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The diaptomid fauna of Israel (Copepoda, Calanoida, Diaptomidae), with notes on the systematics of *Arctodiaptomus similis* (Baird, 1859) and *Arctodiaptomus irregularis* Dimentman & Por, 1985 stat. rev

Federico Marrone^{1*}, Adam Petrussek², Giuseppe Alfonso³ and Marco Arculeo¹

Abstract

Background: To date, only scarce information is available about the diaptomid copepods of the Middle East despite the ecological and biogeographical importance of the family Diaptomidae in the inland waters of the Holarctic region. Moreover, the taxonomic status of some of the taxa occurring in the area is in need of revision. We studied crustaceans collected from temporary and permanent lentic water bodies in Israel with the aim of providing an updated census of the diaptomid copepods occurring in the country. Furthermore, we morphologically and genetically analysed samples of *Arctodiaptomus similis* s.l. to shed light on its taxonomy.

Results: Five diaptomid taxa were collected during this survey. Among these, *Phyllodiaptomus blanci* is new for the country and the whole circum-Mediterranean area and might be an allochthonous species of eastern origin. Within the collected samples, we singled out two parapatric groups of populations within *A. similis* s.l.; these consistently differ both based on morphology (chaetotaxy of the left male antennule) and molecular data (divergence over 17% at mitochondrial DNA gene for cytochrome b). We thus attribute the full species rank to *Arctodiaptomus irregularis* Dimentman & Por, 1985 stat. rev., originally described as a subspecies of the widespread species *Arctodiaptomus similis* (Baird, 1859).

Conclusions: We critically evaluated all species hitherto reported for Israeli inland waters. Considering both the confirmed literature data and the new findings, Israeli diaptomid fauna is composed of at least seven species. However, the need for further surveys in the Middle East and for detailed systematic revisions of some controversial taxa is stressed. Our results on the systematics of *A. similis* s.l. illustrate the importance of implementing molecular analyses when investigating diversity patterns of groups which are difficult to resolve based on morphology alone.

Keywords: Copepod diversity; Middle East; *Hemidiaptomus gurneyi canaanita*; *Arctodiaptomus similis*; *Arctodiaptomus irregularis* stat. rev.; *Phyllodiaptomus blanci*; *Neolovenula alluaudi*

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33 Background

34 Representatives of the copepod family Diaptomidae
35 often dominate the lentic inland water bodies of the
36 Holarctic, Oriental, and Afrotropical biogeographical
37 regions, being a key taxon in many lacustrine and pond
38 ecosystems (Dussart and Defaye 2001, 2002). Species
39 of this family are as a rule characterised by limited dis-
40 tributional ranges, which are significantly constrained
41 by the legacies of historical biogeographical events
42 (Leibold et al. 2010). However, an ever-increasing cor-
43 pus of molecular evidence suggests that our knowledge
44 on diaptomid species distributions and biogeography is
45 currently hampered by a gross underestimation of the
46 actual diversity of the group (e.g., Marrone et al. 2013,
47 and references therein). In the inland waters of the
48 Mediterranean area, about 100 diaptomid species be-
49 longing to 14 genera are currently reported to occur
50 (Dussart and Defaye 2002), but the information avail-
51 able for certain regions is far from being satisfactory
52 (cf. Marrone 2006).

53 To date, uneven information is available on the inland
54 water calanoid copepod fauna of the Middle East. While
55 the diaptomid faunas of Turkey (e.g., Gündüz 1998;
56 Ustaoglu 2004; Ustaoglu et al. 2005) and Iran (e.g., Brehm
57 1937; Löffler 1956, 1961) are relatively well-known, only
58 scarce and anecdotal records are currently available for
59 other countries of this region (e.g., Gurney 1921; Spandl
60 1923; Kiefer 1978b; Dumont 1979, 2009; Khalaf 2008;
61 Mohamed and Salman 2009). The Israeli diaptomid fauna
62 is quite a peculiar case: although several papers and re-
63 views are available (e.g., Baird 1859; Richard 1893; Kiefer
64 1930; Yaron 1964; Dimentman and Por 1985, Azoulay
65 2001, and references therein), only five diaptomid taxa
66 are currently listed for the country; this seems quite a
67 species-poor fauna when compared to other circum-
68 Mediterranean regions of comparable area, where usually
69 about 9 to 14 diaptomid species are present (e.g., Ruffo
70 and Stoch 2005; Marrone et al. 2005; Marrone 2006; Turki
71 and Turki 2010; Alfonso and Belmonte 2011). Further-
72 more, the taxonomical validity of some 'forms' or 'sub-
73 species' described in the past decades based on Israeli
74 specimens is rather controversial, and the presence itself
75 of some taxa in the country is in need of confirmation,
76 thus casting further uncertainty on the actual composi-
77 tion of the Israeli diaptomid fauna.

78 We studied plankton samples collected in Israeli inland
79 waters between 2003 and 2011 in order to update the
80 available information on the composition and distribution
81 of diaptomid copepods in the country. Furthermore, we
82 genetically analysed several populations of *Arctodiapto-*
83 *mus similis* s.l. to test the hypothesis that two parapatric
84 groups of populations differing in morphology, observed
85 in our dataset, actually represent distinct evolutionary lin-
86 eages of species rank.

87 Methods

88 Plankton samples were collected throughout the country,
89 focusing on small- to medium-sized freshwater habitats;
90 both permanent and temporary water bodies were investi-
91 gated, and some sites were sampled multiple times on dif-
92 ferent dates. Altogether, we analysed samples from 60
93 different sites (Figure 1). Samples were collected using a
94 200- μ m mesh hand net along the water bodies' shorelines;
95 open waters were sampled using 80-to-200- μ m mesh-
96 sized towing nets. Collected crustaceans were fixed *in situ*

F1

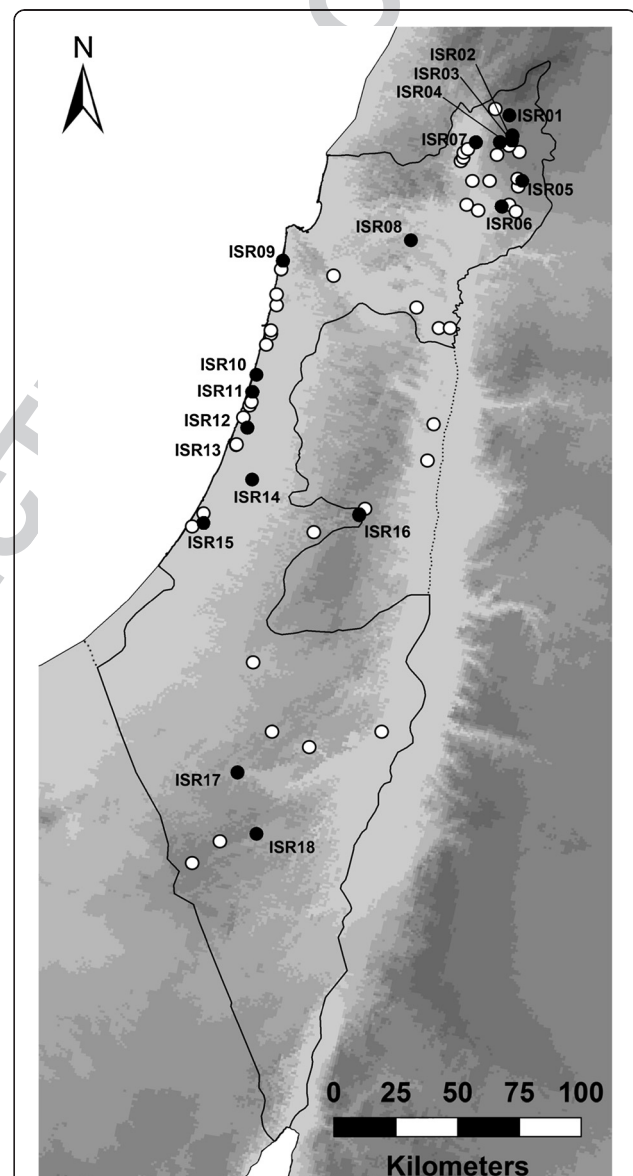


Figure 1 Map of the sampling sites. Samples collected between 2003 and 2011 from both temporary and permanent water bodies were analysed to improve knowledge on diversity and distribution of diaptomid copepods of Israel. Black dots represent sites where at least one diaptomid species was collected; white dots are sites without diaptomids.

97 with 96% ethanol. They were then sorted in the laboratory
98 under a dissecting microscope, and diaptomid specimens
99 were prepared according to Dussart and Defaye (2001).
100 Morphological identification was performed according
101 to Kiefer (1974, 1978a), Borutzky et al. (1991), and
102 Ranga-Reddy (1994). Line drawings were prepared
103 using a compound microscope equipped with a camera
104 lucida.

105 Samples are stored in the crustacean collection of
106 Federico Marrone and are available for loan on request.
107 Voucher specimens from the type localities of *Arctodiap-*
108 *tomus similis* (Baird, 1859) and *Arctodiaptomus irregularis*
109 Dimentman & Por, 1985 stat. rev. have been deposited in
110 the collection of the Smithsonian Institution (National
111 Museum of Natural History) in Washington DC, USA,
112 with the catalogue numbers USNM #1226919 and USNM
113 #1226920.

114 Thirteen specimens of *A. similis* s.l. from various regions
115 of Israel and two congeneric species to be used as out-
116 groups (*Arctodiaptomus* cf. *stephanidesi* (Pesta, 1935) and
117 *Arctodiaptomus alpinus* (Imhof, 1885), both collected in
118 Italy) were analysed genetically by amplifying and sequen-
119 cing a 329-bp long fragment of the mitochondrial gene for
120 the cytochrome b (Cyt-b), a molecular marker which is
121 known to be informative on the phylogeography and the
122 molecular systematics of closely related diaptomid taxa
123 (e.g., Staton et al. 2003; Thum and Derry 2008; Thum
124 and Harrison 2009; Marrone et al. 2010, 2013). Genetic
125 analyses were performed following the protocols and
126 procedures described in Marrone et al. (2010, 2013),
127 with the aim of investigating the molecular structuring
128 of the taxon and to compare it with the observed patterns
129 of morphological variation. Chromatograms were imported
130 and edited with Chromas Lite 2.01 (Technelysium Pty.
131 Ltd., South Brisbane, Australia) and aligned with BioEdit
132 (Ibis Biosciences, Carlsbad, CA, USA) (Hall 1999). The
133 quality of the obtained sequences was checked with Se-
134 quence Scanner v1.0. Only sequences with continuous
135 reads of high quality bases were used; when the sequences
136 were not of sufficient quality, the reverse complement se-
137 quences were also obtained. MEGA 5 (Tamura et al. 2011)
138 was used to translate the Cyt-b sequences to amino acids
139 in order to check for the possible presence of frameshifts
140 or stop codons, which would indicate the presence
141 of sequencing errors or pseudogenes. The sequences
142 were deposited in GenBank under Accession Numbers
143 KM488608 to KM488622.

144 Bayesian inference (BI) of phylogeny and maximum
145 likelihood (ML) analyses were performed on the Cyt-b
146 dataset as implemented by MrBayes 3.2.1 (Ronquist
147 et al. 2012) and PhyML v.3 (Guindon and Gascuel 2003),
148 respectively. Both analyses were performed using a
149 Hasegawa, Kishino, and Yano model of sequence evolu-
150 tion for molecular data with a proportion of invariable

151 sites (HKY + I), as selected by the Akaike information 151
152 criterion in MrModeltest 2.2 (Nylander 2004). Node 152
153 supports were evaluated by their posterior probabilities 153
154 in the BI tree and with 1,000 bootstrap replicates in the 154
155 ML analysis. The BI analysis was performed with two in- 155
156 dependent runs of 2,000,000 generations and four Markov 156
157 chains using default heating values. Trees and parameter 157
158 values were sampled every 100 generations resulting in 158
159 20,000 saved trees per analysis. An initial fraction of 5,000 159
160 trees (20%) was conservatively discarded as 'burn-in'. 160
161 For all analyses, standard deviation of split frequencies 161
162 reached values lower than 0.0065, and values of the poten- 162
163 tial scale reduction factor (PSRF) were between 1.0 and 163
164 1.004 for all parameters, indicating convergence of the 164
165 runs. 165

166 In order to compare the observed molecular dis- 166
167 tances with those available in literature for other dia- 167
168 ptomid taxa, uncorrected molecular distances among 168
169 specimens and between groups were calculated in 169
170 PAUP 4.0b10 (Swofford 1998). 170

171 Results

172 Morphological identification

173 We analysed samples originating from 60 different sam- 173
174 pling sites. In 18 sites, diaptomid copepods were present 174
175 (Figure 1, Table 1). Most of these habitats were temporary T1
176 rain pools, diaptomids were only rarely encountered in 176
177 permanent water bodies such as reservoirs and fishponds, 177
178 although these were well-represented in our sample set. 178
179 Altogether, five diaptomid taxa were collected (Table 2). T2
180 Among these, *Hemidiaptomus gurneyi canaanita*, two 180
181 'forms' of *A. similis* s.l., and *Neolovenula alluaudi* were 181
182 already known for the fauna of the country. Conversely, 182
183 the finding of *Phyllodiaptomus blanci* in a reservoir of a 183
184 city park in Tel Aviv is the first one for Israel and for the 184
185 whole circum-Mediterranean area. In spite of previously 185
186 published findings, no *Eudiaptomus* species were col- 186
187 lected during the present survey. 187

188 Studied *A. similis* s.l. populations differed in the anten- 188
189 nular chaetotaxy, which consistently presents one *versus* 189
190 two setae on the 15th and 17th segments of the left male 190
191 antennule (Figure 2). Based on this character, these F2
192 could be ascribed to two parapatric groups, one res- 192
193 tricted to water bodies of the Golan Heights only, the 193
194 other found in other regions of the country (Table 3). T3

195 Molecular analyses

196 The BI and ML trees based on a 329-bp long fragment 196
197 of the Cyt-b showed a concordant topology, with a clear 197
198 division of the investigated *A. similis* s.l. samples into two 198
199 groups, hereafter referred to as the 'Golan' and the 'Israeli' 199
200 clades (Figure 3). These clades are in good accordance F3
201 with the two groups singled out based on morphology 201
202 (Table 3) and show a sharp geographical segregation. 202

t1.1 **Table 1 List of the sampled localities with diaptomid presence**

t1.2	Code	Site name - district	Sampling date(s)	Latitude (N)	Longitude (E)	Hydroperiod
t1.3	ISR01	Lake Ram - Golan Heights	14 March 2011	33.23639	35.76583	Permanent
t1.4	ISR02	Pool at El Rom - Golan Heights	9 March 2010	33.16472	35.77694	Temporary
t1.5	ISR03	Bab El Hawa pool - Golan Heights	9 March 2010	33.14333	35.77417	Temporary
t1.6	ISR04	Orvim reservoir - Golan Heights	7 March 2011; 11 March 2011	33.13972	35.73194	Permanent
t1.7	ISR05	Khusniya pool - Golan Heights	8 March 2010	32.99583	35.81056	Temporary
t1.8	ISR06	Vernal pools close to Daliyot Reservoir, Golan Heights	2 January 2003	32.89972	35.77589	Temporary
t1.9	ISR07	Lehavot Habashan - Northern District	15 March 2011	33.13833	35.64389	Permanent
t1.10	ISR08	Mashkena pool - Northern District	6 March 2010; 17 March 2011	32.78111	35.4075	Temporary
t1.11	ISR09	Ditch at Atlit - Haifa District	3 January 2003	32.70444	34.94194	Temporary
t1.12	ISR10	Brechat Reserve - Haifa District	7 March 2011	32.29111	34.84583	Temporary
t1.13	ISR11	Ga'ash pond - Haifa District	7 March 2011	32.22889	34.83083	Temporary
t1.14	ISR12	Pond in Yarkon park - Tel Aviv District	29 January 2003	32.09722	34.81278	Permanent
t1.15	ISR13	Pond in Holon - Tel Aviv District	26 January 2004	32.03472	34.77194	Temporary
t1.16	ISR14	Moshav Ishrash - Center District	Not available.	ca 31.90	ca 34.83	Temporary
t1.17	ISR15	Rainwater-flooded field near Tel Ashdod - Southern District	22 January 2004	31.75167	34.65194	Temporary
t1.18	ISR16	Mamilla pool - Jerusalem District	4 March 2011	31.77801	35.22058	Temporary
t1.19	ISR17	Small pools in Sde Boker, Vadi Zin - Southern District	9 March 2011	30.84167	34.77722	Temporary
t1.20	ISR18	Pool in Makhtesh Ramon crater - Southern District	7 March 2011; 12 March 2011	30.61694	34.84611	Temporary
t1.21	Decimal geographical coordinates (WGS84) are provided.					

203 The mean intra-clade uncorrected molecular distance was 1.6% (ranging from 0.9% to 3%) within the Israeli clade and 0.7% (ranging from 0% to 0.9%) within the Golan clade. The average uncorrected molecular distance between the two clades was 17.3%. 213 part of the Israeli diaptomid checklist based on bibliographical evidence. The reports of *Arctodiaptomus* (*Arctodiaptomus*) *wierzejskii* and *Eudiaptomus gracilis* in the country are in need of being substantiated and are possibly erroneous (see comments below). At the present state of knowledge, the checklist of Israeli diaptomid copepods is thus composed of seven taxa (Table 2). 214 215 216 217 218 219

208 Discussion

209 Checklist and distribution

210 Five diaptomid taxa were collected in the present survey; 211 in addition to these, *Eudiaptomus drieschi* and *Arctodiaptomus* (*Rhabdodiaptomus*) *salinus* have to be considered 212 part of the Israeli diaptomid checklist based on bibliographical evidence. The reports of *Arctodiaptomus* (*Arctodiaptomus*) *wierzejskii* and *Eudiaptomus gracilis* in the country are in need of being substantiated and are possibly erroneous (see comments below). At the present state of knowledge, the checklist of Israeli diaptomid copepods is thus composed of seven taxa (Table 2). 220 The paradiaptomid *N. alluaudi*, which was previously known in the country only from the Sinai and Negev deserts (Dimentman and Por 1985), was collected in our survey both in the Negev desert and on the Golan Heights, 221 222 223

t2.1 **Table 2 Checklist of Israeli Diaptomidae (Copepoda, Calanoida)**

t2.2	Taxa	Sites of occurrence (<i>present study</i>)	Sources
t2.3	Diaptominae		
t2.4	<i>Hemidiaptomus</i> (<i>Hemidiaptomus</i>) <i>gurneyi canaanita</i>	ISR02, ISR05, ISR06, ISR11, ISR14	2, 6, 8, 9, 11, 13
t2.5	Dimentman & Por, 1985		
t2.6	^a <i>Eudiaptomus drieschi</i> (Poppe & Mrázek 1895)	n.d.	10
t2.7	<i>Arctodiaptomus</i> (<i>Arctodiaptomus</i>) <i>similis</i> (Baird, 1859)	ISR07, ISR08, ISR09, ISR10, ISR11, ISR13, ISR15, ISR16	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 13
t2.8	<i>Arctodiaptomus</i> (<i>Arctodiaptomus</i>) <i>irregularis</i> Dimentman & Por, 1985	ISR02, ISR03, ISR04, ISR05, ISR06	
t2.9	^a <i>Arctodiaptomus</i> (<i>Rhabdodiaptomus</i>) <i>salinus</i> (Daday, 1885)	n.d.	2
t2.10	^b <i>Phyllodiaptomus blanci</i> (Guerne & Richard, 1896)	ISR12	13
t2.11	Paradiaptominae		
t2.12	<i>Neolovenula alluaudi</i> (Guerne & Richard, 1890)	ISR01, ISR03, ISR17, ISR18	8, 9, 12, 13

t2.13 ^aNot found during the present survey; ^bfirst record for Israel. The actual occurrence of *Arctodiaptomus wierzejskii* and *Eudiaptomus gracilis* in Israel is doubtful, and the species are not included in the table (see 'Discussion' section). The codes of sampling sites refer to Table 1. n.d., not detected. Sources: 1: Baird (1859); 2: Richard (1893); 3: Kiefer (1930); 4: Fischer (1953); 5: Petkovski (1961); 6: Yaron (1964); 7: Kiefer (1974); 8: Por (1984); 9: Dimentman & Por (1985); 10: Azoulay (2001); 11: Marrone et al. (2010); 12: Alfonso & Belmonte (2013); 13: Present work.



Figure 2 *Arctodiaptomus similis* (Baird, 1859) and *Arctodiaptomus irregularis* Dimentman & Por, 1985. Anatomical features of *A. irregularis* collected in Bab El Hawa (ISR03) on 9 March 2010 (A-D) and *A. similis* collected in Birket Mamilla pool (ISR16) on 4 March 2011 (E-H). A and E: male fifth pair of the legs (posterior view). B and F: antepenultimate article of the male right antennula. C and G: detail of the chaetotaxy on the articles 13 to 17 of the male left antennula. D and H: articles 12 to 15 of the male right antennula. Scale bar 100 μ m.

224 thus widening to the north the distribution of this species
225 in the country. This finding was recently anticipated by
226 Alfonso and Belmonte (2013) in a review on *N. alluaudi*
227 distribution.

228 *Hemidiaptomus* (*Hemidiaptomus*) *gurneyi canaanita*
229 is an endemic taxon whose distinct status was confirmed
230 by molecular analyses, in spite of the morphological
231 identity of Israeli populations with those collected in the
232 central Mediterranean, including the type locality of the
233 species (Marrone et al. 2010). *Hemidiaptomus gurneyi* s.

234 l. is characterised by a sharply disjointed distribution, 234
235 with the populations belonging to *Hemidiaptomus gur-* 235
236 *neyi gurneyi* occurring in the central Mediterranean area 236
237 (from eastern Algeria to the Balkan Peninsula), and 237
238 those belonging to the subspecies *Hemidiaptomus gur-* 238
239 *neyi canaanita* occurring in Israel (Marrone et al. 2010). 239
240 The report of the presence of the species in Hungary 240
241 (Dussart and Defaye 2002) is not supported by any refer- 241
242 ence or sample (cf. Kiefer 1978a; Petkovski 1983; Stella 242
243 1984; Dussart 1989; Borutzky et al. 1991; Marrone et al. 243

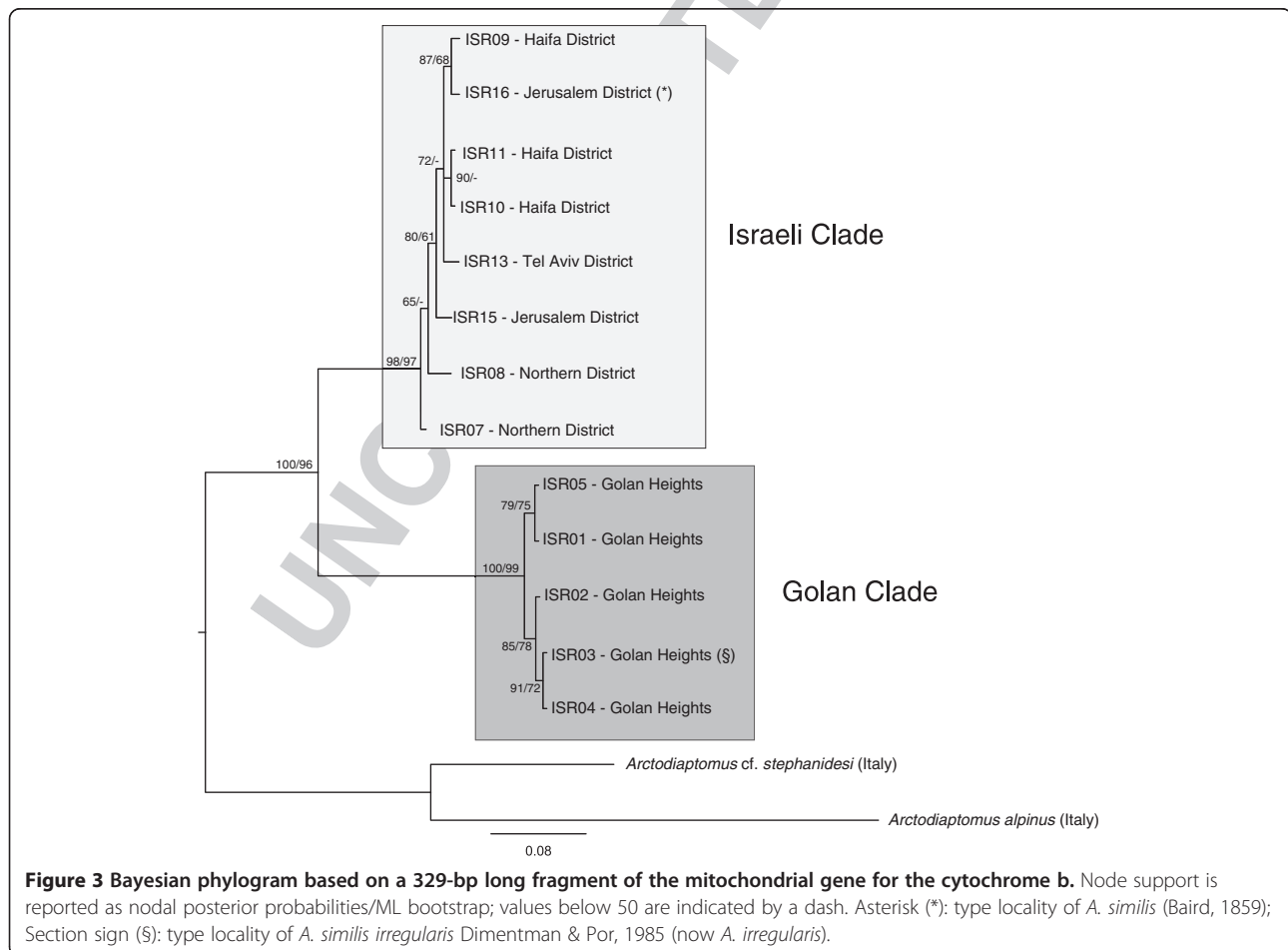
t3.1 **Table 3 A. *similis* s.l. populations based on setae number**
 t3.2 **on 13th, 15th, and 17th segments of left male antennule**

t3.3 Population	N	1-1-1	1-2-2
t3.4 ISR01 - Golan Heights	3		✓
t3.5 ISR02 - Golan Heights	3		✓
t3.6 ISR03 - Golan Heights ^a	5		✓
t3.7 ISR04 - Golan Heights	1		✓
t3.8 ISR05 - Golan Heights	3		✓
t3.9 ISR06 - Golan Heights	5		✓
t3.10 ISR07 - Northern District	1	✓	
t3.11 ISR08 - Northern District	2	✓	
t3.12 ISR11 - Haifa District	1	✓	
t3.13 ISR13 - Tel Aviv District	3	✓	
t3.14 ISR15 - Southern District	4	✓	
t3.15 ISR16 - Jerusalem District ^b	6	✓	

t3.16 No males were available from populations ISR09 and ISR10. N, number of male
 t3.17 specimens studied. ^aType locality of *A. similis irregularis* Dimentman & Por,
 t3.18 1985 (now *A. irregularis*); ^btype locality of *A. similis* (Baird, 1859).

2010); it has thus to be considered a *lapsus calami* of the authors. In our survey, *H. gurneyi canaanita* was collected in water bodies of central and northern areas of Israel, which is in good accordance with the distribution pattern described for the species by Dimentman and Por (1985). Based on the available drawing, the report of the occurrence of a female *Hemidiaptomus* specimen in 'Birket de Baniyas' (Richard 1893), originally attributed to *Hemidiaptomus amblyodon* (Marezneller, 1873) by the author, can in fact be unequivocally ascribed to *H. gurneyi canaanita*.

Two species belonging to the genus *Eudiaptomus* are to date reported for the country: *Eudiaptomus gracilis* (G.O. Sars, 1863) and *Eudiaptomus drieschi* (Poppe & Mrázek, 1895), both of them for Lake Kinneret (see Azoulay 2001, and references therein). As it has already been stressed (e.g., Dimentman and Por 1985; Azoulay 2001), it is possible that the early reports of *E. gracilis* for Lake Kinneret should be in fact ascribed to a misidentification of *E. drieschi*, and that *E. gracilis* should thus be excluded from Israeli diaptomid fauna. However, conclusive evidence is not available, and the report of occurrence of this euryecious diaptomid species in the



267 lake cannot be excluded. *Eudiaptomus* species were ob- 274
 268 served in Lake Kinneret only since the 1960s onwards, al- 275
 269 though the Lake Kinneret zooplankton was investigated by 276
 270 frequent sampling since the early 20th century. This sug- 277
 271 gests a relatively recent colonization of the lake from an 278
 272 unknown source area, possibly corresponding with various 279
 273 anthropogenic changes of the Lake Kinneret system which

took place since the 1950s, including intensive stocking of 274
 fish exotic to the lake (e.g., Gophen 1979). No *Eudiaptomus* 275
 species were collected during our survey; however, we did 276
 not sample this large freshwater lake. 277

A thriving population of the diaptomid *P. blanci* was 278
 observed in a permanent reservoir within a city park in 279
 Tel Aviv (Figure 4). This species is new for Israel and 280 **F4**

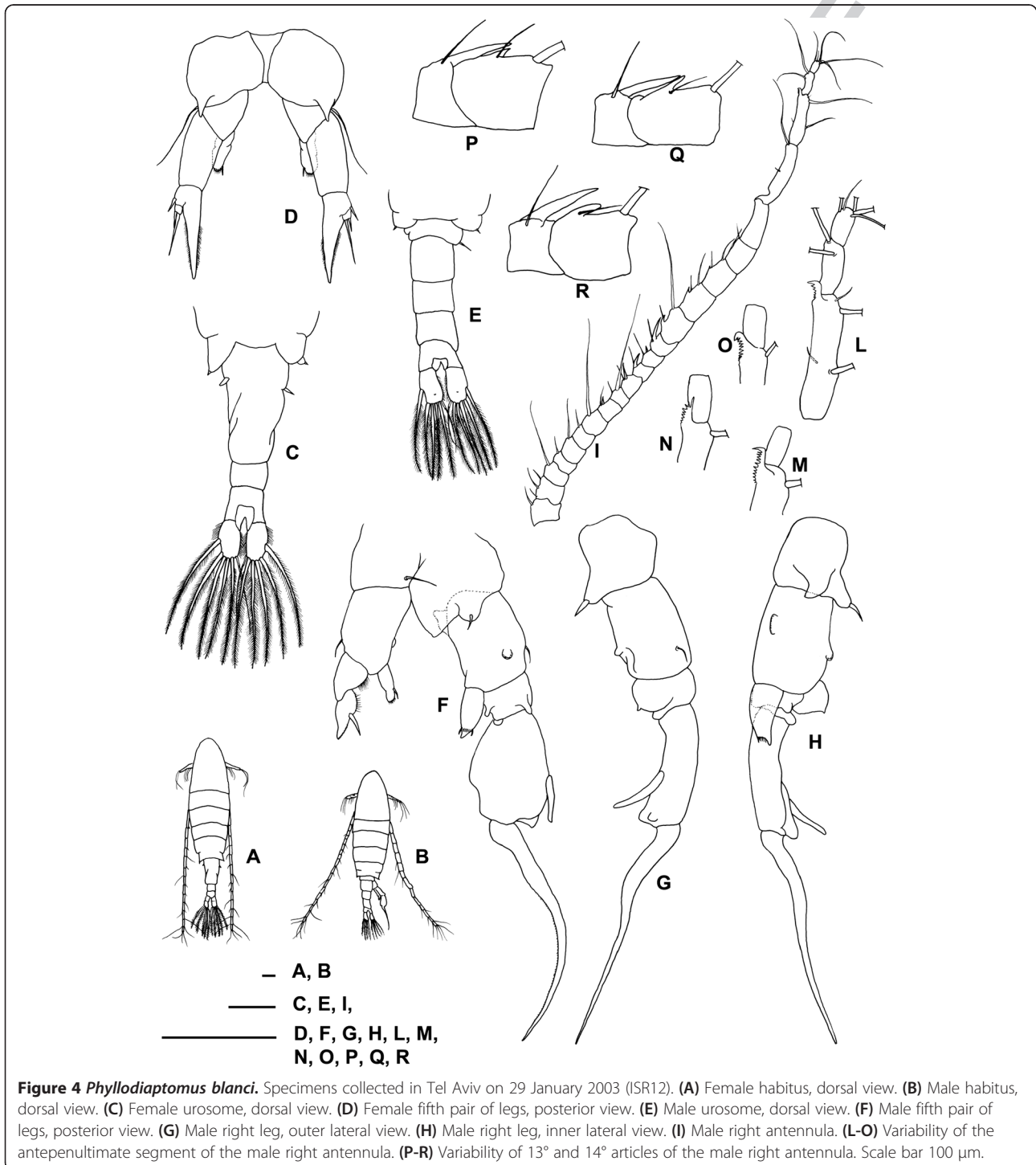


Figure 4 *Phylloidiaptomus blanci*. Specimens collected in Tel Aviv on 29 January 2003 (ISR12). (A) Female habitus, dorsal view. (B) Male habitus, dorsal view. (C) Female urosome, dorsal view. (D) Female fifth pair of legs, posterior view. (E) Male urosome, dorsal view. (F) Male fifth pair of legs, posterior view. (G) Male right leg, outer lateral view. (H) Male right leg, inner lateral view. (I) Male right antennula. (L-O) Variability of the antepenultimate segment of the male right antennula. (P-R) Variability of 13° and 14° articles of the male right antennula. Scale bar 100 µm.

281 the whole circum-Mediterranean area. *Phyllodiapto-*
282 *mus* is a diaptomid genus whose distribution area
283 encompasses Central and Eastern Asia, from India to Iraq
284 (Borutzky et al. 1991; Ranga-Reddy 1994; Sanoamuang
285 and Teeramaethee 2006; Khalaf 2008). *P. blanci* and
286 *Phyllodiaptomus irakiensis* are the westernmost species
287 of the genus, both of them being known to occur in Iraq
288 (Khalaf 2008, and references therein). It is not clear
289 whether the presence of a *P. blanci* population in Israel
290 is to be ascribed to an anthropogenic introduction to
291 the country or whether the species has to be considered
292 autochthonous. However, the man-made origin of the
293 single known Israeli locality of this species suggests that,
294 pending further findings in the area, *P. blanci* is an alien
295 copepod species in Israel.

296 Richard (1893) reported the occurrence of *Arctodiapto-*
297 *mus (Rhabdodiaptomus) salinus* from 'Birket Abo-Zeineh',
298 a brackish marsh close to the northern coast of Lake
299 Kinneret. The species is considered part of the Israeli
300 fauna by Ranga-Reddy (1994) and Dussart and Defaye
301 (2002). Dimentman and Por (1985) considered that this
302 finding needed to be substantiated; however the presence
303 of *A. salinus* in Israel is rather likely as this halophilous
304 taxon is characterised by a broad circum-Mediterranean
305 and Palaearctic distribution, including several countries in
306 the Middle East (Dussart and Defaye 2002; Dumont
307 2009). Inland endorheic water bodies and salty coastal
308 marshes and lagoons are the habitats to be sampled in
309 order to find new evidence for the presence of this taxon
310 in Israel.

311 *Arctodiaptomus (Arctodiaptomus) wierzejskii* was erro-
312 neously cited to be present in Israel by Yaron (1964),
313 who misidentified *A. similis* s.l. for this species (this er-
314 roneous datum was then unfortunately perpetuated by
315 Dussart and Defaye 2002). The mistake was possibly due
316 to the use of the trinomen *Diaptomus wierzejskii palaes-*
317 *tinensis* by Kiefer (1930) for the diaptomid population
318 inhabiting 'Birket Mamilla' and by Fischer (1953) for the
319 populations inhabiting some fish ponds throughout the
320 country. *D. wierzejskii palaestinensis* is in fact a synonym
321 of *Arctodiaptomus similis* (Kiefer 1932, 1974).

322 The diaptomin taxon *Arctodiaptomus (Arctodiaptomus)*
323 *similis* s.l. (Baird, 1859) inhabits both permanent and tem-
324 porary water bodies of central and northern parts of the
325 country, proving to be the commonest calanoid copepod
326 occurring in Israeli inland waters. In spite of its abun-
327 dance, the taxonomy of *A. similis* s.l. is to date controver-
328 sial. Currently, two taxa of subspecific rank are ascribed to
329 *A. similis* s.l., but the taxonomical arrangement of the spe-
330 cies is in need of revision (cf. Ranga-Reddy 1994; Dussart
331 and Defaye 2002). The species was described from Israel
332 by Baird (1859) and later reported to occur throughout
333 Southwestern Asia and Eastern Europe (e.g., Richard 1893;
334 Petkovski 1961; Kiefer 1930, 1974, 1978; Dimentman and

Por 1985, Azoulay 2001, Dussart and Defaye 2002). Some 335
authors reported the presence of the species in Sardinia 336
(Kiefer 1978a; Dussart and Defaye, 2002) without providing 337
any drawing or precise locality data; furthermore, extensive 338
limnological surveys carried out in the island (e.g., Stella 339
1970; Stella et al. 1972; Stella and Margaritora 1975/1976; 340
Fadda et al. 2011; Marrone and Stoch, *unpublished data*) 341
only recorded the presence of the congeneric species *A.* 342
salinus and *A. wierzejskii*, and no evidence of the presence 343
of *A. similis* s.l. was ever collected. Thus, the report of the 344
presence of the species in Sardinia is almost certainly erro- 345
neous, and the species is currently not considered part of 346
the Italian copepod fauna (Stella 1984; Ruffo and Stoch 347
2005). The Israeli populations of *A. similis* s.l. studied by us 348
could be split into two parapatric groups (Table 3), differing 349
in the chaetotaxy of the left male antennule (Figure 2C,G) 350
and in the mtDNA Cyt-b sequences (Figure 3). 351

352 **Taxonomical notes on *Arctodiaptomus (Arctodiaptomus)*** 353 ***similis* (Baird, 1859) and *Arctodiaptomus (Arctodiaptomus)*** 354 ***irregularis* Dimentman & Por, 1985 stat. rev**

355 *A. similis* was described by Baird (1859) based on speci- 355
mens raised from dried mud collected in the pool of 356
Gihon in Jerusalem (now Birket Mamilla pond). Later on, 357
Kiefer (1930) described *D. wierzejskii palaestinensis* based 358
on specimens collected in Birket Mamilla, but this taxon 359
was later synonymised, by the author himself, with *A.* 360
similis (see Kiefer 1974 for an annotated list of the syno- 361
nyms of the species). In the same work, Kiefer (1974) 362
stressed the variability of the ornamentation and chaeto- 363
taxy of the male antennule and established two infrasub- 364
specific *formae* based on the presence of two *versus* one 365
setae on the 13th, 15th, and 17th segments of the left male 366
antennule (*forma saetosior*) and on the presence of a rod- 367
like instead of claw-like process of the antepenultimate 368
segment of the right male antennule (*forma irregularis*). 369
Based on this last character, and on the presence *versus* 370
absence of a tooth on the 14th segment of the right male 371
second antenna, Dimentman and Por (1985) established 372
the subspecies *Arctodiaptomus similis irregularis*, whose 373
type locality lies in Birket Bab el Hawa, on the Golan 374
Heights. However, it has to be stressed that several au- 375
thors (Richard 1893; Petkovski 1961; Kiefer 1974, 1978a) 376
reported the presence of a pronounced intra-population 377
morphological variability for the morphological characters 378
which, according to Dimentman and Por (1985), should 379
allow unequivocal assignment of each population to one 380
or the other subspecies. 381

382 In good accordance with Richard (1893) and Petkovski 382
(1961), the *A. similis* s.l. populations studied by us showed 383
a noteworthy variability in the morphology of the right 384
male antennule; although the populations from the 385
Golan Heights show, as a rule, a smaller tooth on the 386
14th segment (Figure 2D) and a blunter process on the 387

388 antepenultimate segment of the antennule (Figure 2B),
389 exceptions and intermediate forms were observed. Con-
390 versely, the number of setae on the 15th and 17th seg-
391 ments of the left male antennule allowed us to soundly
392 distinguish the specimens collected throughout the
393 country in two groups (Table 3). This observation is in
394 sharp contrast with Kiefer (1974, 1978a), who stressed a
395 significant variability for the chaetotaxy of the segments
396 13th, 15th, and 17th both at intra- and inter-population
397 level.

398 The two groups of populations singled out based on
399 the number of setae present on the 15th and 17th seg-
400 ments of the left male antennule (Figure 2C,G) are
401 parapatric and in good accordance with the observed
402 molecular clustering in two clades of the studied popula-
403 tions (Figure 3). The molecular distance observed between
404 the two groups is of the same order of magnitude of those
405 observed among different lineages deserving the status of
406 cryptic species within other diaptomid species, like *Skisto-*
407 *diaptomus pallidus* (14.3% to 17.2%, Thum and Harrison
408 2009), *Hemidiaptomus ingens* (18%, Marrone et al. 2010),
409 and *Onychodiaptomus sanguineus* (22%, Thum and Derry
410 2008); furthermore, a high sequence similarity was ob-
411 served within each of the two clades.

412 Our morphological and genetic data thus support a clas-
413 sification of Israeli *A. similis* s.l. into two main lineages of
414 species rank. Accordingly, two species are present in Israel:
415 *A. similis* (Baird, 1859) (Figure 2E,F,G,H), inhabiting the
416 whole country with the exception of the Golan Heights,
417 and *A. irregularis* Dimentman & Por, 1985 stat. rev.
418 (Figure 2A,B,C,D), apparently confined to the Golan
419 Heights.

420 *Arctodiaptomus similis* (Baird, 1859)

421 Type locality: Mamilla pool (Jerusalem District; ISR16)
422 syn.: *Diaptomus wierzejskii palaestinensis* Kiefer, 1930
423 *Arctodiaptomus similis similis* Dimentman & Por, 1985

424 *A. irregularis* Dimentman & Por, 1985 stat. rev.

425 Type locality: Bab el Hawa pool (Golan Heights; ISR03)
426 syn.: *Arctodiaptomus similis* forma *irregularis* Kiefer,
427 1974
428 *Arctodiaptomus similis irregularis* Dimentman & Por,
429 1985

430 The two taxa *Arctodiaptomus similis* var. *smirnovi*
431 Brehm, 1938 and *Arctodiaptomus spectabilis* Mann, 1940
432 are junior synonyms of *A. similis* s.l. (cf. Kiefer, 1974), but
433 at the current state of knowledge, it is impossible to
434 soundly ascribe them to, or differentiate from, either *A.*
435 *similis* s.s. or *A. irregularis*. The distribution of these two
436 taxa in the Middle East and Eastern Europe is in fact to
437 date unknown. Interestingly, a parapatric distribution of

two distinct lineages similar to that within *A. similis* 438
has also been observed in Israeli populations of the cla- 439
doceran *Daphnia* (*Ctenodaphnia*) *chevreuxi* Richard, 440
1896: one lineage was only detected in lowland pools 441
in the Mediterranean coastal plain, while a genetically 442
distinct lineage was widespread in the Golan Heights 443
but not found elsewhere (*A. Petrussek, unpublished data*). 444

445 Conclusions

446 In the light of a critical review of the existing and new
447 data, the calanoid family Diaptomidae proved to be
448 better represented in Israel than previous literature
449 data suggested, with seven species certainly occurring
450 in the country. This value is close to that observed in
451 other circum-Mediterranean countries of comparable
452 size (e.g., Marrone 2006). Furthermore, it also needs to
453 be stressed that representatives of the genus *Metadiap-*
454 *tomus*, known to occur throughout the arid regions of
455 the Mediterranean and Black Sea (e.g., Kiefer 1978b;
456 Jaume 1989; Rayner 1999; Marrone and Naselli-Flores
457 2005; Samchysyna 2011, and references therein), although
458 never recorded to date in Israel, are likely to also occur
459 in the country; for instance, *Metadiaptomus chevreuxi*
460 (de Guerne & Richard, 1894) is known from Jordan, and
461 *Metadiaptomus mauretanicus* Kiefer & Roy, 1942 from
462 Egypt (Dumont 1979, 2009).

463 Based on the updated checklist of Israeli diaptomids
464 (Table 2), counts of endemic (i.e., *H. gurneyi canaanita*,
465 *A. irregularis*) and eastern taxa (*A. similis*, *E. drieschi*, *P.*
466 *blanci*) in this country are comparable to counts of taxa
467 with wider distribution areas (i.e., *Arctodiaptomus sali-*
468 *nus* and *Neolovenula alluaudi*). Unfortunately, due to a
469 lack of sound checklists for most of the other Middle
470 East countries, it is currently difficult to understand the
471 biogeographic affinities of the Israeli calanoid copepod
472 fauna.

473 The possible presence of an allochthonous species in the
474 country is in accordance with the ever-growing number of
475 successful biological invasions affecting the freshwater zoo-
476 plankton in the last decades. Such phenomenon is becom-
477 ing increasingly important in the Western Palaearctic
478 region, where the records of allochthonous calanoid co-
479 pepods are increasing at a fast pace (e.g., Ferrari et al.
480 1991; Rossetti et al. 1996; Alfonso and Belmonte 2008;
481 Brandorff 2011; Alfonso et al. 2014).

482 Competing interests

483 The authors declare that they have no competing interests

484 Authors' contributions

485 FM carried out the morphological identification of the samples, carried out
486 the molecular analyses, and drafted the manuscript. AP carried out the
487 samplings in Israel and helped to draft the manuscript. GA helped with the
488 bibliographical research, realised the figures, and provided important
489 comments to a first draft of the manuscript. MA supervised and coordinated
490 the research and helped with the molecular analyses. All authors read and
491 approved the final manuscript.

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