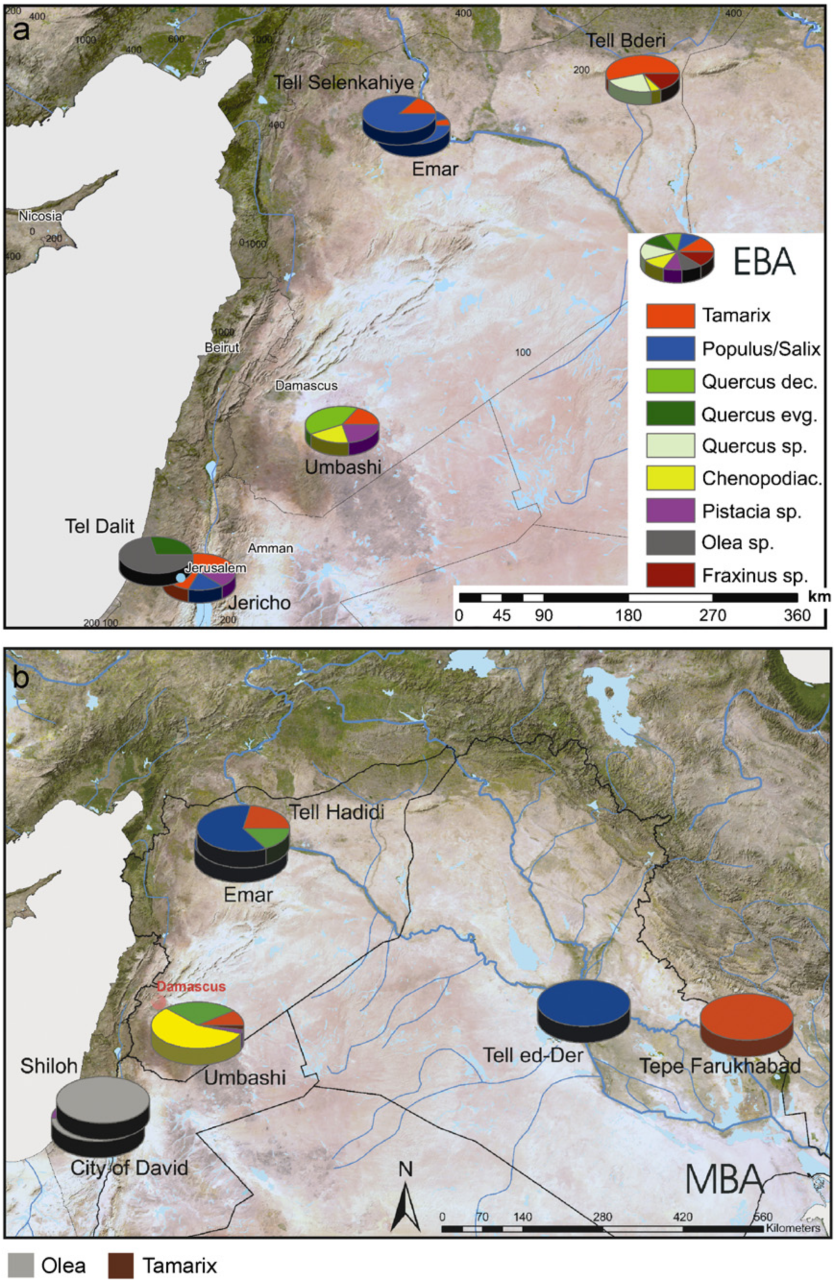

Fig. 5. Changes in percentage proportions of nine wood taxa selected according to highest frequencies during the Bronze Age at some archaeological sites in the southern WG-2 study region. EBA, Early Bronze Age (ca 3000–2000 BC); MBA, Middle Bronze Age (ca 2000–1800 BC). The composition of the covered pie chart for MBA Emar is: 79% *Populus/Salix*, 20% *Tamarix* and 1% *Pistacia*.

lake cores, respectively. Some of the reported taxa, particularly at the family level, include several genera and species that were counted separately in the full pollen analysis filed in the BIOME database. For example, three different pollen taxa were included in the Oleaceae (Fig. 6): the genera *Olea*, *Fraxinus ornus* and *Phyllirea* were distinguished by differences in the coarseness of the ektexine, furrow length and presence of a small pore in *Fraxinus ornus* (see Fig. 7 caption).

Lake Manyas is located about 10 km south of the central Marmara Sea. Despite the ~two-fold over-representation of *Pinus* in the marine core (Fig. 5b), the pollen diagrams are remarkably similar particularly with respect to the decline of pollen concentration, % *Pinus* and corresponding rise in % *Quercus* pollen during the Beysehir Occupation Period. The representation of most tree species is also in reasonable agreement, although *Juglans* is over-represented in the marine core. In contrast, Poaceae (Gramineae) and Asteraceae Liguliflorae (*Taraxacum*- and *Sonchus*-type pollen) are more strongly represented in the Manyas core MAN98-11, as would be expected for the marshy and lacustrine environments at Lake Manyas. On the other hand, the Cerealia and Asteraceae Tubuliflorae pollen signals are quite similar at the two sites.

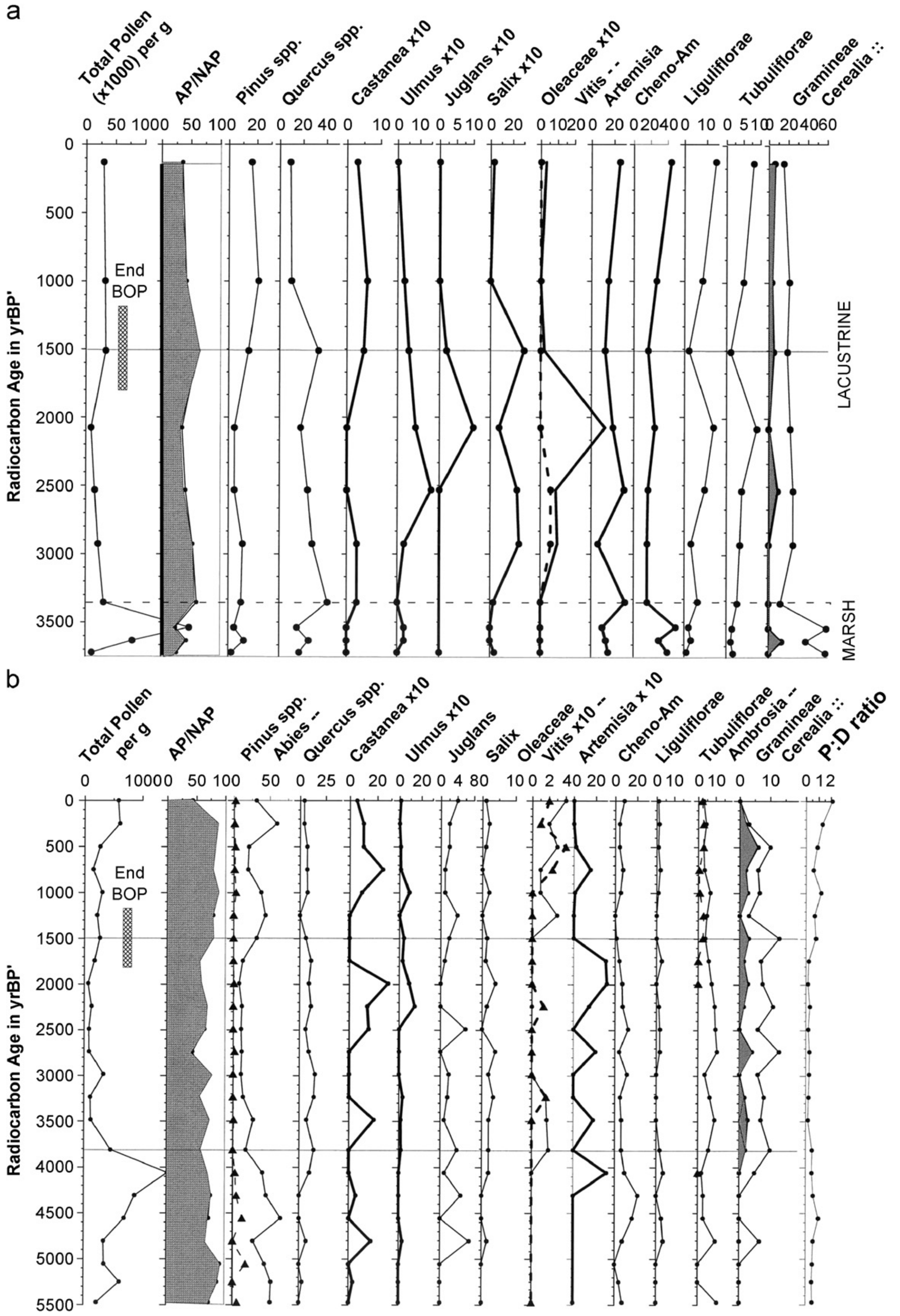

Fig. 6. Comparison of pollen percentage diagrams from lacustrine and marine cores from the Marmara Sea region of the WG-2 study area. Percentages are based on total pollen, excluding indeterminate and reworked grains. (a) Core ML98-11 from Lake Manyas, 14 m a.s.l. (see Leroy et al., 2002 for details); (b) Core MAR97-2 from −1080 m a.s.l., NW Marmara Sea. BOP, Beysehir Occupation Period.

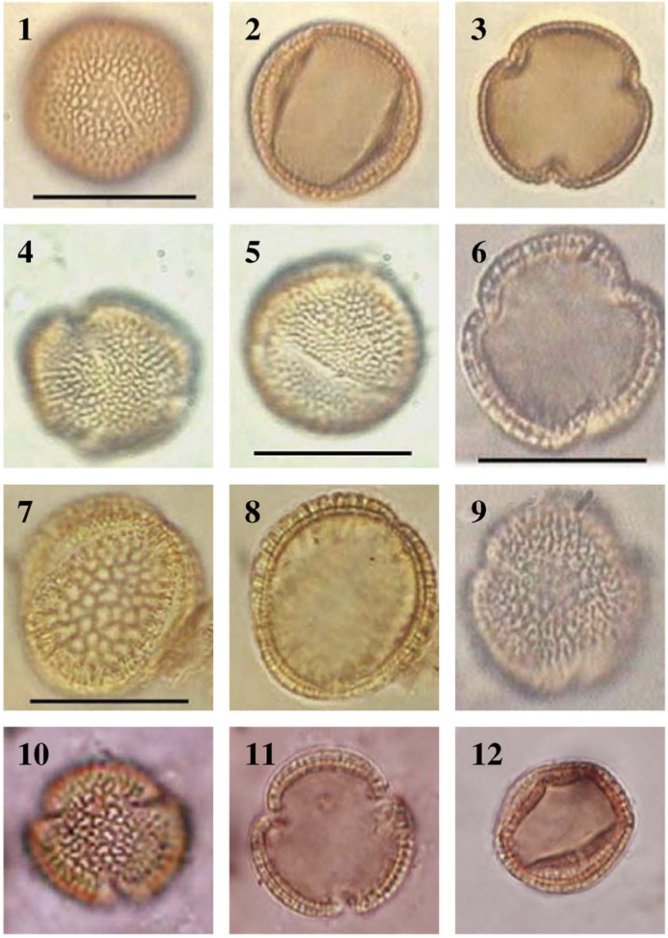

Fig. 7. Light microscope photographs of some Oleaceae pollen from the Mediterranean (1–8; per courtesy of Florence Boutet and Christiane Tisse, Common Service of the Laboratories (SCL), Marseille Laboratory, France), and from the Marmara Sea sub-region of the Mediterranean-Black Sea Corridor. Scale bar is 20 μm in length. 1–3, *Phyllirea angustifolia* reference material of F. Boutet. 1, High focus, showing fine reticulum; 2, mid-focus, equatorial view, showing long colpi with wide pores; 3, mid-focus, polar view. 4, 5, *Fraxinus ornus* reference material of C. Tisse. 4, High focus on fine reticulum; 5, mid-focus on long oncus (colpi with a thickened intine) and small pore. 6, 9, *Olea* reference material of F. Boutet. 6, Mid-focus, showing coarse ektexine and short colpi; 9, high focus, polar view. 7, 8, *Olea* pollen from Core MAR97-02, 20 cm depth, SW Black Sea. 7, High focus, equatorial view; 8, mid-focus. 10, 11, *Olea* pollen from 702 cm in a core from Lake Ulubat near Lake Manyas. 10, High focus; Leroy ref. no. AK02_108_4_2; 11, mid-focus; Leroy ref. no. AK02_108_4_4. 12, Oleaceae pollen from 712 cm depth in a core from Lake Ulubat near Lake Manyas. Mid-focus, showing relatively fine ektexine and small pore often found in *Fraxinus ornus*. Leroy ref. no. AK02_108_14_1.

6. Discussion and conclusions

The outlined approach, based on a comprehensive synthesis of pollen, plant macrofossil and charcoal data from the Mediterranean-Black Sea Corridor region, will allow reconstruction of the changing patterns of vegetation and fire regimes across this region through the last glacial–interglacial cycle. The construction of a standardized database, which is currently under development, will allow use of a uniform and objective methodology for these reconstructions. Preliminary analyses show that, while there are many methodological issues still to be resolved, the available data are sufficient to draw substantive conclusions about the nature of past climate and environmental changes, and about the interaction between natural changes and human activities.

One major focus of future analyses will be to investigate whether the Mediterranean-Black Sea Corridor region provided suitable locations for forest refugia during the Last Glacial Maximum and to document the post-glacial migration of temperate trees. Pollen-based reconstructions of vegetation patterns across southern Europe and across Russia during the LGM (Elenga et al., 2000; Tarasov et al., 2000; Bigelow et al., 2003) show that the temperate regions were characterized by non-forest vegetation, but clearly some forest was present around the southern and eastern part of the Black Sea. Plant macrofossil and genetic studies suggest that the Caucasus may have acted as refugia for temperate trees and provided the nucleus from which temperate trees expanded during the deglaciation (Bennett et al., 1991; Petit et al., 2005). With the exception of studies on *Castanea sativa* (Krebs et al., 2004), there has been little work on this problem in the Mediterranean-Black Sea Corridor region, although potential refugial areas in the Crimean Mountains, the coastal areas in the western Caucasus (Cordova, 2007) and the region around the northern–eastern Marmara Sea (Caner and Algan, 2002) have been suggested (Leroy and Arpe, accepted for publication).

Palaeoenvironmental data syntheses serve multiple purposes, but perhaps one of the most important uses of these data is for evaluation of the performance of climate models under climates that are radically different from today (Joussaume and Taylor, 2000; Kohfeld and Harrison, 2000; Harrison et al., 2002; Harrison and Prentice, 2003). As climate models evolve to include more components of the Earth System, new palaeoenvironmental data syntheses are required for model evaluation. Thus, the incorporation of vegetation and vegetation-disturbance (e.g. through fire) in climate models (e.g. Brovkin et al., 2003; Betts et al., 2004; Notaro et al., 2005), provides a strong motivation for the synthesis of data on past vegetation patterns and fire regimes. The BIOME 6000 project was created explicitly to provide global vegetation reconstructions for model evaluation (Prentice et al., 1996, 2000) but the existing maps need to be updated because more data become available in recent years. BIOME 6000 concentrated on mapping palaeovegetation at two iconic periods, the Mid-Holocene and the Last Glacial Maximum, for "time-slice" model simulations. However, as computer resources become less limiting, climate models are being exercised in transient mode to investigate e.g. the causes of rapid climate changes and this necessitates the reconstruction of the transient changes in vegetation through time. Thus, emphasis within IGCP 521 WG-2 will be on the reconstruction of changes in vegetation patterns between the LGM and the present.

The underlying goal of WG-2 is to understand the causes of past changes in vegetation in the Mediterranean-Black Sea Corridor Region. Multiple factors may have been important in determining vegetation changes in this region, including climate changes, climate-induced changes in the fire regime, geomorphological changes such as changes in the level of the inland lakes/seas, changes in the salinity of the water and soils and human activities. The interaction of these factors can, to some extent, be disentangled by comparing the reconstructed vegetation changes with sources of information on past climates (e.g. isotopic records) or with archaeological data on population density and cultural activities. However, the results of such comparison may be equivocal. An alternative approach is to use models of different components of the Earth System as a tool for exploring specific hypotheses (see e.g. Prentice et al., 1992; Jolly and Haxeltine, 1997; Vassiljev et al., 1998; Broström et al., 1998; Harrison and Prentice, 2003). Mechanistically based models, such as the LPJ-SPITFIRE dynamic vegetation-fire model (Thonicke et al., submitted) incorporate treatments of both the effects of climate and the effects of human activities on vegetation and fire. Such a model can therefore be exercised to test contrasting hypotheses regarding the role of climate or increased fire activity in vegetation changes. Comparison of the simulated vegetation and fire patterns under these two assumptions with reconstructed patterns will provide critical insights into the causes of past environmental changes in the Mediterranean-Black Sea Corridor region.

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