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Climatic pacing of Mediterranean fire histories from lake sedimentary microcharcoal

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ABSTRACT

The microcharcoal content (particles <180 μm) of overlapping sedimentary sequences from two crater lake basins in central Turkey are used to reconstruct the regional fire history of the East Mediterranean oak–grass parkland zone from the Last Glacial Maximum to the present-day. These results are correlated with stable isotope and pollen data from the same cores in order to assess the changing role of climate, vegetation and human activity in landscape burning. This indicates that climatically-induced variation in biomass availability was the main factor controlling the timing of regional fire activity during the Last Glacial–Interglacial climatic transition, and again during Mid-Holocene times, with fire frequency and magnitude increasing during wetter climatic phases. Spectral analysis of the Holocene part of the record from Eski Acıgöl indicates significant cyclicity with a periodicity of ~1500 years that may be linked with large-scale climate forcing. Although proto-agricultural societies were established in this region as early as 10,000 years ago, it is only during the last two to three millennia that the pacing of wildfire cycles appears to have become decoupled from climate and linked instead to human-induced changes in land cover and fuel load availability.

1. Introduction

Under natural conditions fire, climate and biomass are inextricably linked (Pausas, 2004; Whelan, 1995). The nature of the climate (e.g. humid vs. arid) influences the structure and species composition of a vegetation community and therefore fuel availability, which is a powerful influence on fire regimes. In turn, fire is itself a major determinant of seasonally dry ecosystems including the global distribution of tree cover (Bond et al., 2005). People modify the natural patterns of biomass burning through their manipulation and management of vegetation communities, including via practices of fire suppression or promotion (Clark and Royall, 1995), and through accidental or deliberate ignition of "natural" vegetation.

Eastern Mediterranean parklands are a classic example of an ecosystem where fire, grazing and other forms of disturbance are fundamental to the maintenance and regeneration of the ecosystem (Grove and Rackham, 2001; Naveh, 1974). In addition, but in contrast to other summer-dry Mediterranean-type regions of the world (Köppen type Cs; e.g. California, S. African Cape), the Mediterranean has a long history of human occupation and impact. There is archaeological evidence of semi-sedentary advanced hunter–gatherers during the Last Glacial–Interglacial transition (LGIT), and the Eastern Mediterranean subsequently became one of the earliest centres where Neolithic agriculture developed. Therefore this might be anticipated to have been a region where anthropogenic agencies joined, or even overtook, natural ones in exerting control over regional fire activity at an early date (Roberts, 2002).

Charcoal particles have been widely used to reconstruct fire events over multiple timescales in different parts of the world. For example, microscopic charcoal analysis has been central in understanding vegetation change in the North American forests (e.g. Clark and Royall, 1995; 1996) and forest succession in the Western Mediterranean (e.g. Carrión and van Geel, 1999; Múgica et al., 1998; 2001; Sadori and Giardini, 2007; Colombaroli et al., 2007; Vannière et al., 2008), the history of human fire use by pre-European populations in Australia and the Americas (Clark, 1983; Clark and Royall, 1995; Kershaw et al., 1997; Trabaud et al., 1993) and understanding changes in the global carbon cycle with increased biomass burning (e.g. Carcaillet et al., 2002; Crutzen and Andreae, 1990). However, there has been limited research into long-term fire dynamics in the Eastern Mediterranean, and this has generally had low temporal resolution (e.g. Yasuda et al., 2000). In this paper we present a high resolution sedimentary record of regional fire history since the Last Glacial Maximum (LGM) from two nearby crater lake basins located in the oak parkland zone of Central Turkey. In order to assess the changing roles of climate, biomass and people on burning regimes, we compare microcharcoal results with other multi-proxy (pollen and oxygen isotope) data from the same stratigraphic sequences, along with archaeological evidence from the study region.

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2. Study area

The principal data we report here derive from Eski Acıgöl (38°33'01"N, 34°32'41"E; 1270 metres above sea level (masl)), a small, former brackish lake, drained in 1972, with no inflow streams and a surface catchment not much larger than the lake itself (Roberts et al., 2001). Its sedimentary record extends back to around the time of the LGM, although it is poorly resolved for the last two millennia. Consequently we overlap this during the late Holocene with a shorter, but highly resolved, sequence from Nar crater lake, located 25 km away. Nar lake (38°22′N, 34°27′E; elevation 1363 masl) is still extant with a maximum water depth of 26 m (Jones et al., 2005, 2006; England et al., in press). Nar is also relatively small (~0.7 km^2) with a watershed catchment of ~4 km^2, and the lake is stratified and forms annual varve layers. Both sites are hydrologically closed in terms of surface outflows, and are sensitive to climatic changes.

These lakes are located in the oak parkland zone that covers the Anatolian plateau and western Iran (Zohary, 1973) mostly between 900 and 1500 masl (Fig. 1). The surrounding area would comprise *Quercus pubescens*, *Q. cerris*, *Pistacia*, *Crataegus, Prunus, Pyrus*, and *Juniperus* with *Festuca*, *Poa* and other grasses, and *Artemisia* and chenopods common at drier, low-elevation sites (Woldring and Bottema, 2003). Most woodland is degraded today, partly due to grazing by sheep and goat herds, and almost all fertile soils have been converted to agriculture. The regional climate is modified Oro-Mediterranean, being summer-dry, with precipitation ranging between ~300 and ~600 mm y^{-1}. Average summer temperatures range between 20 °C and 27 °C, while those in winter fall to 3 °C to −3 °C, reflecting the continentality and elevation of the area. The study sites lie in Cappadocia, which has a well-documented archaeological record of continuous human habitation since Neolithic times. The excavated proto-agricultural Neolithic village of Aşıklı Höyük lies to the south west of Eski Acıgöl and dates to between 10,000 and 9500 cal. years BP (Esin, 1991) (all dates are given in calendar years). The region was important throughout later prehistory for raw materials such as obsidian, it lay close to the centre of the Hittite Empire during 2nd millennium BC, and became a Roman province in 17 AD. During the last two millennia, Cappadocia was especially important during early to mid-Byzantine times, and the again during the early Turkish Selçuk period (England et al., in press).

3. Methods

At Eski Acıgöl, a 1566 cm composite sequence was obtained from parallel, overlapping cores taken with a modified Livingstone piston corer and Eijkelcamp corer with a percussion Cobra motor (ESK 96/99). Palynological analysis was conducted on a parallel sequence taken in 1992 (ESK92) using a Dachnowsky corer (which reached 1420 cm) (Woldring and Bottema, 2003). The ESK96/99 and ESK92 sequences were cross correlated through a series of well-constrained tie points, e.g. tephra horizons. Because the ESK92 sequence is shorter than ESK96/99, published pollen data are not available for the period prior to the Late Glacial Interstadial. At Nar, coring was undertaken in the deepest part of the lake using Glew, 3 m Mackereth and Livingstone lake sediment corers.

Multi-proxy studies, including $\delta^{18}O$ (measured on precipitated authigenic carbonate) and pollen analyses, have been conducted on cores taken from both crater lake systems, with dating based on U-series (Eski Acıgöl) and varve counting (Nar); (see England et al., in press; Jones et al., 2005; Roberts et al., 2001 for methodological details).

3.1. Microcharcoal analytical methods

Fire events produce a pulse in charcoal which is transported away from the fire site and can be incorporated into lake sediments. Identifying individual fire events is dependent on sampling the peaks in charcoal concentration within the sedimentary record; a contiguous sampling strategy was therefore adopted in this study. This differs from microcharcoal counts made on pollen slides which are normally derived from samples taken at discrete depth intervals within a core sequence (e.g. at Eski Acıgöl, pollen samples were taken on average every 18.5 cm; Woldring and Bottema, 2003). For microcharcoal analysis from Eski Acıgöl, contiguous 1 cm^3 sediment samples measuring 4.0×1.0×0.25 cm were extracted from the full length of the ESK 96/99 composite core sequence, apart from 0–76 and 1267–1294 cm for which there was no core recovery. A higher sampling resolution of 2.0×1.0×0.5 cm was applied to selected periods of major climatic change, e.g. Late Glacial–Holocene transition. Contiguous samples were also analysed at Nar, but in this case by laminae age rather than depth interval. For the last 100 varve years, thin blocks of 10 laminations were used (i.e. 1–10, 11–20 VY, etc), while the rest of the sequence sampled contiguously every 20 laminations (i.e. 101–120, 121–140 VY, etc).

After adding *Lycopodium* tablets to enable estimation of charcoal concentrations, samples were prepared using density separation (Turner, 2007). This preparation method was found experimentally by Turner et al. (in press) to have a higher recovery than other published methods for the fine charcoal fraction, and more than ten times the recovery of standard pollen preparation method. Samples

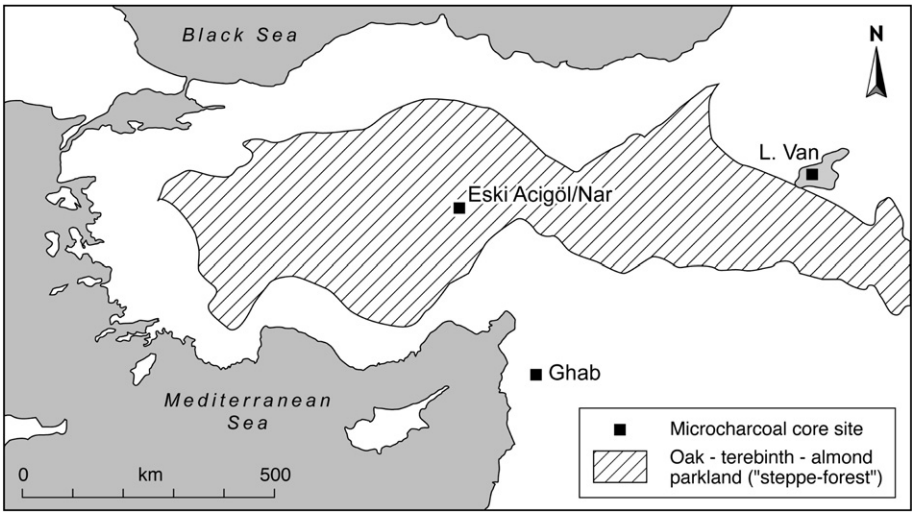

Fig. 1. Location of study sites. Distribution of parkland ecosystem from Zohary (1973).