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1 **Climate and environmental reconstruction of the Epipaleolithic**
2 **Mediterranean Levant (22.0-11.9 ka cal. BP)**

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13
14 **Abstract**

15 This study presents, for the first time, an environmental reconstruction of a sequence
16 spanning nearly the entire Mediterranean Epipaleolithic (~22.0 to 11.9 ka cal. BP).
17 The study is based on a well-dated, high-resolution pollen record recovered from the
18 waterlogged archaeological site Jordan River Dureijat (JRD), located on the banks of
19 Paleolake Hula. JRD's continuous sequence enabled us to build a pollen-based
20 paleoclimate model providing a solid background for the dramatic cultural changes
21 that occurred in the region during this period. Taxonomic identification of the
22 waterlogged wood assemblage collected from JRD was used to fine-tune the
23 paleoenvironmental reconstruction. The chronological framework is based on
24 radiocarbon dating and the typology of archaeological findings. The LGM (~22-19 ka
25 cal. BP) was found to be the coldest period of the sequence, marked by a distinct
26 decrease in the reconstructed January temperatures of up to 5°C lower than today,

27 while mean annual precipitation was only slightly lower than the present-day average
28 (~450 vs. 515 mm, respectively). The wettest and warmest period of the record was
29 identified between ~14.9 to 13.0 ka cal. BP, with maximum values of 545 mm mean
30 annual precipitation reached at ~14.5 ka cal. BP. This time interval is synchronized
31 with the global warm and moist Bølling-Allerød interstadial as well as with the onset
32 of the Natufian culture and the emergence of sedentism in the Levant. The Younger
33 Dryas began around 12.9 ka cal. BP and was identified as an exceptional period by
34 the JRD sequence with low temperatures and minimal climatic seasonality contrast:
35 an increase in rain contribution during spring, summer, and autumn was documented
36 concurrently with a significant decrease in winter precipitation. The detailed
37 vegetation and climatological reconstruction presented in this study serves as
38 backdrop to seminal events in human history: the transition from small nomadic
39 groups of hunter-gatherers to the sedentary villages of the Natufian, eventually
40 transitioning to the agricultural, complex communities of the Neolithic.

41

42 **Keywords**

43 Palynology; Last Glacial Maximum; Younger Dryas; Eastern Mediterranean; paleoclimate
44 modeling; Levantine Epipaleolithic; Natufian; waterlogged-wood; sedentism and agriculture

45

46 **1. Introduction**

47 The period between the Last Glacial Maximum (LGM; ~23-19 ka BP) and the
48 beginning of the Holocene interglacial (~11.7 ka BP) was an era of dramatic climatic
49 changes in the northern hemisphere. This time interval accompanied the transition

50 from the Last Glacial period to the Post-Glacial period, which was punctuated by
51 short-term climatic phases (LGM, Heinrich Event 1, Bølling-Allerød, and the
52 Younger Dryas). Yet, the actual impact of these global changes on the local
53 Mediterranean southern Levant environment and climate (Figure 1) is under debate.
54 Studies of Lake Lisan, the late Pleistocene precursor to the Dead Sea, demonstrated
55 that a high lake stand occurred during the last glacial (Bartov et al., 2002, 2003, 2006,
56 2007; Haase-Schramm et al., 2004; Torfstein and Enzel, 2017). It is argued that the
57 existence of the larger Lake Lisan during the glacial period, compared to the
58 Holocene's smaller Dead Sea, required significantly more rainfall (Zak, 1967; Begin
59 et al., 1974; Bartov et al., 2002, 2003, 2006, 2007; Hazan et al., 2005; Kolodny et al.,
60 2005; Bookman et al., 2006; Enzel et al., 2008; Stein, 2014). Most speleothem records
61 from the Mediterranean southern Levant (Soreq and Peqi'in caves) indicate
62 contradictory, dry conditions during the last glacial period (Bar-Matthews et al., 1997,
63 1999, 2003, 2017, 2019).

64 Archaeologically, the time interval between the LGM and the Holocene is known in
65 the Levant as the Epipaleolithic period and is characterized by significant cultural
66 changes. It marks the shift from small nomadic groups of hunter-gatherers into larger
67 and complex communities accompanied by reducing population mobility patterns and
68 changing subsistence strategies, leading to the establishment of the sedentary
69 agricultural communities of the Neolithic (Belfer-Cohen and Goring-Morris, 2013,
70 2014; Bar-Yosef, 2014). The interrelationship between climate and culture is a key
71 question in Levantine Epipaleolithic research. Correlation between these two sets of
72 evidence has proven difficult to achieve (Wright, 1993; Goring-Morris and Belfer-
73 Cohen, 1997; Maher et al., 2011, 2012; Belfer-Cohen and Goring-Morris, 2013;
74 Belmaker, 2017). The discussion is hampered by the scarcity of both continuous,

75 well-dated Levantine Epipaleolithic sequences documenting cultural changes, and
76 environmental datasets that derive directly from Epipaleolithic sites. The paucity of
77 past environmental information is mainly due to poor preservation of organic remains
78 and is particularly true for the Early and Middle Epipaleolithic in the Mediterranean
79 zone of the southern Levant.

80 In this study, we present a high-resolution, continuous fossil pollen record that was
81 recovered from a sediment outcrop at the Epipaleolithic site of Jordan River Dureijat
82 (JRD). JRD is located at the southern edge of the Hula Basin, on the shore of
83 Paleolake Hula. Its archaeological sequence is dated from ~20 to 10 ka cal. BP
84 (Sharon et al., 2020). Previous palynological studies from Paleolake Hula were
85 analyzed at relatively low resolution and/or suffered from chronological uncertainties
86 (Horowitz, 1971, 1979; Tsukada, cited in Bottema and van Zeist, 1981; Weinstein-
87 Evron, 1983; Baruch and Bottema, 1999; Meadows, 2005; Van-Zeist et al., 2009).
88 Palynological records from nearby archaeological sites were retrieved from much
89 shorter time spans of the Epipaleolithic (Weinstein-Evron et al., 2015) or from
90 different periods (Aharonovich et al., 2014). Here we provide a well-dated, high-
91 resolution palynological record that encompasses all Levantine Epipaleolithic phases
92 from which we have generated a quantitative reconstruction of the period's climate
93 changes. Additionally, we used taxonomic identification of JRD's waterlogged wood
94 assemblage to fine-tune our paleoclimate model. Currently, this is the only
95 consecutive, regional wood record that covers the entire Epipaleolithic period.
96 Previous dendroarchaeological studies from the Mediterranean southern Levant were
97 limited to short time intervals within the Epipaleolithic. These include the wood and
98 charcoal assemblage from the 23 ka cal. BP Ohalo II site located on the shore of the
99 Sea of Galilee (Liphschitz and Nadel, 1997; Nadel and Werker, 1999) and the

100 Natufian wood-charcoal remains recovered from the El-Wad site on Mount Carmel
101 (Lev-Yadun and Weinstein-Evron, 1994; Caracuta et al., 2016). Because many
102 Epipaleolithic Levantine archaeological sites are small and ephemeral, they are
103 characterized by relatively poor preservation of botanical remains, resulting in limited
104 and inconsistent environmental information. In contrast, JRD not only includes an
105 assemblage of waterlogged wood, it is also endowed with a well-preserved, high-
106 resolution fossil pollen record.

107 The pollen-based paleoclimate reconstruction presented in this study offers a
108 significant contribution to two primary research questions: First, what were the
109 climate conditions in the Mediterranean Levant during the end of the last glacial
110 period, and second, did the dramatic climate changes during the end of the Pleistocene
111 impact the cultural shift to sedentism and agriculture?. With regard to climate
112 conditions, the climate reconstruction of seasonal changes of both precipitation and
113 temperatures presented here contributes to unraveling the regional discrepancy
114 between the observed lake level datasets and inferred amounts of annual precipitation
115 derived from cave speleothem isotopes.

116

117 **2. Research Area**

118 **2.1 Location and geographical settings**

119 The JRD archaeological site is situated in the Hula Valley, a northern section of the
120 Levantine segment of the Syrian-African Rift system (also referred to as the northern
121 Jordan Rift Valley). This narrow and elongated valley is a pull-apart basin (Schattner
122 and Weinberger, 2008; Heimann et al., 2009). Until the mid-twentieth century, the
123 shallow Lake Hula occupied the southern part of this small valley. The lake had a

124 surface area of some 14 km², bordered on the north by extensive swamp area (> 30
125 km²; Figure 2; Dimentman et al., 1992). Large-scale drainage operations carried out
126 during the 1950s drained most of the lake, leaving only a small nature reserve.
127 Evidence from JRD indicates that during the end of the Pleistocene-early Holocene,
128 Paleolake Hula extended more than 2 km south of its historically documented
129 boundaries (Figure 2; Sharon et al., 2002).

130 The Hula Valley is bordered by the Naftali carbonate mountains of the Upper Galilee
131 (700–900 meters above sea level; m asl) to the west, Mt. Hermon (up to 2,814 m asl)
132 to the northeast, and the basaltic Golan Heights (ca. 1,000 m asl) to the east (Figure
133 2). To the south, the basin is flanked by the Korasim basaltic block, damming the
134 Hula Valley at its southern end. Lakes and swamps have occupied the southern half of
135 the Hula Valley at least since the early Pleistocene, which, in combination with the
136 continuous subsidence of the valley floor, has resulted in thick lacustrine, peat, and
137 lignite deposits. The northern part of the valley is composed of alluvial soil deposits
138 (Horowitz, 1979; Dimentman et al., 1992; Belitzky, 2002).

139 The largest stream in the area is the Jordan River. It flows south, feeding the Sea of
140 Galilee, and continues through the Lower Jordan Valley where it finally outflows into
141 the Dead Sea (Figure 1). At its outflow south from the Hula Basin, the Jordan River
142 flows at the boundary of two tectonic plates, the Sinai sub-plate (a segment of the
143 African plate) to the west, and the Arabian plate to the east. The sediment formations
144 exposed at the river banks range in age from the Pliocene to Holocene (Horowitz,
145 1973, 2001; Belitzky, 1987). The JRD site, located 60-70 m asl, was discovered
146 during an archaeological survey preceding a massive drainage operation of the Jordan
147 River in December 1999. The archaeological material-bearing horizons of JRD stretch

148 over 50 m on the east bank of the artificial Jordan River trench south of the outlet of
149 the small Dureijat Stream (Sharon et al., 2002; Marder et al., 2015).

150 The Hula Valley and its surroundings are characterized by a typical Mediterranean
151 climate. Rain falls almost exclusively during winter and spring, and summers are hot
152 and dry. Temperature and precipitation vary considerably with altitude and latitude.
153 The mean annual rainfall is 400–520 mm in the valley and above 600 mm in the
154 mountain ranges bordering to the west and east (Figure 1b). Inter-annual variations in
155 precipitation are mainly influenced by the strength of the Cyprus Low systems (Ziv et
156 al., 2006). At Ayelet Hashahar, the nearest meteorological station west of JRD, mean
157 temperatures in January and August are 11°C and 29°C, respectively. The mean
158 annual temperature is 21°C and mean annual precipitation is 515 mm (Figure 3a;
159 Israel Meteorological Service, 2020).

160 From the pattern of current wind direction and intensity (Figure 3b), it is suggested
161 that the wind-borne pollen is embedded in the valley's deposits by the dominant winds
162 from the northwest, together with a degree of contribution from the east, north and
163 south, mainly during winters. The pollen grains are then spread throughout the valley
164 by the most common local winds, the northern and southern winds, which change
165 direction during the day (Weinstein-Evron, 1983; Israel Meteorological Service,
166 2020). Pollen grains that are deposited by fluvial transportation originate primarily
167 from the north, transported by the Jordan River and its tributaries. Some contribution
168 is observed, however, from smaller streams, originating from the Golan Heights in the
169 east and the Naftali ridge in the west (Weinstein-Evron, 1983; Aharonovich et al.,
170 2014).

171 2.2 Vegetation

172 The region supports typical Mediterranean vegetation. Beyond the lake and
173 marshland, the natural vegetation of the Hula Valley and the nearby lower slopes is
174 the *Quercus ithaburensis* – *Pistacia atlantica* (Mount Tabor oak – Atlantic terebinth)
175 woodland or park-forest (Zohary, 1973, 1982). The open terrain between the widely
176 spaced trees is covered by herbaceous vegetation, while various shrubs such as *Styrax*
177 *officinalis* (storax), *Ziziphus lotus* (wild jujube) and *Ziziphus spina-christi* (Christ's
178 thorn jujube) also form part of the woodland vegetation. To the east of the Hula
179 Basin, on the west-facing slopes of the Golan Heights, at elevations of above 500 m,
180 the thermophilic deciduous Mount Tabor-oak woodland is replaced by woodland
181 formations of evergreen *Quercus calliprinos* (Kermes oak). As elevation increases, on
182 the northern Golan Heights and Mount Hermon, this evergreen oak is joined by the
183 deciduous oak *Quercus boissieri* (Aleppo oak). To the west of the valley, at elevations
184 above 400–500 m, the Mount Tabor-oak woodland zone is succeeded by a belt of
185 *Pistacia atlantica* – *Amygdalus korschinskii* (Atlantic terebinth – wild almond)
186 woodland (Zohary, 1973), which, in turn, above 700 m is replaced by *Quercus*
187 *calliprinos* – *Pistacia palaestina* forest/maquis. *Quercus boissieri* is present on the
188 highest summits of the Upper Galilee, alongside evergreen oak.

189 In the Hula Valley, on banks of permanent and intermittent water currents, various
190 trees and shrubs are found including: *Tamarix jordanis* (Jordanian tamarisk), *Populus*
191 *euphratica* (Euphrates poplar), *Platanus orientalis* (oriental plane), *Salix acmophylla*
192 (brook willow), *Salix alba* (white willow), *Ulmus minor* (field elm) and *Fraxinus*
193 *syriaca* (ash). The vegetation of the marshland north of the now drained Hula Lake is
194 dominated by *Cyperus papyrus* – *Polygonum acuminatum* (= *Persicaria acuminata*)
195 association accompanied by various other marsh plants such as *Thelypteris palustris*

196 (= *Dryopteris thelypteris*), *Rorippa amphibian* (great yellowcress), *Galium elongatum*
197 (marsh bedstraw), and *Lycopus europaeus* (bugleweed) (Zohary, 1973; Dimentnan et
198 al., 1992). Before the draining, a few other marsh-plant associations formed the outer
199 belt of the swamp (Zohary, 1973, 1982). On the east and west, the lake was fringed by
200 a marsh-vegetation belt consisting of riparian plants such as: *Phragmites australis*
201 (common reed), *Typha latifolia* (bulrush), *Scirpus lacustris* (common club-rush),
202 *Sparganium erectum* (simplestem bur-reed), *Lythrum salicaria* (purple loosestrife),
203 *Mentha longifolia* (horse mint), and *Cyperus longus* (galingale). Water plants
204 included a few *Potamogeton* (pondweed) species, *Myriophyllum spicatum* (spiked
205 water-milfoil), *Nuphar lutea* (yellow water-lily), *Nymphaea alba* (white water rose),
206 *Ceratophyllum demersum* (hornwort) and *Ranunculus peltatus* (= *aquaticus*, pond
207 water-crowfoot; Van-Zeist et al., 2009). Currently, the natural landscape of the Hula
208 Valley is heavily damaged due to millennia of overgrazing, tree clearance and
209 agricultural activities (Palmisano et al., 2019: fig. 8). The natural vegetation is
210 restricted to protected areas and to less accessible deep canyons and steep mountain
211 slopes.

212

213 **2.3 The archaeological site of Jordan River Dureijat (JRD)**

214 For over 10,000 years, during the Epipaleolithic period, people repeatedly returned to
215 the site of JRD on the shore of Paleolake Hula to fish, hunt, and exploit other aquatic
216 resources (Sharon et al., 2020). The excavation exposed a thick sequence of sediments
217 that accumulated within the fluctuating water levels of Paleolake Hula. The
218 archaeological horizons were deposited within near-shore layers that were embedded
219 during low water stands. These layers are separated by archaeologically sterile, fine
220 silt layers, deposited during higher water stands of the lake. The stratigraphic

221 sequence and chronology were established in Area B, the primary site excavation
222 area. The chronology was based on numerous radiocarbon dates obtained on wood-
223 charcoal remains (Sharon et al., 2020). The lowest excavated layer (Layer 5) dates to
224 ~20 ka cal. BP and is characterized by an Early Epipaleolithic lithic tradition. The
225 lithics from Layer 4 ascribed to the Middle Epipaleolithic, i.e., the Geometric
226 Kebaran tradition and date to 17.46-15.75 ka cal. BP. The three upper layers, 3c, 3b
227 and 3a, belong to the Late Epipaleolithic Natufian culture (15-11.5 ka cal. BP) based
228 on radiocarbon dates and on the presence of typical flint artifacts such as microlithic
229 lunates (Grosman, 2018; Sharon et al., 2020).

230 The unique waterlogged conditions at the site captured an unusually well-preserved
231 record of perishable plant remains attesting to both human activities and to the local
232 environmental conditions along much of the Epipaleolithic (Sharon et al., 2020). The
233 primary activity documented at the JRD archaeological horizons was fishing (Figure
234 4; Pedergrana et al., in press) and utilization of additional aquatic resources such as
235 mollusks, crabs, amphibians, turtles and, equally significant, aquatic and near-shore
236 plants (Sharon et al., 2020). The importance of fishing is evident by the presence
237 throughout the sequence of limestone cobbles that served as net sinkers, forming the
238 largest collection of such tools in the Levant (Sharon et al., 2020). Fishbones are also
239 abundant in all archaeological layers. In the Natufian layers, as many as 19 bone
240 fishhooks were found, accompanied by small grooved pebbles used as line weights
241 (Sharon et al., 2020; Pedergrana et al., in press). The presence of shell horizons
242 (Sharon et al., 2020), the wealth of mollusk shells and of non-marine ostracod taxa
243 (Björgvinsson, 2017), and the high number of valves (Valdimarsson, 2017), also point
244 to the existence and exploitation of a shallow freshwater lake environment at JRD.

245

246 **3. Materials and Methods**

247 **3.1 Archaeological context and chronology**

248 The eastern border of Area B (the primary archaeological excavation area; 33°1'19N /
249 35°37'41E) is the type locality for the site's full stratigraphic sequence. This outcrop
250 forms the longest exposure of the site's sedimentology and yielded both palynological
251 and ¹⁴C radiocarbon samples (Sharon et al., 2020). Several lines of evidence indicate
252 that the sedimentation environment of the JRD archaeological horizons is a nearshore
253 water stand (shallow lake environment). Hence, the horizons document fishing and
254 aquatic resources utilization during short-term visits rather than a long-term
255 permanent occupation. This reconstruction explains, for example, the absence of
256 identified hearths at the site, coupled by a widespread distribution of charcoal remains
257 throughout the layers. This is probably due to the flooding of small fire-places by
258 rising lake water levels and spreading of charcoals on the surface. This reconstruction
259 of wet depositional environment also explains the excellent preservation of pollen and
260 wood remains, as well as other botanical remains (charcoal, seeds, fruits) in the site's
261 waterlogged layers.

262 Even if the context of the archaeological remains is not that of a settlement (Figure 4),
263 the stratigraphy and archaeological context of the finds are secure, due to the
264 separation of the archaeological horizons by sterile layers of fine silt formed during
265 high water lake stands. Hence, each assemblage has good chronological control.
266 Furthermore, there is a clear chrono-cultural affinity between the various flint tools
267 and the specific layers from which they originated (Sharon et al., 2020). This solid
268 stratigraphy of cultural sequences enables correlation of specific pollen zones to
269 specific cultural units and discussion of their interrelations (Figure 5).

270 The eight ^{14}C radiocarbon samples used for the chronological age-depth model in the
 271 current study (Table 1) were selected from the available JRD dates (Sharon et al.,
 272 2020: table 1). These samples were chosen due to their location in the eastern
 273 sediment outcrop, as well as for their reliability (dubious samples due to size or state
 274 of preservation were excluded). The aim was to achieve good chronological control
 275 and the highest possible accuracy. All the wood and charcoal remains submitted for
 276 ^{14}C radiocarbon dating were identified as terrestrial plants to avoid bias from the
 277 reservoir effect of the water body. When possible, young branches rather than old or
 278 unknown wood trunk sections were preferred for radiocarbon dating.

279 The ^{14}C samples were analyzed at the Poznań Radiocarbon Laboratory and at the Beta
 280 Analytic Laboratory. ^{14}C ages were calibrated using the default calibration data set
 281 IntCal13 northern Hemisphere radiocarbon (Table 1). The age-depth model presented
 282 in Figure 6 was processed using the Bayesian Bacon 2.3.6 software package (Blaauw
 283 and Christen, 2011).

284 **Table 1:** ^{14}C radiocarbon ages of wood remains used in the age-depth model. Both the
 285 wood and pollen samples were extracted from the same eastern sediment outcrop.

Lab. Number	Depth, above sea level (m)	Archaeological layer	^{14}C Age (cal. yrs BP)	Calibrated age range, 1σ (cal. yrs BP)	Calibrated age range, 2σ (cal. yrs BP)
Poz-94159	57.73	3-0	$10,010 \pm 60$	11,391 – 11,620	11,269 – 11,744
Beta-457488	57.15	3b	$11,490 \pm 40$	13,316 – 13,411	13,298 – 13,462
Poz-94158	57.03	3c	$12,350 \pm 60$	14,181 – 14,475	14,102 – 14,617
Beta-457489	56.73	3c	$13,320 \pm 40$	15,933 – 16,105	15,841 – 16,182
Poz-94160	56.58	4b	$13,960 \pm 80$	16,839 – 17,081	16,657 – 17,142
Poz-100258	56.49	4c	$14,433 \pm 40$	17,456 – 17,627	17,397 – 17,823
Poz-100321	55.98	5	$16,612 \pm 72$	19,950 – 20,179	19,874 – 20,293
Poz-100295	55.40	6	$16,867 \pm 71$	20,312 – 20,480	20,200 – 20,542

286

287 **3.2 Palynology**

288 Fifty-four sediment samples were collected for palynological investigation from the
289 JRD eastern sediment outcrop during the 2016 and 2017 excavation seasons (Figure
290 5). Samples of 1-cm thickness were taken at 5-cm intervals along the 2.70-m long
291 sequence from 55.33 to 58.03 m asl. In addition, a recent Jordan River mud surface
292 sample was collected ca. 20 m east of the sediment outcrop to examine the
293 relationship between the fossil pollen results and the modern pollen rain in the region.

294 Pollen extraction procedure followed a physical-chemical treatment successfully
295 employed in other Dead Sea Rift Valley lacustrine sediments (Langgut et al., 2014a).
296 Samples were immersed in HCl to remove the calcium carbonates. In order to float
297 the organic material, a density separation was carried out using a ZnBr₂ solution (with
298 a specific gravity of 1.95), together with 5 min of sonication. After sieving (150 µm
299 mesh screen), the unstained residues were homogenized and mounted onto
300 microscope slides using glycerin. Acetolysis was not carried out in order to enable the
301 identification of any non-pollen palynomorph (NPP) such as algae (e.g., Langgut,
302 2018). Pollen grains were identified under a light microscope at magnifications of
303 200×, 400× and 1,000× (oil immersion), to the most detailed possible systematic
304 taxonomic level. For pollen identification, a comparative reference collection of the
305 Israeli pollen flora of Tel Aviv University (The Steinhardt Museum of Natural
306 History) was used, in addition to pollen atlases (Horowitz and Baum, 1967; Reille,
307 1995, 1998, 1999; Beug, 2004). At least 500 pollen grains were counted from each
308 sample.

309 For the preparation of the palynological diagram (Figure 7), PolPal software was used
310 (Walanus and Nalepka, 1999). The total sum of the palynological diagram is
311 composed of Arboreal Pollen (AP, trees and large shrubs) and Non-Arboreal Pollen

312 (NAP). The latter includes herbaceous plants and dwarf shrubs of the upland
313 vegetation. The proportions of all pollen taxa are expressed as percentages of this
314 total pollen sum. Pollen taxa counted in less than five samples were not included in
315 the pollen diagram (for a detailed palynological diagram that presents all identified
316 taxa, see Figure A1). Cyperaceae, *Sparganium*, *Typha*, *Phragmites* type and various
317 trees and shrubs that inhabit banks of permanent and intermittent streams such as
318 *Salix*, *Tamarix* and *Vitis* were grouped together. This group was excluded from the
319 basic sum (AP + NAP) but was calculated as ratios of the total sum. Aquatic plants
320 and spores were not included in the total sum and are presented in the last section of
321 the pollen diagram. This category also includes spores and the green algae
322 *Pediastrum* (*P. simplex* type and *P. boryanum* type). The zonation of the pollen
323 record is based primarily on changes in AP/NAP ratios, together with principal
324 component analysis (PCA) and cluster analysis.

325

326 **3.3 Waterlogged wood**

327 The waterlogged, un-burned wood fragments exposed during the JRD excavation
328 were recorded on-site using a Leica Total Station to indicate their exact location. All
329 excavated sediments were collected from sub-squares, wet sieved in the Jordan River
330 and sorted for wood remains. The remains were stored in plastic bags, covered with
331 water and transferred to the Laboratory of Archaeobotany and Ancient Environments,
332 Tel Aviv University, for identification, analysis and conservation.

333 Wood remains were identified to the lowest possible taxonomic level. Each wood
334 sample was cut and examined along three observational axes (transverse, radial
335 longitudinal and tangential longitudinal) using a stereoscopic Carl Zeiss SteREO
336 Discovery.V20 microscope with magnifications of up to 360× under oblique-angled

337 top-lighting. A Scanning Electron Microscope (SEM: Tescan VEGA 3) was used
338 when higher magnifications were needed. The abundance, arrangement and size of the
339 wood's anatomical structures (e.g., vessels, rays, fibers, annual growth rings), along
340 with several other diagnostic characteristics of the eastern Mediterranean arboreal
341 flora, were noted. Observations were compared with the modern reference collection
342 of tissue structure of the southern Levant flora (The Steinhardt Museum of Natural
343 History) and with literature on plant anatomy (Fahn et al., 1986; Wheeler et al., 1989;
344 Schweingruber, 1990; Richter et al., 2004; Akkemik and Yaman, 2012; Crivellaro and
345 Schweingruber, 2013).

346

347 **3.4 Paleoclimate reconstruction**

348 The pollen-based climate reconstruction enabled us to quantify monthly precipitation
349 and temperature for the time span encompassed by the JRD fossil pollen record
350 (Figure 8). The statistical approach used to infer the climate variables from pollen
351 samples was designed to minimize two major, known palynological difficulties: (1)
352 the potential lack of analogy between the fossil pollen assemblages and the modern
353 ecosystems; and/or (2) the potential adaptation of species to different climatic ranges
354 over time which may lead to a misuse of the modern climate to infer past climate
355 variables (Cheddadi et al., 2016, 2017). The model applied in the current study
356 hypothesizes that plant species may co-occur only if their climatic ranges intersect.
357 The first step of the climate reconstruction was the assignment of the fossil pollen
358 taxa to their most probable corresponding present-day plant species. In the second
359 step, we computed the weighted median of the present-day climatic range of each
360 assigned species (Figure A2). The reconstructed temperature and precipitation values

361 correspond to the weighted median value of the climatic ranges of the plant species
362 that correspond to pollen taxa identified in a fossil sample. Pollen taxa abundances
363 (percentages) within each fossil sample are used as normalized (between 0 and 1)
364 weight for computing the weighted median climatic values.

365 The standard deviations were computed using a leave-one-out approach: For each
366 fossil pollen sample, one taxon was removed and a median climatic value for the
367 remaining taxa was computed. This computation was performed as many times as the
368 number of taxa used in the climate reconstruction model. The standard deviation of
369 each reconstructed climatic value corresponds to the median value of all leave-one-
370 out iterations.

371 The pollen-based climate reconstruction required modern plant species geographic
372 distribution data as well as the dataset of their corresponding climatic ranges. The
373 modern plant species distributions were georeferenced from the Atlas Florae
374 Europaeae (Jalas and Suominen, 1973, 1979, 1980) and downloaded from the Global
375 Biodiversity Information Facility (<https://www.gbif.org>). The modern climate dataset
376 was obtained from the WORLDCLIM database (Hijmans et al., 2005). The
377 temperature and precipitation range of each plant species was obtained by
378 interpolating the present-day climate values onto the geographical species
379 occurrences. The statistical approach code was written with R software (R Core
380 Team, 2020) using the following packages: RMySQL (Ooms et al., 2019), Akima
381 (Akima and Gebhardt, 2016) and stats (R Core Team, 2020).

382

383 4. Results

384 4.1 The palynological record

385 Pollen was preserved in most sections of the JRD sediment outcrop. The section of
386 55.33-57.73 m asl provided 45 fertile pollen samples, whereas the nine samples from
387 the upper 70 cm of the sequence (57.33-58.03 m asl) were pollen barren. In all fertile
388 samples, a large variety of well preserved pollen types was identified. The full fossil
389 pollen results are presented in Figure A1.

390 The chronological framework of the JRD pollen diagram is based on the age-depth
391 model presented in Figure 6. It covers the time interval between ~22 and 12 ka cal.
392 BP. The diagram was divided into six pollen zones based on changes in the AP/NAP
393 ratios together with the cluster analysis and the PCA analysis results. The uppermost
394 part of the JRD section, where pollen was not preserved, was marked as pollen zone 6
395 (Figures 5 and 7). The following description of the diagram presents the observed
396 pollen zones from bottom to top.

397

398 Pollen Zone 1 (55.40-56.58 m asl; ~21.6-17.3 ka cal. BP)

399 The lower part of the JRD sequence, corresponding to the later stages of the Last
400 Glacial period and to the Early Epipaleolithic, is characterized by relatively low
401 percentages of Mediterranean arboreal pollen (0-18.1%) and relatively high
402 frequencies of *Artemisia* and chenopods (up to 21.4% and 28.6%, respectively). At
403 ~20.9 ka cal. BP, no arboreal pollen was documented. High values of riparian taxa
404 were observed between ~19.5-20.5 ka cal. BP (the highest being 10.3%). Zone 1 was
405 subdivided into two subzones, Zone 1a (~21.6-18.5 ka cal. BP) and Zone 1b (~18.5-
406 17.3 ka cal. BP). Subzone 1b is distinguished from subzone 1a by a decline in

407 Poaceae and an increase in Chenopodiaceae and Apiaceae, together with a slight
408 decrease in the ratios of *Quercus ithaburensis* type and a total disappearance of
409 *Cedrus libani*.

410 Pollen Zone 2 (56.58-56.85 m asl ~17.3-15.6 ka cal. BP)

411 This zone, archaeologically corresponding to the Middle Epipaleolithic Geometric
412 Kebaran lithic assemblage, is marked by a rise in the ratios of the tree taxa, with a
413 peak of 29.4% at ~15.9 ka cal. BP. Another significant feature is the regular
414 appearance of *Quercus calliprinos* and *Pisatacia* sp. during this time interval.
415 *Artemisia*, Poaceae, Chenopodiaceae and Apiaceae are present but in medium ratios.
416 At the upper part of this zone, a slight drop in the ratios of the stream/marsh-bank
417 vegetation was documented (0.3-3.1%).

418 Pollen Zone 3 (56.85-56.96 m asl ~15.6-15.0 ka cal. BP)

419 This short time interval, preceding the appearance of the Natufian culture at JRD, is
420 characterized by a sharp decline of AP ratios (5.7-8.5%). While both oak types (*Q.*
421 *ithaburensis* and *Q. calliprinos*) and *Pinus* are present in lower frequencies, the total
422 disappearance of other tree taxa was documented. This zone also exhibits a profound
423 increase in *Artemisia* values (15.4-20.3%) and the first appearance of the alga
424 *Pediastrum*. The stream/marsh-bank vegetation was again characterized by relatively
425 low values (3.0-4.3%).

426 Pollen Zone 4 (56.96-57.30 m asl ~14.9-13.0 ka cal. BP)

427 This zone is equivalent to the early stages of the Natufian culture at JRD. The most
428 striking feature of zone 4 is the strong increase in the total tree pollen values, with
429 maximum ratios documented at ~14.2-13.2 ka cal. BP (reaching up to 53.1%). This
430 increase is almost entirely due to *Quercus ithaburensis* type with a maximum at 13.4

431 ka cal. BP of 32.1%. Almost at the same time, at ~14.2-13.1 ka cal. BP, *Olea* pollen
432 shows a relatively high and constant presence (0.3-1.5%). The significant rise in the
433 tree percentages is accompanied by a profound decline in the ratios of both *Artemisia*
434 and *Chenopodiaceae* (0.7-8.1% and 7.7-13.1%, respectively). *Poaceae* and *Apiaceae*
435 are present in medium ratios.

436 Pollen Zone 5 (57.30-57.55 m asl ~13.0-12.0 ka cal. BP)

437 In this pollen zone, archaeologically documenting the Late Natufian at JRD, a drop in
438 AP ratios was registered (9.3-28.2%). Both oak curves, evergreen and deciduous,
439 declined, as well as the *Pistacia* and *Olea* curves. *Asteraceae* *Asteroideae* and
440 *Asteraceae* *Cichorioideae* as well as *Apiaceae* values are relatively high. *Artemisia*
441 and *Chenopodiaceae* are present in relatively low frequencies (not exceeding 2.6%
442 and 16.2%, respectively). *Asphodelus* pollen is characterized by a constant
443 appearance and relatively high percentages. Zone 5's palynological assemblages are
444 also typified by high ratios of the alga *Pediastrum* and relatively low percentages of
445 aquatic plants. A slight increase in the group of riparian taxa was also observed (up to
446 5.8%).

447

448 Pollen Zone 6 (57.55-58.03 m asl ~11.9-11.0 ka cal. BP)

449 This is equivalent to the uppermost archaeological layer at JRD, Layer 3-0
450 (archaeologically, it seems that this layer was modified by later inhabitants, possibly
451 of the Early Neolithic, as evident by the El-Khiam arrowheads and limestone axes;
452 Sharon et al., 2020). Pollen was not preserved in this uppermost section (Figure 5),
453 most probably due to oxidation when lake levels decreased, causing loss of the
454 waterlogged conditions.

455

456 Recent sample

457 The recent river mud surface sample collected as a comparative control sample
458 demonstrates that the arboreal pollen spectrum is dominated by the following taxa:
459 *Olea*, *Pinus*, *Cupressus* type, and neophytic trees such as *Eucalyptus* spp. (Table A1).
460 The presence of these tree taxa is most likely due to modern afforestation rather than
461 representing the natural flora. The Hula Valley environment has been subject to
462 thousands of years of human disturbances. Similar to other southern Levantine areas,
463 the intensity of human interference increased dramatically in the last 100 years due to
464 modern agriculture, forestry and development. Human interference completely
465 transformed the vegetation of the Hula Basin into an artificial environment. Hence,
466 the contribution of the recent pollen sample to the interpretation of the fossil pollen
467 data is limited.

468

469 **4.2 Waterlogged wood assemblage**

470 The waterlogged wood assemblage analyzed in the current study is composed of 227
471 fragments from all layers tested. Twenty-five different taxa were identified (Table 2
472 and Figure 9). The assemblage can be subdivided into two groups: Trees and shrubs
473 typical of the Mediterranean forest/maquis comprise 37.3% of the assemblage, while
474 riparian trees and shrubs form the majority, comprising 59.6% of the samples.
475 Undetectable taxa include only 3.1% of the assemblage. The first group is dominated
476 by the two deciduous oaks species, *Quercus boissieri* and *Q. ithaburensis*. In the
477 second group, the identified samples belong to various trees and shrubs common
478 today on banks of permanent and intermittent water bodies and streams in the Hula
479 Valley. The most abundant taxa among this group are *Fraxinus syriaca*,
480 *Salix/Populus* and Monocots (mainly reeds).

481

482

Table 2: Identified waterlogged wood remains recovered from the JRD

483

archaeological site in absolute numbers and percentages

Category	Taxon	Absolute number	Percentages
Mediterranean woodland/maquis	<i>Quercus calliprinos</i> (Kermes oak)	2	0.9
	<i>Quercus ithaburensis</i> (Mount Tabor oak)	13	5.7
	<i>Quercus boissieri</i> (Aleppo oak)	20	8.8
	<i>Quercus</i> deciduous (unidentifiable deciduous oak)	20	8.8
	<i>Quercus</i> sp. (unidentifiable oak)	8	3.5
	<i>Laurus nobilis</i> (laural)	2	0.9
	<i>Platanus orientalis</i> (oriental plane)	3	1.3
	<i>Pistacia</i> sp. (terebinth)	1	0.4
	<i>Pistacia atlantica</i> (Atlantic turpentine)	2	0.9
	<i>Ziziphus spina-christi</i> (jujube)	2	0.9
	<i>Paliurus spina-christi</i> (Jerusalem thorn)	2	0.9
	<i>Cercis siliquastrum</i> (Judas tree)	2	0.9
	<i>Rhus coriaria</i> (elm-leaved sumac)	1	0.4
	<i>Ononis natrix</i> (yellow restharrow)	3	1.3
	<i>Viburnum tinus</i> (laurustine)	2	0.9
	<i>Myrtus communis</i> (true myrtle)	1	0.4
<i>Rosa</i> sp. (rosa)	1	0.4	
Riparian trees	<i>Fraxinus syriaca</i> (ash)	30	13.2
	<i>Salix/Populus</i> (willow/poplar)	27	11.9
	<i>Tamarix parviflora</i> (smallflower tamarisk)	7	3.1
	<i>Tamarix</i> sp. (tamarisk unidentifiable)	14	6.2
	<i>Vitis vinifera</i> (grapevine)	2	0.9
	<i>Arundo donax</i> (giant reed)	7	3.1
	<i>Phragmites australis</i> (common reed)	7	3.1
	Monocots	41	18.1
	Undetectable	7	3.1
Total		227	100.0

484

485 The potential of this wood assemblage to provide a robust ecological picture

486 documenting changes in the Mediterranean woodland on a time trajectory is limited.

487 This is due to the relatively small size of the assemblage (when subdivided according

488 to stratigraphic location) and its high ratios of riparian taxa, as water bank vegetation

489 is less sensitive to climatic changes in the region (Melamed et al., 2011). However,
490 the JRD wood assemblage was instrumental in refining the pollen results when wood
491 identification was possible to a lower systematic level than the identification achieved
492 by the pollen, as in the cases of *Pistacia* and the deciduous oak pollen type. Three
493 *Pistacia* species are native to the southern Levant: *P. palaestina*, *P. lentiscus* and *P.*
494 *atlantica*. Whereas *Pistacia* pollen cannot be distinguished from one another, the
495 species can be easily identified based on the anatomical structure of the wood
496 (Grundwag and Werker, 1976). Among the deciduous oak pollen type, the most
497 abundant species in the studied area today are *Q. ithaburensis*, a thermophilic
498 deciduous tree typical of low elevations and *Q. boissieri*, a deciduous oak species of
499 the upper mountain zones of the Galilee, Golan Heights and Mount Hermon (Zohary,
500 1973). However, as in the case of *Pistacia* species, the two deciduous oak species are
501 palynologically indistinguishable. The results of the JRD wood assemblage presented
502 in Table 2 indicate that *P. atlantica* grew at the vicinity of JRD and that *Q. boissieri*
503 was more prevalent in the study region than *Q. ithaburensis*.

504

505 **5. Discussion**

506 **5.1 Vegetation reconstruction at the Hula Basin**

507 *5.1.1 The Mediterranean woodland/maquis*

508 The most dominant component of the arboreal pollen vegetation in and around the
509 Hula Valley was the deciduous *Quercus ithaburensis* (Mount Tabor oak) pollen type
510 (Figure 7). Some pollen grains of this type may have been of *Q. boissieri* (Aleppo
511 oak), which is a deciduous oak species of the surrounding higher mountain zones, and
512 some may have derived from the thermophilic deciduous *Q. ithaburensis*, typical of

513 lower elevations. Palynologically, these two deciduous oaks are indistinguishable and
514 therefore appear in the pollen diagram as *Q. ithaburensis* pollen type. In the JRD
515 wood assemblage, *Q. boissieri* was slightly more common than *Q. ithaburensis*
516 (Table 2). In contrast to the pollen record, human agency was most likely involved in
517 the accumulation of the archaeological wood assemblage – people collected wood as
518 raw material for construction, firewood, and for preparing various wooden tools.
519 Based on the assumption that the timber for everyday use was usually collected in the
520 site vicinity (Deckers et al., 2007; Lev-Yadun, 2007), it can be argued that both
521 deciduous oak species were growing around JRD. Hence, both contributed to the
522 pollen rain over Paleolake Hula. The other two dominant taxa in the palynological
523 record are the evergreen oak (*Q. calliprinos*) and *Pistacia*. Their occurrence with
524 nearly identical trends throughout the pollen record reflects the expansion and
525 reduction of the Mediterranean woodland/maquis. For example, the increasing values
526 of their curves together with the rising values of *Quercus ithaburensis* pollen type at
527 the beginning of pollen zone 2 (~17 ka cal. BP), point to a gradual expansion of the
528 Mediterranean woodland/maquis in the environs of the Hula Valley. The presence of
529 sclerophyllous trees such as evergreen oak and *Pistacia*, though in very low
530 frequencies and inconsistent appearance during the LGM, suggests that the mountains
531 near JRD (Upper Galilee; Figures 1 and 2) may have served as glacial plant refugia.
532 The same phenomenon was observed in other Mediterranean pollen studies (Tzedakis
533 et al., 2002; Carrión et al., 2003; Cheddadi and Khater, 2016).

534 The pollen values of *Pinus* are relatively low throughout the JRD sequence, but its
535 occurrence is almost constant except during two short phases: at ~21 ka cal. BP, and
536 around ~13 ka cal. BP. These episodes may be related to the LGM and Younger
537 Dryas cold climates. *Pinus halepensis* (Aleppo pine) is the only pine species native to

538 Israel and it is sensitive to frost (Pardos et al., 2003). Typically, it is a minor arboreal
539 component of the Mediterranean maquis/forest (Zohary, 1973; Weinstein-Evron and
540 Lev-Yadun, 2000), though some *Pinus* pollen grains may have originated from
541 Lebanon where at present *P. brutia* (Turkish pine) is the predominant pine (Zohary,
542 1973; Van Zeist and Bottema, 2009). *Pinus* pollen is usually over-represented in
543 palynological assemblages, owing to its high production, efficient long-distance
544 transport ability, and high resistance to degradation (Cheddadi and Rossignol-Strick,
545 1995; Van Zeist et al., 2009). The total lack of waterlogged pine wood remains at
546 JRD (Table 2) supports the hypothesis of long-distance transportation of *Pinus* pollen
547 and/or its presence as a very minor component in the Mediterranean woodland/maquis
548 in the area around the Hula Valley.

549 Olive (*Olea europaea*) was always a minor component of the Levantine native
550 Mediterranean maquis/forest (Langgut et al., 2019, and references therein). This
551 observation is supported by the total absence of *Olea* remains in the JRD wood
552 assemblage (Table 2). After its domestication during the early Chalcolithic, olive
553 became the most dominant tree in wood-charcoal assemblages of the Mediterranean
554 southern Levant Bronze and Iron Ages sites (e.g., Benzaquen et al., 2019). *Olea* is a
555 predominantly wind-pollinated species that releases large amounts of pollen into the
556 atmosphere and is usually well-represented in palynological spectra (Bottema and
557 Sarpaki, 2003; Mercuri et al., 2013; Langgut et al., 2014b). *Olea* pollen appears in the
558 JRD pollen sequence mainly at the time interval of 14.2-13.1 ka cal. BP. Olive does
559 not grow in areas where winter temperatures fall below 3°C (Zohary, 1973);
560 therefore, increasing *Olea* pollen levels signal warmer climate conditions in the
561 region (Cheddadi and Rossignol-Strick, 1995; Aharonovich et al., 2014; Langgut et
562 al., 2011, 2018). In contrast, *Cedrus libani*, only sporadically occurring in the JRD

563 pollen record, is usually an indicator of colder climate conditions, since it is restricted
564 to cold and sunny high elevation slopes in the region (Weinstein-Evron, 1983;
565 Cheddadi et al., 1991). Scattered cedar populations are still found today in the
566 mountains of Lebanon, in the mountain ranges of southern Turkey and in
567 northwestern Syria (Beals, 1965; Hajar et al., 2010), probably relics of a formerly
568 extensive distribution. Indeed, no cedar wood remains were found at JRD nor at other
569 Pleistocene sites in Israel. Beginning in the Mid-Holocene, the cedar of Lebanon was
570 imported to ancient Israel as a prestigious tree (Lev-Yadun, 1992; Langgut and
571 Gleason, 2020; Langgut et al., 2021).

572 The arboreal pollen and wood results demonstrate that the Mediterranean
573 maquis/forest was always present in the region during the end of the Pleistocene, and
574 was composed of the same components. Changes were, however, observed in taxa
575 proportions in the different periods investigated, resembling shrinkage and expansion
576 of the maquis/forest.

577

578 5.1.2 Open fields vegetation

579 The lower part of the JRD sequence (pollen zones 1-3) is characterized by high ratios
580 of *Artemisia* and Chenopodiaceae pollen. In the southern Levant, *Artemisia* (in non-
581 hot-desert conditions) is considered the best palynological marker for dryer and colder
582 climate conditions (Cheddadi and Rossignol-Strick, 1995; Langgut et al., 2011).
583 Similarly, members of Chenopodiaceae family are found in the same environmental
584 conditions since they are common constituents of *Artemisia* dwarf-shrub steppe.
585 However, they can also thrive in saline habitats (Van-Zeist et al., 2009).

586

587 Pollen zone 4 (~14.9-13.0 ka cal. BP) is marked by a decrease in *Artemisia* and
588 Chenopodiaceae values. This decline represents a profound shift in the vegetation
589 cover of the Hula Basin, from extensive dwarf-shrub steppe (at pollen zones 1-3) to a
590 restricted steppe cover and widening of the Mediterranean woodland/maquis. Pollen
591 zone 5, which begins at ~13 ka cal. BP, corresponds to the Younger Dryas event
592 (Andres et al., 2003). This zone is typified by an exceptional non-arboreal
593 palynological spectrum. *Artemisia* frequencies show their lowest values anywhere
594 along the sequence. Yet, unlike previous pollen zones, the *Artemisia* low percentages
595 were accompanied by a significant rise of the following taxa: *Asphodelus*, Asteraceae
596 Asteroideae type (aster-like), Asteraceae Cichorioideae type (dandelion-like) and
597 *Apiaceae*. These ecosystem changes indicate a significant shift in the regional
598 vegetation cover in the JRD area during the Younger Dryas. Assemblages of pollen
599 zone 5 indicate a decline in Mediterranean arboreal pollen and an increase in the
600 abundance of Mediterranean open field small shrubs and herb components. In
601 contrast, in previous JRD pollen zones, a decrease in Mediterranean trees was
602 accompanied by a rise in open field steppe environment components such as
603 *Artemisia* and Chenopodiaceae.

604 The occurrence of Cerealia pollen type is scattered throughout the JRD pollen record
605 without a specific trend that can be attributed to environmental change and/or human
606 interference.

607

608 5.1.3 Marsh-bank vegetation and aquatic plants

609 Slightly higher pollen percentages of the marsh-bank vegetation group were
610 documented for the lower part of the palynological diagram (~22.0-16.5 ka cal. BP),

611 covering pollen zone 1 and the lower section of zone 2. This may indicate that the
612 edge of the lake was closer to the studied site. It is therefore suggested that slightly
613 lower lake levels characterized Paleolake Hula from ~22.6-16.5 ka cal. BP. After
614 ~16.5 ka cal. BP, during the accumulation of the upper part of zone 2 and until the
615 end of the diagram, a minor decrease in the percentages of the riparian plants was
616 recorded, probably representing an increase in the lake level stands.

617 The pollen and the waterlogged wood assemblages from JRD enable characterization
618 of the Paleolake Hula bank vegetation during site occupation. They provide direct
619 evidence for the aquatic vegetation resources that were available to the Epipaleolithic
620 fishers and gatherers. The marsh-bank palynological spectra include pollen of
621 *Phragmites* type (reed), Cyperaceae, *Typha* (cattail), and *Salix* (willow), all
622 ethnographically and experimentally known to be used in basketry and rope
623 interweaving (Kristal, 2020). Water plants are highly reproductive and abundant and
624 they are known to be used in the production of various fishing gear, including
625 fishline, nets and traps (Salls, 1989; Nadel et al., 1994; Dounias et al., 2016). Other
626 components of this group, such as *Vitis* (grape), have been used as food, while woody
627 taxa such as *Tamarix* (tamarisk) may have been used as raw material for the
628 preparation of wooden objects (Nadel and Werker, 1999; Nadel et al., 2006; Langgut
629 et al., 2016). Various Poaceae plants (grasses) could have been used for bedding
630 (Nadel et al., 2004). The JRD wood assemblage confirms the high riparian taxa
631 diversity that was available to the site's inhabitants, including ash, tamarisk,
632 poplar/willow and grapevine, as well as Monocots such as giant reed (Table 2 and
633 Figure 9).

634 A significant observation emerging from the study of JRD palynomorphs is the first
635 appearance of two types of freshwater alga, *Pediastrum simplex* type and *P.*

636 *boryanum* type. This alga appears at the upper segment of the JRD section, after
637 ~15.5 ka cal. BP. Typically, increasing percentages of these two algae taxa are
638 indicative of warmer climate conditions and a nutrient-rich environment (Jankovská
639 and Komárek, 2000, and references therein). The appearance of *Pediastrum* is almost
640 parallel to the marked rise in Mediterranean arboreal pollen and a decrease in pollen
641 of aquatic plants. Van Zeist et al. (2009), who identified the same phenomenon in a
642 previous Paleolake Hula pollen investigation, suggested that the growth of
643 *Pediastrum* was encouraged by a rise in the influx of organic material into the lake. It
644 was proposed that increased density of upland vegetation cover resulted in more
645 organic debris being washed into the lake, enriching the organic nutrients available in
646 the water. The decline in aquatic pollen percentages is probably a result of the rise in
647 lake levels. The lake became (locally) too deep for water plants to take root in the lake
648 bottom (Van Zeist et al., 2009). The observation regarding the increase in lake levels
649 since ~16.5 ka cal. BP based on the increase in pollen of riparian taxa is, therefore,
650 corroborated by the declining pollen values of the aquatic taxa.

651

652 **5.2 Climate reconstruction of the Mediterranean southern Levant:**

653 **~22.0-11.9 ka cal. BP**

654 *5.2.1 Last Glacial Maximum (LGM): ~22-19 ka cal. BP*

655 Our paleoclimate model indicates that the reconstructed annual precipitation exhibits
656 no dramatic changes throughout the later part of the LGM represented in this study
657 (~22-19 ka cal. BP) with an average of 450 mm (Figure 8c). However, mean January
658 (Tjan), August (Taug) and annual (Tann) temperatures fluctuated greatly during this
659 time interval (Figure 8a). Tjan ranged between 5.5°C and 10°C (present-day value is
660 11°C). Both the Taug and the overall mean annual temperature were ca. 4°C lower

661 than today, which had a positive effect on the precipitation/evaporation ratio of the
662 region. Previous regional studies confirm that during the LGM, temperatures in the
663 Levant were cooler than at present; fluid inclusion δD from Soreq Cave speleothems
664 yielded calculated annual average temperatures of $\sim 7\text{-}9^\circ\text{C}$ at the cave during the
665 height of the LGM, $9\text{-}11^\circ\text{C}$ cooler than today (McGarry et al., 2004). Annual average
666 temperatures on the Mitzpe Shelagim summit of Mount Hermon (2,224 m asl) were
667 below 0°C (Ayalon et al., 2013: table 3). Drier and cooler conditions during the LGM
668 are also evidenced by erosion in the Negev Desert (Goodfriend, 1987; Goodfriend and
669 Magaritz, 1988). However, speleothem deposition at the northern Negev Desert at
670 $\sim 23\text{-}13$ ka signifies that the climate was not extremely arid; moisture was available
671 from a Mediterranean source for the formation of these cave deposits (Vaks et al.,
672 2006).

673 Slightly before the beginning of the JRD sequence, at $\sim 27\text{-}23$ ka BP, the reconstructed
674 Lake Lisan reached its highest levels (Bartov et al., 2002, 2003, 2006, 2007; Haase-
675 Schramm et al., 2004; Hazan et al., 2005; Torfstein and Enzel, 2017). Our
676 paleoclimate model (Figure 8) suggests that temperature was the critical climate
677 variable influencing the lake level changes of the Jordan Rift Valley. While the
678 reconstructed annual precipitation was only slightly below that of today (~ 450 mm vs.
679 515 mm, respectively), annual mean temperatures were much lower during the end of
680 the last glacial period. These low temperatures most probably reduced evaporation,
681 resulting in high lake levels. This scenario is in line with south Levantine speleothems
682 studies (Ayalon et al., 2013; Bar-Matthews et al., 2019 for a recent review) and
683 climate model simulations (Stockhecke et al., 2016), but contradicts claims explaining
684 high lake levels by an extensive increase in precipitation (Bartov et al., 2003; Enzel et
685 al., 2008; Stein, 2014; Torfstein and Enzel, 2017). The vegetation patterns that

686 emerged from this study for the LGM indicate a reduction of the Mediterranean
687 woodland/maquis and the prevalence of steppe vegetation, which translates into a
688 reduction in the overall amounts of annual precipitation. The decrease in the total
689 woodland density resulted in more surface runoff, which was then washed into the
690 lakes of the Jordan Rift Valley. The JRD pollen-based vegetation reconstruction is
691 confirmed by high-resolution well-dated palynological investigations from the nearby
692 Birkat Ram (Golan Heights; Schiebel, 2013) and the Sea of Galilee (Miebach et al.,
693 2017, though this sedimentary sequence was dated slightly earlier, to ~28-22 ka BP).
694 A palynological and environmental study of a northern Levantine core from Lake
695 Yammoûneh in Lebanon also indicates that the LGM was one of the coldest periods
696 during the last 250 ka BP (Develle et al., 2011). Eastern Mediterranean marine pollen
697 records are also characterized by low values of Mediterranean arboreal pollen during
698 the LGM, with almost no occurrence of frost-sensitive and summer-drought-adapted
699 trees such as *Olea* and *Pistacia*, indicating that winter frost may have occurred
700 (Cheddadi and Rossignol-Strick, 1995; Langgut et al., 2011). The total lack of
701 speleothems growth at Mizpe Shelagim Cave during Marine Isotope 2 suggests
702 permafrost conditions along the higher elevations of Mount Hermon (Ayalon et al.,
703 2013). The vegetation cover could have been shaped by effective moisture in the
704 habitats, while additional precipitation was stored as snow on high mountains
705 (Robinson et al., 2006). Rapid snowmelt in spring would have fed the Jordan Rift
706 lakes but would have hardly affected the vegetation cover (Miebach et al., 2017). A
707 palynological study from the Dead Sea reveals an expansion of the *Artemisia* steppe
708 from 60 to 20 ka BP under a drier and cooler climate with an average of 3°C lower
709 during MIS 3 than today (Miebach et al., 2019; Richter et al., 2020). According to
710 recent Dead Sea pollen studies (Chen and Litt, 2018; Miebach et al., 2019; Richter et

711 al., 2020), the decline in temperatures during glacial periods reduced evaporation, yet
712 sufficient moisture was available in the Dead Sea region to support steppe vegetation.
713 Thus, the Lisan Lake level rose without a corresponding increase in the annual
714 amount of precipitation (Chen and Litt, 2018; Miebach et al., 2019; Richter et al.,
715 2020).

716

717 *5.2.2: The post-glacial time interval: ~18.7-11.9 ka cal. BP*

718 This time span began with a marked rise in temperatures (mean annual, winter and
719 summer) of between 3-5°C from ~19 to ~17 ka cal. BP (Figure 8a). A similar pattern
720 emerged from the reconstruction of average annual temperatures for Soreq Cave,
721 based on speleothem fluid inclusion δD , with 7-9°C at ~19.2-18.9 ka increasing to 9-
722 12°C at ~18.9-18.6 ka (McGarry et al., 2004). The JRD paleoclimate model also
723 indicates a slight increase in winter precipitation (Figure 8d) accompanied by a slight
724 decrease for the three other seasons, indicating a rise in seasonality contrast (Figure
725 8e-g). At ~16-15 ka cal. BP the model points to a decline in temperatures as well as a
726 decrease in winter and spring precipitation (Figure 8d-e). This climatic shift to cooler
727 and dryer climate conditions is most probably related to Heinrich Event 1. This short-
728 duration cooler and dryer episode was also identified in other southern Levantine
729 paleoclimate records: 16.5 ka at Soreq Cave (Bar-Matthews et al., 1999) and 16 ± 1
730 ka at Lake Lisan (Bartov et al., 2003).

731 The wettest and warmest time interval throughout the JRD sequence was identified
732 between ~14.9 and 13.0 ka cal. BP. This period coincides with the global warm and
733 moist Bølling-Allerød interstadial (=Greenland Interstadial 1, Lowe et al., 2008)
734 (Figure 8a and d). This warm trend reached its maximum at ~14 ka cal. BP, with
735 reconstructed January temperatures similar to today's average (~11°C; Figure 8a).

736 The mean annual temperature values during the warm Bølling-Allerød interstadial
737 remained ca. 2°C lower than today, which is consistent with the global temperature
738 ice record (GRIP members, 1993), the Mediterranean Sea surface temperature (Cacho
739 et al., 1999) and regional climate records (Cheddadi and Khater, 2016).

740 Speleothem formation at Mizpe Shelagim beginning at ~15 ka (after a total lack of
741 growth during the time interval of ~34-15 ka) was due to the melting of permafrost at
742 the higher elevations of Mount Hermon, indicating the onset of a warm phase in the
743 Levant (Ayalon et al., 2013). Based on the reconstructed seasonal precipitation from
744 the JRD model, not only did winter precipitation increase, but also spring and autumn
745 precipitation (Figure 8e-g). This multi-seasonal increase in precipitation likely
746 resulted from multiple contributors, with autumn and winter moisture originating
747 from the Mediterranean (Cyprus Low) and spring moisture from a southern source
748 (Red Sea Low).

749 Lake Lisan levels during the Bølling-Allerød were relatively high, suggesting an
750 increase in precipitation to evaporation ratio in comparison to conditions during
751 Heinrich Event 1 (Bartov et al., 2002). The Soreq Cave speleothem stable isotope data
752 are also suggestive of an increase in temperatures and precipitation during this time
753 interval (Bar-Matthews et al., 1997, 1999). The Bølling-Allerød period was also
754 identified in the eastern Mediterranean marine pollen record based on a marked rise in
755 Mediterranean arboreal pollen values (Langgut et al., 2011).

756 The onset of the Younger Dryas event is dated in the JRD sequence to ~12.9 ka cal.
757 BP. At the uppermost part of the JRD record, pollen grains were not preserved (Pollen
758 zone 6); hence, the end of the Younger Dryas is missing. The reconstructed
759 paleoclimate conditions for this time interval are exceptional, as for the first time in

760 the JRD record, temperature and precipitation show opposite trends: While
761 temperatures decreased, annual precipitation slightly increased (Figure 8a and 8c). A
762 higher contribution of moisture derived from spring, summer and autumn rains, while
763 winter precipitation decreased in comparison to the previous periods (Figure 8d-g).
764 This reconstruction points to a reduced seasonal contrast during the Younger Dryas.
765 Identical observations emerged from the study of fluorescent banding patterns of
766 Soreq Cave speleothems, revealing that during Heinrich Event 1 and the Younger
767 Dryas, the supply of drip water to Soreq Cave was more consistent year-round
768 (Orland et al., 2012). Thus, a reduced gradient of seasonal precipitation, occasional
769 snowfall, and vegetation cover differences may have all contributed to the isotope and
770 fluorescent banding patterns observed for these two exceptionally short time intervals
771 that led to less distinct wet and dry seasons (Orland et al., 2012). The decrease in the
772 magnitude of difference in $\delta^{18}\text{O}$ values between the wet and dry seasons in the
773 Mediterranean Levant during the Younger Dryas is supported by an isotopic study of
774 hunted gazelles (Hartman et al., 2016). Similar seasonality trends were also observed
775 during the same time period from palynological records of the northern Levant
776 (Cheddadi and Khater, 2016). These records show a lowering of winter precipitation
777 over Lebanon during the Younger Dryas and a slight increase of summer
778 precipitation, resulting in a more balanced contribution of moisture from the
779 southwest and northwest Mediterranean basin during summer and winter (Cheddadi
780 and Khater, 2016: figs 1 and 5). Today, the Mediterranean climate is characterized by
781 a highly marked amplitude of precipitation between summer and winter, related to the
782 dominant northwest storm tracks during winter. The cooler temperatures during the
783 Younger Dryas reconstructed for the JRD record are corroborated by other isotope

784 studies available from the Mediterranean Levant (Orland et al., 2012; Hartman et al.,
785 2016).

786

787 The JRD reconstructed precipitation during the Younger Dryas is also intensively
788 fluctuating, potentially pointing to climate instability (Figure 8c-f). Based on multiple
789 Levantine paleoclimate datasets, Robinson et al. (2006) proposed that the Younger
790 Dryas was cold in comparison to the Bølling-Allerød and the Holocene (Robinson et
791 al., 2006: fig. 15C). The Younger Dryas was also depicted in other Levantine
792 terrestrial and marine palynological records, based on the identification of steppe
793 dominating plant taxa, primarily *Artemisia* and Chenopodiaceae (Kadosh et al., 2004;
794 Langgut et al., 2011; Cheddadi and Khater, 2016). Unfortunately, the beginning of the
795 Holocene is not recorded in the JRD pollen sequence. Other palynological records in
796 the vicinity of JRD reveal increasing percentages of arboreal pollen accompanied by
797 an abundance of frost-sensitive and summer-drought-adapted taxa such as *Olea*,
798 *Pistacia*, and evergreen oaks during the early Holocene (Lake Hula: Van-Zeist et al.,
799 2009, based on their revised chronology; Sea of Galilee: Schiebel and Litt, 2018).
800 Similar vegetation and environmental patterns were observed in the northern Levant
801 during the Early Holocene (Develle et al., 2011; Gasse et al., 2015; Cheddadi and
802 Khater, 2016).

803

804 **5.3 Environmental preconditions to sedentism and the onset of** 805 **agriculture**

806 The transition from small nomadic groups of hunter-gatherers, to the sedentary
807 villages of the Natufian, followed by the agricultural communities of the

808 Neolithic period, is a seminal process in human history. This transition involved not
809 only a shift to food production-based subsistence strategies, but also the creation of
810 the complex societies of early civilizations. Yet, the exact location, reasons, and
811 processes that led to this dramatic cultural change remain in dispute (e.g., Lev-Yadun
812 et al., 2000; Fuller et al., 2011). The current study does not aim to resolve this debate;
813 however, the long and well-dated stratigraphic sequence of JRD yielded a continuous,
814 site-based palynological record covering the great majority of the Levantine
815 Epipaleolithic. Our record is especially important due to the correlation achieved
816 between the palynological and the paleoclimatic reconstruction with the cultural
817 changes evident at JRD, based on well-defined archaeological horizons. This
818 correlation enables identifying several unique environmental circumstances which
819 characterized the Mediterranean southern Levant, forming the background for the
820 dramatic shift toward sedentism and Neolithization (Table 3).

821

822 The paleoclimate reconstruction generated from the Epipaleolithic JRD sequence
823 demonstrates that a significant climate shift to warmest and wettest conditions
824 occurred during the time interval of ~14.9-13.0 ka cal. BP (Figure 8). This warm and
825 humid interval was accompanied by a high seasonal contrast of precipitation.
826 Significantly, the beginning of this phase is synchronous with the onset of the
827 Natufian culture, characterized by reduced population mobility and sedentism in the
828 Hula Valley and the entire southern Levant (Bar-Yosef and Belfer-Cohen, 1989,
829 1992, 2016; Kaufman, 1992; Moore and Hillman, 1992; Grosman, 2003, 2018; Byrd,
830 2005; Maher et al., 2011; Bar-Yosef and Valla, 2013; Yeshurun et al., 2014). The data
831 indicate that the Early Natufian documented by archaeological finds emerged during a
832 time of favorable climatic conditions and abundant resource availability. Such

833 conditions may have augmented the capability of the first sedentary communities to
834 face the environmental and subsistence challenges that surely accompanied early
835 sedentism and population increase (Belfer-Cohen and Bar-Yosef, 2000; Boyd, 2006).

836

837 The JRD Younger Dryas pollen assemblages differ from all other pollen spectra
838 observed during the glacial/interglacial time intervals (Figure 7; Table 3). They are
839 characterized by high frequencies of Mediterranean open field vegetation. This flora
840 may appear unrelated to steppe semi-arid vegetation as demonstrated for previous
841 drier and colder periods in the same sequence. The occurrence of herb plants such as
842 *Cirsium*, *Achillea* and *Epilobium* (Figures 7 and A2) is interpreted by their favorable
843 conditions including both a decrease in winter temperature and an increase in water
844 availability during the summer. This herbaceous landscape enabled us to quantify the
845 significant seasonal changes during the Younger Dryas event (Figure 8). The pollen
846 record shows an increase in annual plants. This may have enriched the plant-gathering
847 opportunities of the inhabitants of the Mediterranean Levant. The proliferation of
848 herbs, and specifically of annuals, may have paved the way to the emergence of
849 agriculture in the Near East, since all seven Neolithic founder crops are annuals.

850 Munro (2003), based on the archaeozoological record of the southern Levant, also
851 sees the Younger Dryas as forcing Late Natufian (~12.9-11.6 cal. BP) populations to
852 cope with the changing climate and environment by shifting to a wide spectrum diet.

853 In parallel, Belfer-Cohen and Bar-Yosef (2000) noted that the Late Natufian hunter-
854 gather communities are characterized by increasing population mobility patterns.

855

856 The exceptional climatic and environmental conditions during the Younger Dryas
857 event are evidenced by its vegetation change and the lowest climatic seasonal contrast

858 reconstructed for the JRD sequence. The primary expression of this observation is an
859 increase in rains during spring, summer and autumn, together with a significant
860 reduction in winter precipitation (Figure 8c-f). In contrast, at the beginning of the
861 Holocene, the regional climate was typical Mediterranean, of stronger seasonality
862 than today, with mild winters and hyper-arid summers (Orland et al., 2012; Cheddadi
863 and Khater, 2016). The early Holocene seasonal stress of long, hot dry summers
864 probably increased the need for food storage by sedentary communities. We suggest
865 that the significant vegetation and climate changes at the late Pleistocene-Holocene
866 boundary contributed to the development of agriculture-based subsistence (Table 3).
867 Admittedly, similar environmental changes also occurred during earlier phases of the
868 Pleistocene. Yet, the climate changes that occurred during the Pleistocene-Holocene
869 boundary were, for the first time, accompanied by sedentism, complex social
870 organization, food storage and curating technologies for harvesting and processing of
871 wild plants. Sickles (Groman-Yaroslavski et al., 2016; Maeda et al., 2016), grinding
872 stones (Weiss et al., 2008; Marder et al., 2013; Rosenberg, 2013) and pounding tools
873 (Nadel and Rosenberg, 2010; Marder et al., 2013; Rosenberg and Nadel, 2014), as
874 well as storage facilities (Liu et al., 2018), are all well documented in the Levantine
875 Epipaleolithic.

876

877 This study suggests that the confluence of separate natural events and cultural
878 developments promoted the emergence of agriculture in the Mediterranean Levant.
879 The sudden, exceptional Younger Dryas climate induced a major vegetation change,
880 which was followed by a severe seasonality during the Early Holocene and related
881 changes in vegetation cover. Together with the shrinking of the Jordan Valley lakes,
882 these conditions presented new subsistence challenges to the sedentary communities

883 of the Mediterranean Levant. A similar synergic scenario was suggested three decades
 884 ago by McCorrison and Hole (1991). Yet, their proposal lacks a solid paleo-
 885 vegetation dataset and detailed paleoclimate model as presented in this study.
 886 McCorrison and Hole (1991) claimed that the convergence of several cultural and
 887 environmental factors, each forming a piece of the puzzle, generated the
 888 Neolithization process. They list a series of social, ideological, cultural, technological,
 889 climatological and environmental preconditions that must have existed before
 890 Natufian groups could cross the threshold to agriculture-based subsistence. Hence,
 891 agricultural economy developed because the right people were in the right place, at
 892 the right time, with the “right” annuals. Although local changes in vegetation cover
 893 and climate including seasonality played a central role in the origins of agriculture,
 894 they were not the sole cause and occurred during earlier periods of the Pleistocene.
 895

896 **Table 3: Summary of the primary JRD sequence vegetation and environmental**
 897 **patterns**

Archaeological period	Palynological framework	Vegetation cover	Climate reconstruction	Correlation with northern Hemisphere climate phases	Socio-cultural entity in the Mediterranean Levant*
Late	Pollen Zone 6 ~11.9-11.0 ka	No pollen (~11.7-11.0 ka). Other Levantine pollen records indicate	High precipitation with a dominance of winter rains	Beginning of Early	Neolithic (from ~ 11.6/11.5 ka)

Epipaleolithic	cal. BP	a great expansion of the Mediterranean woodland/maquis from about 11.5 ka, with an abundance of frost-sensitive and summer-drought-adapted trees such as <i>Olea</i> , <i>Pistacia</i> , and evergreen oaks (Cheddadi and Khater, 2016)	from ca. 11.5 ka. Severe seasonality with hot and long dry summers (based on the paleoclimate model of Cheddadi and Khater, 2016)	Holocene climate optimum (from ~ 11.6/11.5 ka)	Final Natufian
		No pollen (~11.9-11.0 ka)		End of the Younger Dryas	Natufian (~ 15-11.6 ka)
	Pollen Zone 5 ~13.0-11.9 ka cal. BP	Mediterranean open field vegetation	Low temperatures. A decrease in winter precipitation and an increase in spring, summer and autumn rains. Very low seasonal amplitude	Younger Dryas (12.9-11.7 ka)	
Pollen Zone 4 ~14.9-13.0 ka cal. BP	The greatest cover of the Mediterranean woodland/maquis. The decrease in riparian taxa and aquatic plants together with the appearance of the algae <i>Pediastrum</i> point to an increase in the lake levels	The wettest and warmest time span with a decrease in seasonality contrast	Bølling-Allerød (14.7-12.9 ka)	Early Natufian	
Middle Epipaleolithic	Pollen Zone 3 ~15.6-15.0 ka cal. BP	A great expansion of dwarf-shrub steppe vegetation	Low temperatures. A decline in annual precipitation with an increasing contribution of summer rains. Reduced seasonality	Most probably related to Heinrich Event 1	
	Pollen Zone 2 ~17.3-15.6 ka cal. BP	A profound increase in arboreal cover dominated by evergreen oaks, deciduous oaks and <i>Pistacia</i> , forming a woodland or park-forest	Stable, annual temperatures with a decrease in winter precipitation. Significant seasonality contrast		Geometric Kebaran (~ 18.5-15 ka)
	Pollen Zone 1b ~18.6-17.3 ka cal. BP	The region is still intensively covered by dwarf-shrub steppe vegetation	A marked temperature increase (ca. 4°C)	Last Deglaciation	

Early Epipaleolithic	Pollen Zone 1 ~21.6-18.6 ka cal. BP	The Mediterranean woodland/maquis is very limited. Abundance of dwarf-shrub steppe vegetation	Low and fluctuating annual temperature (up to 5°C lower than today) and slightly lower annual precipitation (<60 mm than today) with some contribution of summer rains	LGM ~23-19 ka	Mazraqan/Kebaran/Early Epipaleolithic (~ 22.0-18.5 ka)
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898 *Socio-cultural entities chronology after Goring-Morris and Belfer-Cohen, 2017; Grosman, 2018
899 (years in ka cal. BP).
900

901 6. Summary and Conclusions

902 Paleoenvironmental records derived from Epipaleolithic sites are rather scarce in the Levantine
903 region, mainly due to poor preservation of organic remains. This is particularly true for the
904 Early and Middle Epipaleolithic periods. In this regard, the JRD waterlogged record collected
905 from the shores of Paleolake Hula is a new and valuable contribution to the understanding of
906 past environmental changes in the Mediterranean Levant. The JRD record is a well-dated, high-
907 resolution, continuous fossil pollen sequence that, together with well-identified wood
908 assemblages, enabled us to reconstruct environmental changes in the studied area between 22.0
909 and 11.9 ka cal. BP. Quantitative climate reconstruction demonstrates that during this time
910 interval, the mean annual temperature was lower than today (in the range of 14.5-19°C vs. 21°C
911 on average today). During most of the period, the mean annual precipitation was slightly lower
912 than today (average 450 mm vs. 515 mm today). However, from ~15 ka cal. BP, mean annual
913 precipitation increased (reaching maximum values of 545 mm at 14.5 ka cal. BP). Our climate
914 model of seasonal changes for both temperatures and precipitation enabled us to reconstruct in
915 detail the climatic conditions of the region, providing the environmental background for the
916 dramatic socio-cultural human shifts that occurred at this time interval.

917 1. During the Early Epipaleolithic period, corresponding to the LGM, a limited
918 Mediterranean woodland/maquis with a lush dwarf shrub steppe vegetation
919 covered the area around Paleolake Hula. Our paleoclimate model points to low

920 temperatures, reaching the lowest values of the sequence at 20.5 and 19.5 ka cal.
921 BP, with reconstructed January temperatures 5°C lower than today. Average
922 annual precipitation was only slightly lower than today, with some summer
923 precipitation.

924 2. After the LGM, at ~19-17.5 ka cal. BP, dwarf shrub-steppe vegetation continued
925 to dominate the region. The mean annual temperature remained relatively low
926 and a slight increase in precipitation associated with an additional contribution of
927 summer rainfall was inferred. By ~17.5 ka cal. BP, a well-developed
928 Mediterranean woodland probably already existed in the area. The reconstructed
929 climate points to a significant increase in temperature and winter precipitation
930 with increased seasonality.

931 3. The greatest cover of the Mediterranean woodland/maquis was identified at the
932 beginning of the Late Epipaleolithic period. The paleoclimate reconstruction of
933 the time interval ~14.9 to 12.9 ka cal. BP demonstrates a striking climatic shift to
934 the warmest and wettest conditions in the Epipaleolithic JRD sequence. These are
935 likely correlated with the warm and humid Bølling-Allerød interstadial as well as
936 with the onset and duration of the Natufian culture in the Levant. The humid and
937 warm climate certainly helped the early settlers overcome the many challenges of
938 sedentism. The palynological evidence also points to an increase in the lake
939 levels stands.

940 4. Two cold, short-term climate events were identified. The first is dated to ~16-15
941 ka cal. BP and may be related to the cold and dry Heinrich Event 1. The second
942 episode began at ~12.9 ka cal. BP and corresponds to the Younger Dryas. The
943 JRD sequence ends at ~11.9 ka cal. BP and probably lacks the last phase of the
944 Younger Dryas (~11.9-11.7 ka cal. BP). Our paleoclimate model indicates that

945 this period was characterized by unique climatic conditions, with the least
946 contrast of climatic seasonality. There was an increase in precipitation
947 contribution during spring, summer and fall, along with a significant decrease in
948 winter precipitation. The reconstructed vegetation suggests the presence of
949 Mediterranean open field vegetation, probably rich with annuals. We therefore
950 suggest that the extensive herbaceous landscape probably increased the
951 opportunities for plant gathering, specifically of annuals, paving the way towards
952 agriculture. In the following period, the early Holocene, as well as at present, the
953 region is characterized by seasonal stress, with long, hot dry summers.

954 5. We propose that the significant vegetation and climate changes at the late
955 Pleistocene-Holocene boundary contributed to the development of agriculturally-
956 based subsistence communities in the Mediterranean Levant. Undoubtedly,
957 environmental changes similar to those of the Younger Dryas/Early Holocene
958 transition occurred previously during earlier phases of the Pleistocene. But, for
959 the first time, these climatic changes were accompanied by sedentism, more
960 complex social organization, and technologies for harvesting and for food
961 storage.

962

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978

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- 1488

1489 **Figure captions**

1490

1491 **Figure 1: a).** Distribution of vegetation zones in the southern Levant; M =
1492 Mediterranean zone (Garrigue, maquis, woodland); IT = Irano-Turanian zone
1493 (steppeland); SA = Saharo-Arabian zone (desert); S = Sudanian zone (penetration
1494 territory) (after Zohary, 1973, 1982; Danin and Plitmann, 1987); **b).** Map of the
1495 southern Levant indicating mean annual precipitation in mm (Srebro and Soffer,
1496 2011); **c).** The position of the southern Levant.

1497

1498 **Figure 2:** Location of Jordan River Dureijat (JRD) archaeological site (modified after
1499 Van-Zeist and Bottema, 2009: fig. 1).

1500

1501 **Figure 3: a).** Ayelet Hashahar weather station data (under 5 km from JRD). Average
1502 monthly temperature and precipitation for the period of 2010-2020. Red bars
1503 represent seasonal average. Data downloaded from Israel Meteorological Service
1504 (2020); **b).** Normalized wind roses (m/s) for Jan 2015-Dec 2016, and seasonal for
1505 Dec-Feb (2014-2017; DJF) and Jun-Aug (2015-2016; JJA) (taken from Rice, 2018:
1506 fig. 2.5).

1507

1508 **Figure 4:** 1. JRD bone fish hooks; 2. JRD small grooved pebbles (line weights); 3.
1509 JRD stone tools by layers and cultural affinity: a. Early Neolithic; b. Natufian; c.
1510 Geometric Kebaran; d. Early Epipaleolithic

1511

1512

1513 **Figure 5:** Archaeological layers, cultural affiliation, radiocarbon chronology (with
1514 calibrated dates) and pollen zones of the Jordan River Dureijat (JRD) sequence (after
1515 Sharon et al., 2020: fig. 4a).

1516

1517 **Figure 6:** Age-depth model for the Jordan River Dureijat (JRD) sedimentological
1518 outcrop using the Bayesian Bacon software from the R package rbacon v2.3.9.1
1519 (Blaauw and Christen, 2011).

1520

1521 **Figure 7:** Simplified pollen diagram of the Jordan River Dureijat (JRD) sequence. A
1522 10-fold exaggeration is used to show changes in low taxa percentages. Chronology is
1523 based on the age-depth model established in this study.

1524

1525 *At zone 6 pollen was not preserved.

1526

1527 **Figure 8:** Jordan River Dureijat (JRD) paleoclimate model. **a).** average temperature
1528 ($^{\circ}\text{C}$): mean January (T_{jan}), mean annual (T_{ann}) and mean August (T_{aug}); **b).** $d^{18}\text{O}$ of
1529 Soreq Cave; **c).** Annual precipitation (mm); **d).** Winter precipitation (December-
1530 February); **e).** Spring precipitation (March-May); **f).** Summer precipitation (June-
1531 August); **g)** Autumn precipitation (September-November); Red bars represent recent
1532 geographical settings.

1533

1534 **Figure 9:** SEM Images of wood sections of taxa identified at Jordan River Dureijat
1535 (JRD). a: *Quercus ithaburensis*, transverse section, 50x, scale 300 μm ; b: *Quercus* sp.
1536 (*calliprinos?*), transverse, 30x, scale 500 μm ; c: monocot (*Arundo donax?*),
1537 transverse, 137x, scale 300 μm ; d: monocot (*Phragmites australis?*), transverse, 246x,

1538 scale 100 μm ; e: *Tamarix* sp., transverse, 40x, scale 500 μm ; f: *Fraxinus syriaca*,
1539 transverse, 181x, scale 100 μm ; g: *Cercis siliquastrum*, transverse, 40x, scale 500 μm ;
1540 h: *Salix/Populus*, transverse, 50x, scale 400 μm ; i: *Pistacia atlantica*, transverse,
1541 110x, scale 200 μm ; j: *Vitis vinifera*, transverse, 105x, scale 400 μm ; k: *Ziziphus*
1542 *spina-christi*, transverse, 137x, scale 300 μm ; l: *Rhus coriaria*, transverse, 173x, scale
1543 200 μm ; m: *Laurus nobilis*, transverse, 60x, scale 200 μm . Note that due to
1544 preservation conditions, not all identified taxa were able to be imaged satisfactorily;
1545 in other cases, only certain parts of the examined samples were able to be
1546 photographed. Images a, b, e, g, h, i, and m were taken using a stereoscopic Carl Zeiss
1547 SteREO Discovery.V20 microscope. Images c, d, f, j, k, and l were taken using a
1548 Tescan VEGA3 LMH scanning electron microscope.

1549

1550

1551 **Table captions**

1552 **Table 1:** ^{14}C radiocarbon ages of wood remains used in the age-depth model. Both the
1553 wood and pollen samples were extracted from the same eastern sediment outcrop.

1554

1555 **Table 2:** Identified waterlogged wood remains recovered from the JRD
1556 archaeological site in absolute numbers and percentages.

1557

1558 **Table 3:** A summary of the primary JRD sequence vegetation and environmental
1559 patterns.

1560

1561 **Appendices**

1562 **Figure A1:** A detailed palynological diagram for the JRD sequence.

1563

1564 **Figure A2:** Median values of all 26 taxa used for the JRD climate reconstruction

1565

1566 **Table A1:** Pollen results of JRD recent pollen sample collected from the Jordan River

1567 surface sediments, ca. 20 meters west of the studied sediment outcrop.

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