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An expanded ostracod-based conductivity transfer function for climate reconstruction in the Levant

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A B S T R A C T

We present the first modern calibration dataset linking ostracod assemblage composition to water chemistry, and other site-specific variables, in the hydrologically and geopolitically sensitive southern Levant region. A total of 42 ostracod taxa were recorded from the 178 sampled sites in Israel and Jordan. *Ilyocypris* spp., *Heterocypris salina* and *Cypridopsis vidua* are the most abundant taxa. Species strictly confined to freshwater conditions are *Prionocypris zenkeri*, *Gomphocythere ortali* and *Prionocypris olivaceus*. In contrast, *H. salina*, *Bradleytriebella lineata* and *Cyprideis torosa* show high frequencies in brackish waters (waters with higher conductivity). *Humphcypris subterranea*, *G. ortali*, *P. olivaceus* and *Cypridopsis elongata* apparently prefer flowing waters. Specific conductivity optima and tolerance ranges were calculated for the recorded ostracod species and may be used for the palaeoenvironmental assessment of fossil ostracod assemblages. In addition, a transfer-function for quantitative specific conductivity estimation based on 141 samples was established with weighted averaging partial least squares regression (WA-PLS). The resulting coefficient of determination r^2 between observed and predicted conductivity values (0.72) and the root-mean-square error of prediction (RMSEP) in % gradient length (13.1) indicate that conductivity may be reliably estimated from ostracod assemblage data. The transfer function was first applied to last glacial ostracod assemblage data from an archaeological trench in the Sea of Galilee (northern Israel). Relatively large conductivity fluctuations between ca 1 and 7 mS cm^{-1} were inferred for the period 24–20 cal ka BP. In addition, four episodes of freshwater influx near the site of the trench were identified from the presence of shells of freshwater and stream-dwelling species intermingled with very abundant shells of *Cyprideis torosa*. The results of our study allow a better use of Quaternary ostracods from the Levant as palaeoenvironmental indicators of water-body types and past conductivity levels and will contribute to a better understanding of Quaternary environmental and climate change in the Levant.

1. Introduction

Water is an invaluable resource especially in semi-arid to arid regions such as the Levant where freshwater reserves are limited and not easily replenished (Robins and Fergusson, 2014). The competition for water security has already led to political crises in this region and is regarded as a major threat potentially causing future armed conflicts (Trottier, 2003; Phillips, 2012). The Levant is an old cultural area where people have adapted to sub-humid to semi-arid conditions over thousands of years. However, population growth, partly caused by migration due to political conflicts and pronounced drought in the most recent decades increases the pressure on the freshwater resources of the region (Kafle and Bruins, 2009). The exploitation of groundwater has already

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caused lowered groundwater levels and the desiccation of surface waters (El-Naqa et al., 2007; Sherzer, 2010). Knowledge of the natural variability of the water availability and the degree of human impact on the hydrological system is therefore crucial for the society and planning authorities. To better manage the region's resource we must understand the natural variability of effective moisture (precipitation minus evaporation), and the degree to which hydrological systems and especially groundwater resources have already been changed by man in the Levant.

Evidence for wetter conditions in the Pleistocene in present-day semi-arid to arid regions of the Levant comes from large endorheic basins such as Azraq, Al Jafr, the Dead Sea and Mudawwara (Davies, 2004; Petit-Maire et al., 2010; Jones and Richter, 2011; Torfstein et al., 2013) and some smaller valleys such as Arava/Araba Valley, Nahal Zihor, Wadi Burma, Wadi Hasa, and Yammoûneh Basin (Livnat and Kronfeld, 1990; Ginat et al., 2003; Moumani et al., 2003; Develle et al., 2010; Winer, 2010). One of the most widespread bioindicators preserved in these lake and wetland sediments are the remains of micro-crustaceans, the shells of ostracods (Huckriede and Wiesemann, 1968; Livnat and Kronfeld, 1990; Ginat et al., 2003; Moumani et al., 2003; Rosenfeld et al., 2004; Develle et al., 2010; Petit-Maire et al., 2010; Winer, 2010). Based on a comparison of the modern distribution of ostracod species in different water body types such as lakes, ponds, streams and springs and their preferences with respect to water chemistry, temperature, oxygenation and other variables, fossil assemblages can be used to characterize past aquatic habitats in detail (Boomer et al., 2003; Forester et al., 2005; Frenzel and Boomer, 2005). Transfer functions based on the modern distribution of ostracods in water bodies of a specific region provide means for detailed quantitative reconstructions of past hydrochemical conditions (Mezquita et al., 2005; Mischke et al., 2010; Reed et al., 2012). Analyses of the characteristics of modern aquatic habitats and their ostracod populations provide important information on potential analogues for comparison with Pleistocene water bodies in the Levant. Such modern study must be carried out now before many natural water bodies disappear in response to groundwater exploitation and recent drought in the region (El-Naqa et al., 2007; Kafle and Bruins, 2009; Sherzer, 2010).

Mischke et al. (2010) presented a first ostracod-based transfer function for specific conductivity (SC) reconstruction for a data set of 56 samples collected between 2001 and 2008 in northern and central Israel. Their calibration data set covered an SC gradient of 0.3–12.5 mS cm^{-1} and included 22 ostracod species. The low number of sites, the relatively small SC gradient and low number of included ostracod species all limit, however, the applicability of the transfer function of Mischke et al. (2010) for fossil assemblage data. As a consequence, we conducted field measurements and collected sediment and water samples from 117 additional sites in Israel and Jordan to increase the SC gradient and the number of ostracod species included in the calibration data set with the aim of obtaining more reliable quantitative environmental reconstructions of Quaternary water bodies in the region.

2. Study area

The sampled area covers a 200 km wide and 500 km long strip along the Dead Sea Transform (DST) in Israel and Jordan (Fig. 1). The region is characterized by large geographical contrasts mostly reflecting topographical differences and the distance to incoming moisture: the humid maritime coast of the Mediterranean Sea in the west, the uplands of the Golan Heights, Upper Galilee, the Judean Mountains and the Jordan Plateau on both sides of the DST, and the hyperarid regions around the Dead Sea and farther to the south and east. Upper Cretaceous to Paleogene limestones and marls are widely exposed in the area, basalts are abundant in the northeastern part, Lower Cambrian sandstones and Precambrian magmatic rocks dominate in the southeast and Quaternary unconsolidated sediments are mostly found on the coastal plain and in the Jordan and Arava/Araba valleys (Bender, 1968; Sneh et al., 1998). The large altitudinal contrasts are also reflected by regional climate gradients. Annual precipitation is as high as 800–900 mm on the southern slopes of Mount Hermon and on the Golan Heights in the north and decreases to less than 50 mm in the south and in the easternmost region of the sampled area (Bitan and Rubin, 1994; Israel Ministry of Agriculture, unpublished data; Israel Meteorological Service, unpublished data; ESM S1). Precipitation mainly arrives in winter from mid-latitude cyclones (Cyprus Low) during their eastward passage over the Eastern Mediterranean. The mean annual temperature is in a range from 16 to 24 °C, mean January temperatures are between 6 and 15 °C and mean July temperatures between 23 and 33 °C, depending on altitude and distance from the sea (ESM S1). The resulting vegetation ranges from broad-leaved forests on the slopes of Mount Hermon and the Golan Heights to sparse desert vegetation in the south and east.

3. Material and methods

3.1. Sampling and field measurements

A previously presented ostracod calibration data set comprising 37 samples with full environmental data and 24 supplementary samples with SC data from Israel (Mischke et al., 2010) was enlarged by newly collected 117 surface sediment samples from water bodies in Israel and Jordan. Similar to the initial study, surface sediments (130–330 mL from the uppermost 1 cm) were collected by hand in very shallow water bodies. A Hydro-Bios-Ekman grab was used at deeper sites. The uppermost 1 cm of recently accumulated sediments was collected on the assumption that it contained ostracod shells produced during the full-year's cycle and thus represent the fauna at a specific site. Deeper infaunal species are ignored by this sampling approach but it is regarded as the optimal way to obtain the most recently formed ostracod shells which represent the modern hydrological conditions. Decrouy et al. (2012) showed that infaunal species in Lake Geneva usually have highest abundances in the uppermost 1 cm of sediments and decreasing abundances below. Hence the effect of our sampling method on infaunal species is not considered to be significant.

Hydrological variables such as SC, pH, dissolved oxygen (DO) concentration and saturation, Secchi depth, water depth and temperature were measured prior to sediment sampling. A multi-parameter WTW 340i device was used for measurements of SC, DO, pH and water temperature; and a hand-held echo-sounder for water-depth readings at deeper sites. Water samples for analyses of major anions, cations and stable isotopes were collected at 0.1 m below surface. Cation samples were acidified with 100 µL of 65% HNO_3. Alkalinity was determined with a Macherey–Nagel AL 7 titration test kit in the field or determined by titration with 0.5 N HCl at the Geological Survey of Israel soon after sampling.

3.2. Laboratory analyses

Sediment samples were either kept cool and subsequently washed through 1000, 250 and 100 µm sieves or freeze-dried prior to sieving. Adult and late-instar ostracod shells were mainly collected from the 250–1000 µm fraction but the other two fractions were also screened to include very large shells and to check the presence of very small species. Generally, at least 300 and up to 730 ostracod shells were picked per sample under a low-power binocular microscope. If 300 shells were not present in a sample, all