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Vegetation and climate during the Last Glacial high stand (ca. 28–22 ka BP) of the Sea of Galilee, northern Israel

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ABSTRACT

Despite ongoing discussions on hydroclimatic conditions in the southern Levant during the Last Glacial, detailed knowledge about the Levantine paleovegetation, which is an important indicator for the paleoclimate, is limited. To investigate the paleovegetation in northern Israel, we analyzed the pollen assemblage of a sediment core that was drilled at the Ohalo II archaeological site on the southwestern shore of the Sea of Galilee (Lake Kinneret). We refined the lithology and the age-depth model with the help of five new radiocarbon dates. The core comprises a continuous sediment profile of mainly laminated authigenic calcites and detrital material that deposited between ca. 28,000 and 22,500 years before present, when the Sea of Galilee rose above the modern lake level stand and temporarily merged with Lake Lisan, the precursor of the Dead Sea. The well-dated and high-resolution pollen record suggests that steppe vegetation with grasses, other herbs, and dwarf shrubs predominated in northern Israel during the investigated period. In contrast to the Holocene, there was no continuous vegetation belt of the Mediterranean biome in the vicinity of the Sea of Galilee. Mediterranean elements such as deciduous oaks only occurred in limited amounts and were probably patchily distributed. These results disagree with previous pollen-based hypotheses from the region that assumed the spread of Mediterranean forest during glacial periods. While the pollen data may indicate semiarid conditions in northern Israel and give no evidence of increased effective moisture, previous hydroclimatic studies suggested increased precipitation rates that are consistent with high lake levels (Sea of Galilee/Lake Lisan). Thus, we discuss factors influencing the pollen assemblage and the plant cover.

1. Introduction

The Levant, lying at the transition of the Saharo-Arabian desert belt and the subtropical Mediterranean region, is a key area for investigating the relationship between past vegetation dynamics, climate changes, and human history (e.g., Frumkin et al., 2011; Richter et al., 2012). The Dead Sea rift valley was a possible migration route of modern humans (Richter et al., 2012) and accommodated some early prehistoric settlements dating back to the Last Glacial, e.g. the Ohalo II site in the vicinity of the Sea of Galilee (Nadel, 1990; Nadel et al., 1995).

During the Last Glacial, the Sea of Galilee and Lake Lisan (the precursor of the Holocene Dead Sea) rose to higher elevations compared to the Holocene lakes and reached maximum levels of ca. 170 m bmsl (meters below mean sea level), when both lakes converged (Bartov et al., 2003; Hazan et al., 2005; Torfstein et al., 2013). These remarkably high lake levels point to an increased glacial wetness in the southern Levant. Other lines of evidence, e.g. the deposition of speleothems in areas that were too dry for speleothem growth during the Holocene (Vaks et al., 2003, 2006) and the formation of massive travertines in the Beit Shean region requiring enhanced spring activity (Rozenbaum, 2009) also suggest wet glacial conditions. However, there is a long-running debate about whether it was reduced evaporation or increased precipitation that mainly triggered these hydrological conditions (Tzedakis, 2007; Torfstein et al., 2013). Reduced evaporation rates in the catchment of Lake Lisan triggered by low temperatures and low insolation might have caused a positive freshwater balance allowing even less precipitation than present. Such a scenario is in line with climate model simulations (Stockhecke et al., 2016) and was

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previously suggested by Bar-Matthews et al. (1997) based on isotope data of speleothems. However, subsequent investigations suggested that these isotope data were influenced by the water source composition rather than climatic conditions (e.g., Frumkin et al., 1999; Kolodny et al., 2005). According to Torfstein et al. (2013), reduced evaporation rates could not support the deposition of aragonite-detritus laminae, which comprise significant parts of the Lisan Formation (e.g., Begin et al., 1974; Katz et al., 1977; Machlus et al., 2000). Its deposition required a persistent annual influx of freshwater providing bicarbonate to the Ca-chloride brine (Stein et al., 1997; Barkan et al., 2001). Hence, it suggests that increased precipitation instead of decreased evaporation triggered the high lake level (Stein et al., 1997; Torfstein et al., 2013).

Wetter glacial conditions in the southern Levant would contrast with northeastern Mediterranean climate records, which generally suggest colder and drier Last Glacial climatic conditions than today (e.g., Fleitmann et al., 2009; Pickarski et al., 2015; Miebach et al., 2016; Sadori et al., 2016).

Several previous palynological studies in the southern Levant correlated pluvial climates, corresponding to glacials, with large amounts of arboreal pollen and the widespread occurrence of Mediterranean forests. Interpluvials, corresponding to interglacials, were correlated with desert and steppe vegetation (Horowitz, 1979, 1992 and references therein). However, chronologies were poor or not independent (e.g., Birkat Ram: Weinstein, 1976; southern Dead Sea: Horowitz, 1992) or were revised afterwards (e.g., Ghab Valley: Rossignol-Strick, 1995; Hula Valley: van Zeist and Bottema, 2009).

More recent pollen analyses indicate opposite trends. Marine records from the Levantine Basin indicate a cold and dry climate during the Last Glacial (Cheddadi and Rossignol-Strick, 1995; Langgut et al., 2011) with the coldest and driest conditions between 27.1 and 16.2 ka BP (kilo years before present; Langgut et al., 2011). However, despite the proximity to the Levantine coast, these marine records were influenced by a very large pollen catchment area due to the basin size and by pollen brought by the Nile. Terrestrial pollen records from Yammouneh (Lebanon) and the Birkat Ram maar lake (Golan Heights, Israel) also suggest that steppic vegetation and cold and arid climatic conditions prevailed during the Last Glacial (Gasse et al., 2011, 2015; Schiebel, 2013). However, because of the location at 1360 and 940 m amsl (meters above mean sea level), respectively, orographic climate effects were possible at both sites. A possible effect could have been water deficiency due to water storage as ice or frozen soils as proposed by Develle et al. (2011) for the Yammouneh Basin. In contrast, average temperatures of the Sea of Galilee, located at 209 m bmsl, and its proximate surrounding were still relatively high during cold periods. Interpretation of isotopes on *Melanopsis* shells as a temperature proxy by Zaarur et al. (2016) indicate that the average water temperature of the Sea of Galilee was only ca. 3 °C cooler during the LGM (Last Glacial Maximum), when global ice volume maximized at 23–19 ka BP (Mix et al., 2001), compared to today.

The limnological history of the Sea of Galilee was investigated by Hazan et al. (2005). They reconstructed a lake level curve based on exposed sedimentary sections, trenches, and cores. Previous research on the paleovegetation inferred from the Sea of Galilee was carried out by Baruch (1986), Schiebel (2013), and Langgut et al. (2013, 2015), who investigated the past ca. 9000 years. Palynological studies at the Sea of Galilee presented by Horowitz (1971, 1979) might possibly cover the last 18,000 years. However, the sample resolution is very low and a robust chronology is lacking. A palynological investigation at the Sea of Galilee by Weinstein-Evron et al. (2015) provided first insights into the vegetation history of early marine isotope stage (MIS) 2, although dating inconsistencies prevent an exact age determination of the record. A well-dated and high-resolution palynological study encompassing the whole MIS 2 Sea of Galilee/Lake Lisan high stand was still missing.

Here, we show the results of a high-resolution palynological study from Last Glacial Sea of Galilee based on a mainly laminated and undisturbed sediment sequence. In addition, we present a refined lithology and new radiocarbon dates from core KIN2 to enhance the previously published age-depth models by Hazan et al. (2005) and Lev (2014). We discuss our results with emphasis on the paleoenvironmental changes including vegetation, climate, and lake level.

2. Regional setting

The Sea of Galilee is the largest freshwater lake in Israel (21 × 12 km; 168.7 km^2; Fig. 1). With a surface elevation of 209 m bmsl, it is the lowest freshwater lake on the Earth. Its maximal water depth reaches 41.7 m, and its watershed encompasses 2730 km^2 (Berman et al., 2014). The main freshwater source is the Jordan River, coming from the Hula Valley in the north and draining the Sea of Galilee southwards to the Dead Sea. In addition, the lake is fed by saline springs, which dictate its salinity and geochemical composition (Stiller et al., 2009; Stein, 2014).

The regional morphology is shaped by Cretaceous to Eocene carbonate rocks with extensive karst and Neogene and Pleistocene basalts (Sneh et al., 1998). Soils such as terra rossa and rendzina comprise the surface cover of the Galilee Mountains (Dan et al., 1972). The Jordan Valley to the north and south of the Sea of Galilee is filled with alluvial and lacustrine sediments of Neogene to Pleistocene ages. The Sea of Galilee is located in the Kinnarot tectonic basin, which is partly filled by evaporitic and lacustrine sediments of Neogene to Pleistocene origin (Stein, 2014). The basin was partly shaped by the tectonic movements associated with the Dead Sea transform (Ben-Avraham et al., 2014).

Northern Israel is currently characterized by a Mediterranean climate with warm, dry summers and mild, wet winters. The mean annual precipitation and temperature vary considerably in northern Israel because of the steep topography. The Kinnarot Basin, where the Sea of Galilee is located, is locally characterized by a hot and semiarid climate with 400 mm mean annual precipitation and 21 °C mean annual temperature. The surrounding mountains are several hundred to more than thousand meters higher than the present lake level resulting in higher mean annual precipitation rates and lower mean temperatures (Mount Kennan, Upper Galilee: 718 mm, 16.1 °C; Masada, northern Golan Heights: 1042 mm, 14.4 °C (Israel Meteorological Service)). 90% of the precipitation in northern Israel originates from the Mediterranean Sea and is brought by west winds caused by Mediterranean (Cyprus) cyclones (Dayan, 1986; Ziv et al., 2014).

The vegetation in the southern Levant is strongly influenced by precipitation rates but also by temperatures and soils. With decreasing precipitation values towards the south and east, Mediterranean woodland is displaced by Irano-Turanian steppe and Saharo-Arabian desert vegetation. The Sea of Galilee is situated in the Mediterranean vegetation belt. The region is generally characterized by arboreal climax communities (Zohary, 1962). Common trees are *Quercus* spp., *Pistacia* spp., *Ziziphus* spp., *Rhamnus* spp., *Ceratonia siliqua, Phillyrea latifolia, Styrax officinalis*, and several Rosaceae species. At higher altitudes, also conifers such as *Cedrus libani* and *Juniperus excelsa* are abundant (Baruch, 1986). The Jordan Valley south of the Sea of Galilee is characterized by Irano-Turanian steppe. This vegetation type consists mainly of herbs and dwarf shrubs and is dominated by *Artemisia herba-alba*. Nowadays, the vegetation in northern Israel is heavily altered due to human influences over several thousand years (Zohary, 1962).