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Climate change since the last glacial period in Lebanon and the persistence of Mediterranean species

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ABSTRACT

In this study, we quantified the mean January temperature (Tjan) and both winter (Pw) and summer (Ps) precipitation from three fossil pollen records from Lebanon. Tjan showed a strong correlation with the global temperature changes retrieved in the NGRIP Greenland ice core. The amplitude of ca. 8 °C between the Younger Dryas (YD) period and the Holocene is coherent with climate reconstructions from the Eastern Mediterranean.

The overall amount of precipitation was also lower during the YD than during the Holocene but the contrast between Pw and Ps was much more reduced (less than 2 times) during the YD than during the Holocene (up to 8 times). Such different seasonal contrast compare to the present day is coherent with some climate proxies from the Levant that tend to indicate the presence of moisture during the last glacial period. In effect, the low Pw during the YD reflects the replacement of the forest ecosystem by a more shrubby or herbaceous vegetation. Concomitantly, the occurrence of an amount of precipitation higher than the current one during the summer season, along with a reduced evaporation, due to lower temperature, may have contributed to some local observed high lake levels in the area.

During the last glacial period, Lebanon was not under a typical Mediterranean climate such as the one we know today, i.e. with a strong precipitation and temperature contrast between summer and winter seasons, but rather under a less contrasted climate. Mediterranean species persisted in this area due to the low amplitude of temperature change between the last glacial period and the Holocene as well as to an availability of moisture throughout the year instead of an occurrence mainly during the winter season as is the case today.

1. Introduction

Nowadays, the Mediterranean area is considered as a hotspot of biodiversity (Myers et al., 2000) due to the persistence of many endemic species over geological times (Biltekin et al., 2015; Van der Wiel and Wijmstra, 1987a, 1987b) during which climate has varied with strong amplitude (Tzedakis et al., 2003). This persistence of species in a specific area through highly contrasted climate periods reflects directly the regional persistence of part of its climatic niche through time. The Quaternary recorded major cyclic climate changes at the global scale (Berger, 1978; Hays et al., 1976; Imbrie et al., 1992; Ruddiman et al., 1989). Yet, some species have persisted in areas where the local (or regional) climate was buffered in comparison to the global climate changes. These areas are named refugia (Bennett and Provan, 2008), whether they are in a glacial or an interglacial period.

The most recent period when climate was much colder than today along with a decrease of more than 50% of the overall precipitation amount on the Mediterranean borderlands is known as the Last Glacial Maximum (LGM). Peterson et al. (1979) suggested that Eastern Europe was 12 °C colder than today during the LGM. Peyron et al. (1998) reconstructed the mean temperature of the coldest month in western Europe and the Mediterranean and showed that the LGM was 30 °C ± 10 °C colder than the present. This climate reconstruction has been re-evaluated by Jost et al. (2005) who have obtained a cooling that is between 17 °C and 26 °C. In a more recent study, Wu et al. (2007) reconstructed the January Temperature and obtained a cooling that is about 5 °C lower than Jost et al. (2005). The average disagreement between

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these climate reconstructions is about 9 °C (Wu et al., 2007). Overall, these studies tend to indicate that the LGM winter temperature was 10–20 °C colder than the present. Under such severe climate, the northern Mediterranean lands had suitable (micro) climates which played the role of climate refugium areas for many European species (Bennett et al., 1991; Hewitt, 2004; Petit et al., 2003). These glacial refugia were rather scattered areas than a continuous habitat (Médail and Diadema, 2009).

Locating glacial refugia is not only essential for basic science i.e. comprehending the propagation rates and patterns of species through space and time (I.e. Cheddadi et al., 2014; Magri et al., 2006; Svenning and Skov, 2007) and/or identifying where the common ancestors of the modern species are (i.e. Gavin and Fitzpatrick, 2014; Lockwood et al., 2013; Qiao et al., 2007) but also - and mostly - for elaborating conservation strategies for species under the ongoing global climate change (I.e. Keppel and Wardell-Johnson, 2012; Keppel et al., 2012, 2015). The refugia concept is not restricted to glacial periods, as some species will also have to survive in restricted areas during warm periods (Stewart et al., 2010; Bennett and Provan, 2008) when the global temperature will reach their extreme thermal niches.

The quantification of past climate estimations within the refugial areas and an evaluation of how buffered they have remained during the Earth's switch from glacial to interglacial climates (and vice versa) are necessary for the prediction of future species ranges. Thus, quantitatively reconstructing the past climate changes in a putative refugial area represents a basis for future conservation strategies.

The Mediterranean borderlands also served as glacial climate refugium for many species which did not expand over the European continent but remained *in situ* during the warmer periods of the Quaternary (i.e. Tzedakis et al., 2002). This is the case of populations of some well-known European species (Petit et al., 2003; Magri et al., 2006; Liepelt et al., 2009) but also of Mediterranean species that are not tolerant to frost for instance, such as the olive trees, evergreen oaks and pistachios, or species that are highly tolerant to long periods of drought, such as junipers and cedars. Thus, some species, such as the olive trees, persisted through geological times under unfavorable climates in thermophilous glacial refugia (Carrion et al., 2010) and became endemic today in the Mediterranean area (i.e. Besnard et al., 2013), potentially due to the fact that the regional climate remained buffered over glacial and interglacial times.

The Near East, including Lebanon territory, is considered as a hotspot of biodiversity (Myers et al., 2000) as well as a refugial area in the Mediterranean (Hajar et al., 2010a,b; Hajar et al., 2008; Médail and Diadema, 2009). Lebanon is a territory which represents the southernmost edge of the range of some valuable plant species such as firs and cedars. Genetic studies suggest that it is now crucial to evaluate the climate changes and their impacts at the rear edge of relict populations of species (Hampe and Petit, 2005; Petit et al., 2005) such as those found in Lebanon. This is the case of at least two emblematic species, the Cilician fir (*Abies cilicica*) and the Lebanese cedar (*Cedrus libani*) which are nowadays threatened (Awad et al., 2014; Fady et al., 2008) by severe land use change, ecosystem fragmentation and anthropogenic activities. *Cedrus*, which colonized the Near East from the Himalayan Mountains during the Tertiary (Qiao et al., 2007), persisted in the Anatolian flora since at least 23 Ma (Biltekin et al., 2015). The persistence of this species *in situ* over several glacial/interglacial cycles must necessarily have been permitted by a buffered climate. The question is how buffered the local/regional climate was in this refugial area, in comparison with the global one.

The main climatic long term changes in the Northern Hemisphere since the last glacial period have been well documented in many Eastern Mediterranean records. ^{18}O and ^{13}C stable isotopic records from speleothem records in the Levant suggest a prevalence of cold and dry conditions during the Last Glacial Maximum and an enhanced precipitation regime, which took place during the early Holocene (Bar-Matthews et al., 1997, 1999; Bar-Matthews and Ayalon, 2011; Robinson et al., 2006). However, the prevalence of dry conditions during the last glacial period and the Younger Dryas (YD) is challenged by the lake level reconstruction of the Dead Sea and lake Lisan (Stein et al., 2010; Torfstein et al., 2013a, 2013b) as well as by the analysis of stable isotopes from speleothems collected in Jeita cave in northern Lebanon (Cheng et al., 2015; Verheyden et al., 2008). Although Cheng et al. (2015) indicate that the Jeita record covers only the early part of the YD, they conclude that “the YD does not appear to be dry”.

The aim of the present study is to reconstruct past temperature and precipitation variables quantitatively from three unique fossil pollen records collected in Lebanon, discuss the regional climate variability and evaluate its potential suitability for the persistence of plant species since the last glacial period.

2. Materials and methods

2.1. Cores collection and pollen extraction

Three fossil records were collected in Lebanon (Fig. 1). A first coring of 540 cm length was extracted from Aammiq wetlands in the Beqaa valley (33°44′N, 35°47′E, 850 m asl) in January 2005 (Hajar et al., 2008) and a second one of 310 cm from Chamsine wetland (33°44′N, 35°57′E, 856 m asl) in April 2006 (Hajar et al., 2010a,b). A third coring of 300 cm was collected in the northern part of Lebanon in the Al Jourd marsh (34°21′N, 36°12′E, 2100 m asl, new data). Fossil pollen grains were extracted using a standard procedure (see i.e. Hajar et al., 2008) and synthetic pollen diagrams. The pollen percentages were computed on a sum that excludes aquatic plants as well as Compositae Subfam. Cichorioideae whose presence in the pollen records is strongly related to the local environmental changes (Hajar et al., 2010a,b).

2.2. Age/depth models

The three fossil records were dated using AMS ^{14}C dates (Table 1) then the carbon ages were calibrated using CALIB software with the calibration data set IntCal13 (Reimer et al., 2013). The age-depth models available for Ammiq and Chamsine records (Hajar et al., 2008, 2010a,b) as well as Al Jourd record were adjusted (Fig. 2) according to the marine chronostratigraphy proposed by Rossignol-Strick (1995). The latter chronostratigraphy suggests that continental pollen records from the Eastern Mediterranean - which span the last 20,000 years - have a time period marked by high proportions of pollen grains of Chenopodiaceae, which corresponds to the Younger Dryas chronozone (ca. 12900 to ca. 11700 cal BP) in marine pollen records (Rossignol-Strick, 1995). The Chenopodiaceae phase has been assigned to the YD in the Eastern Mediterranean since the radiometric datings do not allow the performance of a coherent correlation between pollen records (Bottema, 1995). Based on these earlier synthetic palynological works for the Eastern Mediterranean, we assigned the inception of the Chenopodiaceae phase and its decline in the three records to 12,900 and to 11,700 cal BP, respectively (Table 1). In order to delineate the upper boundary of the YD (11,700 cal BP) more accurately from the pollen data, we took into account the early and steady re-expansion of the evergreen oaks as a marker of the end of the cold phase. The lower boundary (12,900 cal BP) is marked by a synchronous decline of both the evergreen oaks and Poaceae and the expansion of the Chenopodiaceae, which mark