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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

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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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Background

Representatives of the copepod family Diaptomidae often dominate the lentic inland water bodies of the Holarctic, Oriental, and Afrotropical biogeographical regions, being a key taxon in many lacustrine and pond ecosystems (Dussart and Defaye 2001, 2002). Species of this family are as a rule characterised by limited distributional ranges, which are significantly constrained by the legacies of historical biogeographical events (Leibold et al. 2010). However, an ever-increasing corpus of molecular evidence suggests that our knowledge on diaptomid species distributions and biogeography is currently hampered by a gross underestimation of the actual diversity of the group (e.g., Marrone et al. 2013, and references therein). In the inland waters of the Mediterranean area, about 100 diaptomid species belonging to 14 genera are currently reported to occur (Dussart and Defaye 2002), but the information available for certain regions is far from being satisfactory (cf. Marrone 2006).

To date, uneven information is available on the inland water calanoid copepod fauna of the Middle East. While the diaptomid faunas of Turkey (e.g., Gündüz 1998; Ustaoğlu 2004; Ustaoğlu et al. 2005) and Iran (e.g., Brehm 1937; Löffler 1956, 1961) are relatively well-known, only scarce and anecdotal records are currently available for other countries of this region (e.g., Gurney 1921; Spandl 1923; Kiefer 1978b; Dumont 1979, 2009; Khalaf 2008; Mohamed and Salman 2009). The Israeli diaptomid fauna is quite a peculiar case: although several papers and reviews are available (e.g., Baird 1859; Richard 1893; Kiefer 1930; Yaron 1964; Dimentman and Por 1985, Azoulay 2001, and references therein), only five diaptomid taxa are currently listed for the country; this seems quite a species-poor fauna when compared to other circum-Mediterranean regions of comparable area, where usually about 9 to 14 diaptomid species are present (e.g., Ruffo and Stoch 2005; Marrone et al. 2005; Marrone 2006; Turki and Turki 2010; Alfonso and Belmonte 2011). Furthermore, the taxonomical validity of some ‘forms’ or ‘subspecies’ described in the past decades based on Israeli specimens is rather controversial, and the presence itself of some taxa in the country is in need of confirmation, thus casting further uncertainty on the actual composition of the Israeli diaptomid fauna.

We studied plankton samples collected in Israeli inland waters between 2003 and 2011 in order to update the available information on the composition and distribution of diaptomid copepods in the country. Furthermore, we genetically analysed several populations of *Arctodiaptomus similis* s.l. to test the hypothesis that two parapatric groups of populations differing in morphology, observed in our dataset, actually represent distinct evolutionary lineages of species rank.

Methods

Plankton samples were collected throughout the country, focusing on small- to medium-sized freshwater habitats; both permanent and temporary water bodies were investigated, and some sites were sampled multiple times on different dates. Altogether, we analysed samples from 60 different sites (Figure 1). Samples were collected using a 200-μm mesh hand net along the water bodies' shorelines; open waters were sampled using 80-to-200-μm mesh-sized towing nets. Collected crustaceans were fixed *in situ*

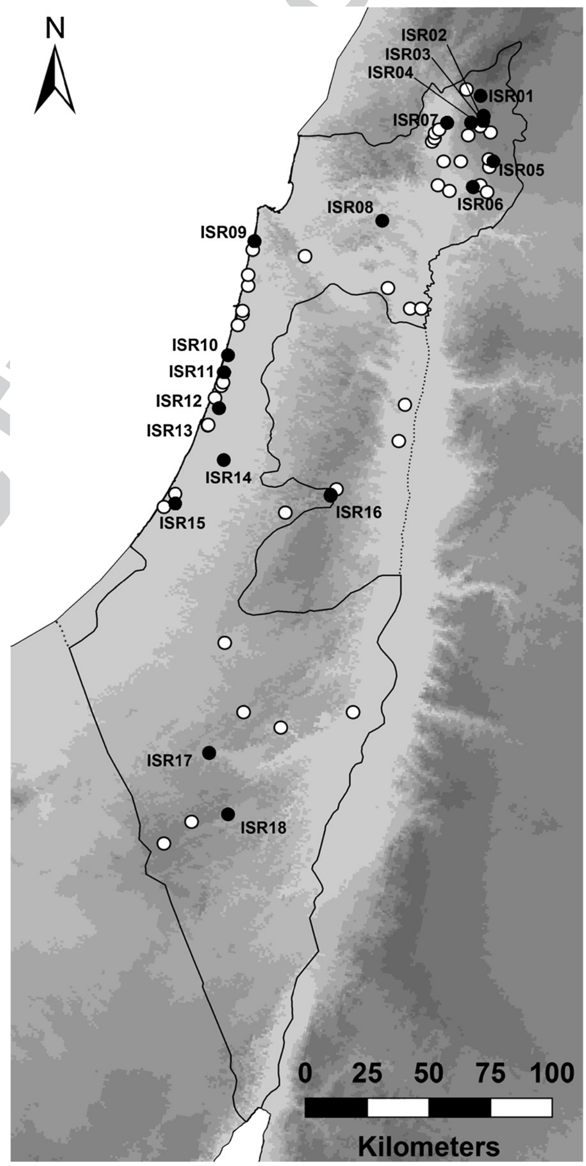

Figure 1 Map of the sampling sites. Samples collected between 2003 and 2011 from both temporary and permanent water bodies were analysed to improve knowledge on diversity and distribution of diaptomid copepods of Israel. Black dots represent sites where at least one diaptomid species was collected; white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

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

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

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

Bayesian inference (BI) of phylogeny and maximum likelihood (ML) analyses were performed on the Cyt-b dataset as implemented by MrBayes 3.2.1 (Ronquist et al. 2012) and PhyMl v.3 (Guindon and Gascuel 2003), respectively. Both analyses were performed using a Hasegawa, Kishino, and Yano model of sequence evolution for molecular data with a proportion of invariable sites (HKY + I), as selected by the Akaike information criterion in MrModeltest 2.2 (Nylander 2004). Node supports were evaluated by their posterior probabilities in the BI tree and with 1,000 bootstrap replicates in the ML analysis. The BI analysis was performed with two independent runs of 2,000,000 generations and four Markov chains using default heating values. Trees and parameter values were sampled every 100 generations resulting in 20,000 saved trees per analysis. An initial fraction of 5,000 trees (20%) was conservatively discarded as 'burn-in'. For all analyses, standard deviation of split frequencies reached values lower than 0.0065, and values of the potential scale reduction factor (PSRF) were between 1.0 and 1.004 for all parameters, indicating convergence of the runs.

In order to compare the observed molecular distances with those available in literature for other diaptomid taxa, uncorrected molecular distances among specimens and between groups were calculated in PAUP 4.0b10 (Swofford 1998).

Results

Morphological identification

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

Studied *A. similis* s.l. populations differed in the antennular chaetotaxy, which consistently presents one *versus* two setae on the 15th and 17th segments of the left male antennule (Figure 2). Based on this character, these could be ascribed to two parapatric groups, one restricted to water bodies of the Golan Heights only, the other found in other regions of the country (Table 3).

Molecular analyses

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

Table 1 List of the sampled localities with diaptomid presence

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

Decimal geographical coordinates (WGS84) are provided.

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%.

Discussion

Checklist and distribution

Five diaptomid taxa were collected in the present survey; in addition to these, *Eudiaptomus drieschi* and *Arctodiaptomus* (*Rhabdodiaptomus*) *salinus* have to be considered 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).

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,

Table 2 Checklist of Israeli Diaptomidae (Copepoda, Calanoida)

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

[a]Not found during the present survey; [b]first 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.

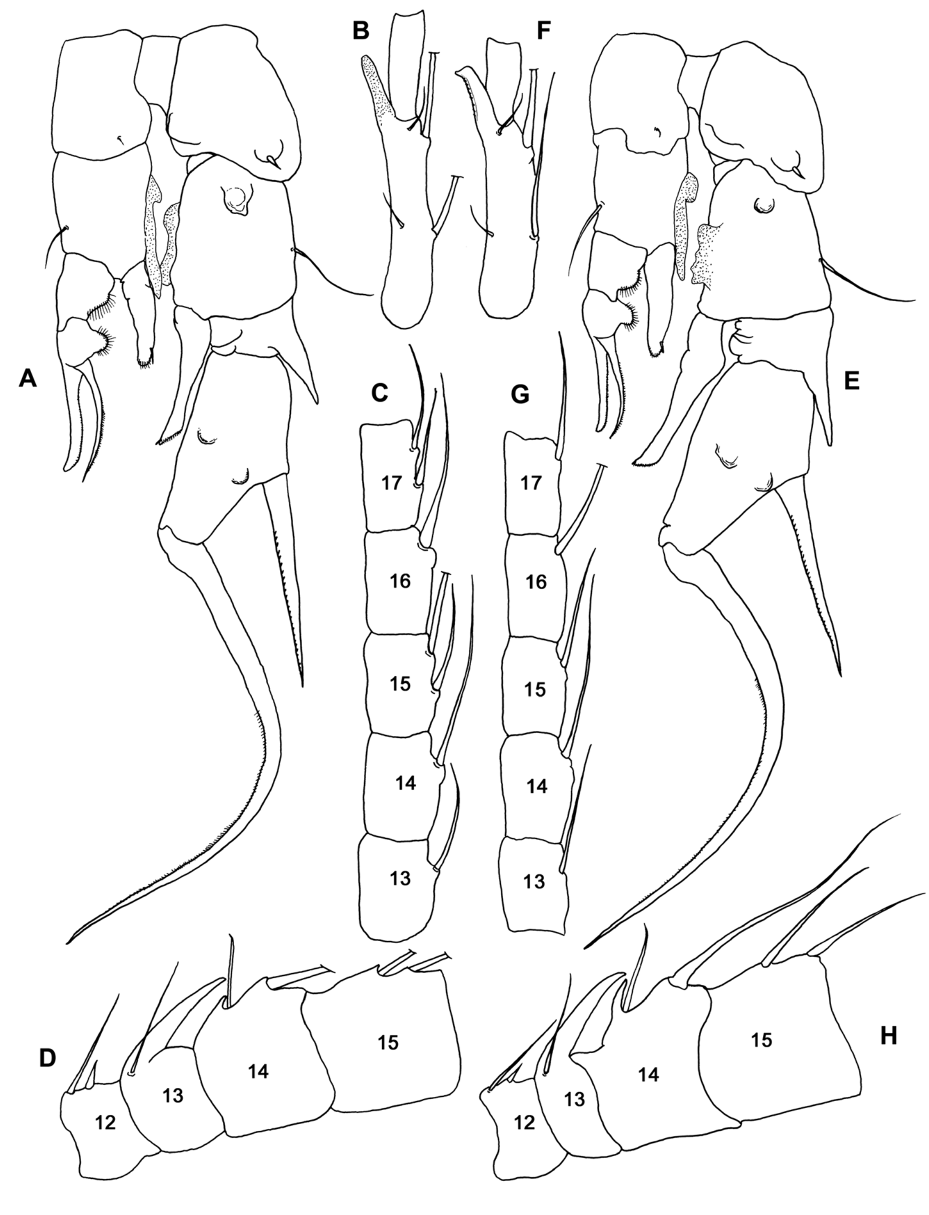

Figure 2 ***Arctodiaptomus similis*** **(Baird, 1859) and** ***Arctodiaptomus irregularis*** **Dimentman & Por, 1985.** Anatomical features of *A. irregularis* collected in Bab El Hawa (ISR03) on 9 March 2010 **(A-D)** and *A. similis* collected in Birket Mamilla pool (ISR16) on 4 March 2011 **(E-H)**. **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 μm.

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

Hemidiaptomus (*Hemidiaptomus*) *gurneyi canaanita* is an endemic taxon whose distinct status was confirmed by molecular analyses, in spite of the morphological identity of Israeli populations with those collected in the central Mediterranean, including the type locality of the species (Marrone et al. 2010). *Hemidiaptomus gurneyi* s. l. is characterised by a sharply disjointed distribution, with the populations belonging to *Hemidiaptomus gurneyi gurneyi* occurring in the central Mediterranean area (from eastern Algeria to the Balkan Peninsula), and those belonging to the subspecies *Hemidiaptomus gurneyi canaanita* occurring in Israel (Marrone et al. 2010). The report of the presence of the species in Hungary (Dussart and Defaye 2002) is not supported by any reference or sample (cf. Kiefer 1978a; Petkovski 1983; Stella 1984; Dussart 1989; Borutzky et al. 1991; Marrone et al.

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

Population	*N*	1-1-1	1-2-2
ISR01 - Golan Heights	3		√
ISR02 - Golan Heights	3		√
ISR03 - Golan Heights[a]	5		√
ISR04 - Golan Heights	1		√
ISR05 - Golan Heights	3		√
ISR06 - Golan Heights	5		√
ISR07 - Northern District	1	√	
ISR08 - Northern District	2	√	
ISR11 - Haifa District	1	√	
ISR13 - Tel Aviv District	3	√	
ISR15 - Southern District	4	√	
ISR16 - Jerusalem District[b]	6	√	

No males were available from populations ISR09 and ISR10. N, number of male specimens studied. [a]Type locality of *A. similis irregularis* Dimentman & Por, 1985 (now *A. irregularis*); [b]type 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 Banias' (Richard 1893), originally attributed to *Hemidiaptomus amblyodon* (Marenzeller, 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

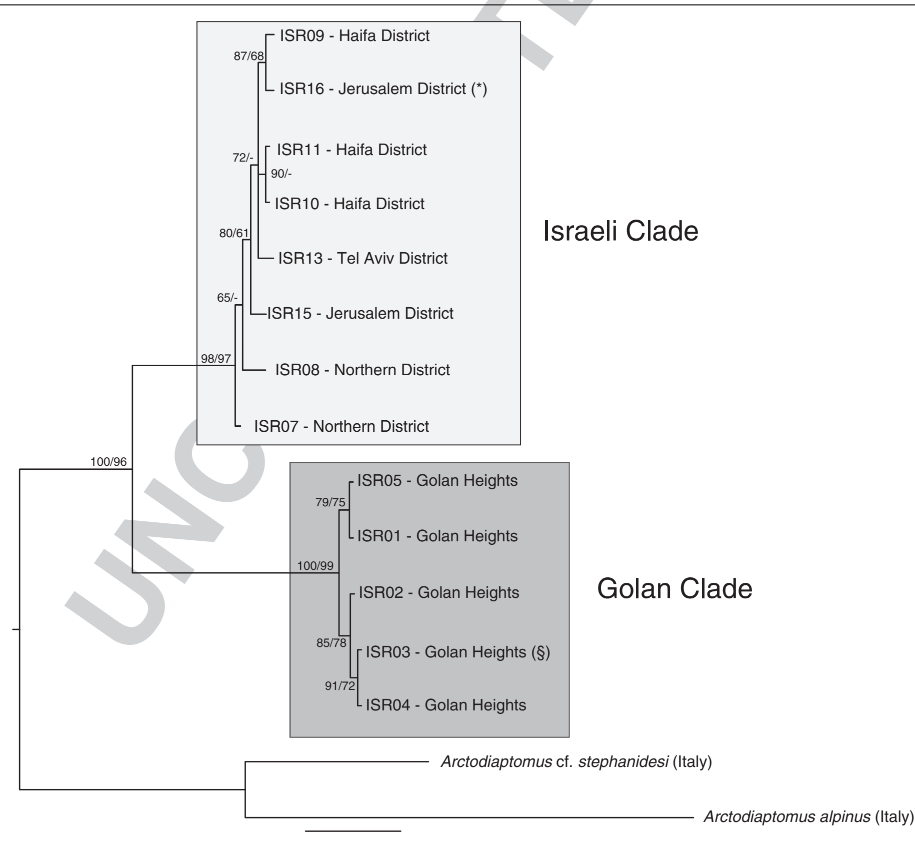

Figure 3 Bayesian phylogram based on a 329-bp long fragment of the mitochondrial gene for the cytochrome b. Node support is reported as nodal posterior probabilities/ML bootstrap; values below 50 are indicated by a dash. Asterisk (*): type locality of *A. similis* (Baird, 1859); Section sign (§): type locality of *A. similis irregularis* Dimentman & Por, 1985 (now *A. irregularis*).

lake cannot be excluded. *Eudiaptomus* species were observed in Lake Kinneret only since the 1960s onwards, although the Lake Kinneret zooplankton was investigated by frequent sampling since the early 20th century. This suggests a relatively recent colonization of the lake from an unknown source area, possibly corresponding with various anthropogenic changes of the Lake Kinneret system which took place since the 1950s, including intensive stocking of fish exotic to the lake (e.g., Gophen 1979). No *Eudiaptomus* species were collected during our survey; however, we did not sample this large freshwater lake.

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

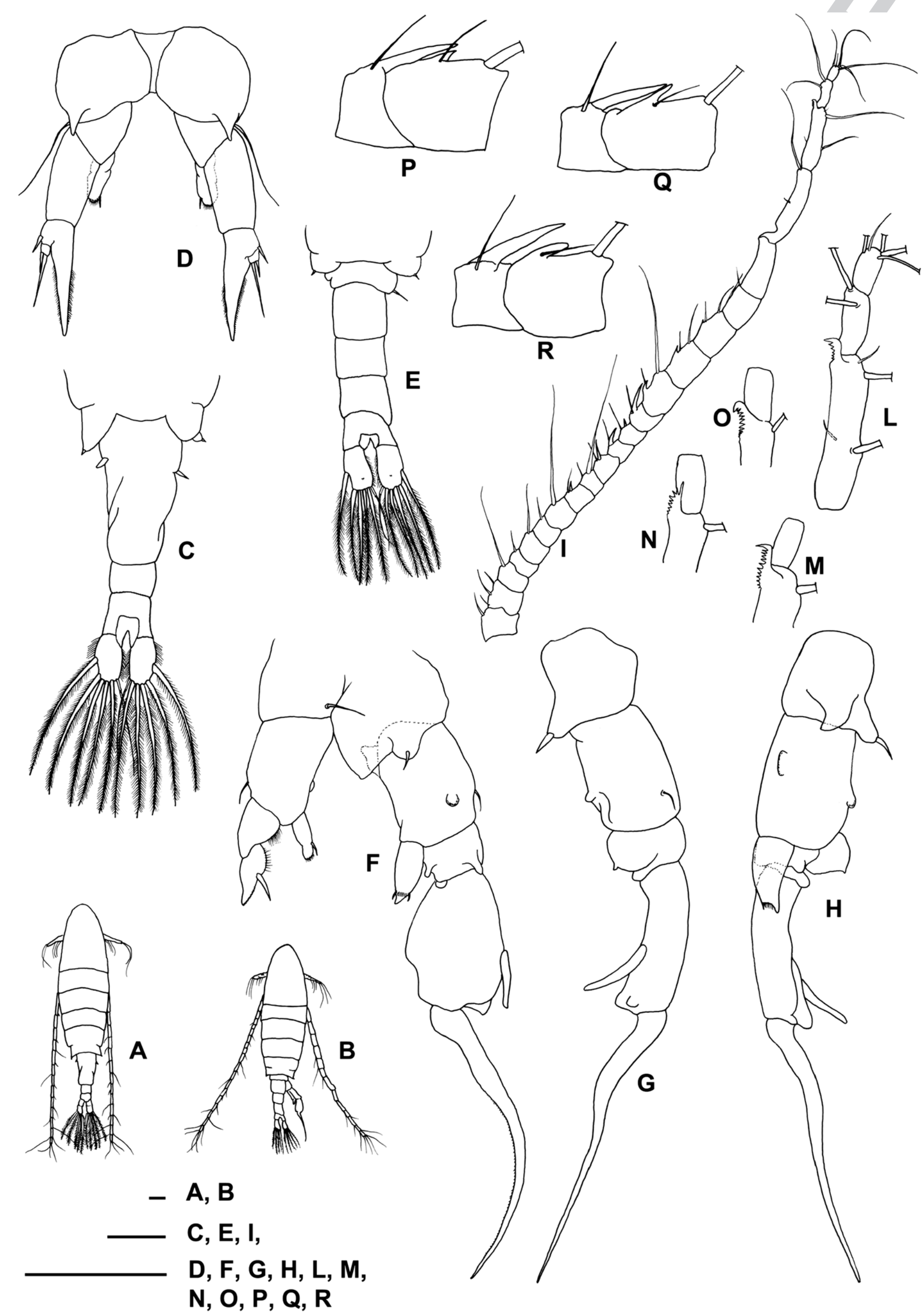

Figure 4 ***Phyllodiaptomus blanci*****.** Specimens collected in Tel Aviv on 29 January 2003 (ISR12). **(A)** Female habitus, dorsal view. **(B)** Male habitus, dorsal view. **(C)** Female urosome, dorsal view. **(D)** Female fifth pair of legs, posterior view. **(E)** Male urosome, dorsal view. **(F)** 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.

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

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

Arctodiaptomus (*Arctodiaptomus*) *wierzejskii* was erroneously cited to be present in Israel by Yaron (1964), who misidentified *A. similis* s.l. for this species (this erroneous datum was then unfortunately perpetuated by Dussart and Defaye 2002). The mistake was possibly due to the use of the trinomen *Diaptomus wierzejskii palaestinensis* by Kiefer (1930) for the diaptomid population inhabiting 'Birket Mamilla' and by Fischer (1953) for the populations inhabiting some fish ponds throughout the country. *D. wierzejskii palaestinensis* is in fact a synonym of *Arctodiaptomus similis* (Kiefer 1932, 1974).

The diaptomin taxon *Arctodiaptomus* (*Arctodiaptomus*) *similis* s.l. (Baird, 1859) inhabits both permanent and temporary water bodies of central and northern parts of the country, proving to be the commonest calanoid copepod occurring in Israeli inland waters. In spite of its abundance, the taxonomy of *A. similis* s.l. is to date controversial. Currently, two taxa of subspecific rank are ascribed to *A. similis* s.l., but the taxonomical arrangement of the species is in need of revision (cf. Ranga-Reddy 1994; Dussart and Defaye 2002). The species was described from Israel by Baird (1859) and later reported to occur throughout Southwestern Asia and Eastern Europe (e.g., Richard 1893; Petkovski 1961; Kiefer 1930, 1974, 1978; Dimentman and Por 1985, Azoulay 2001, Dussart and Defaye 2002). Some authors reported the presence of the species in Sardinia (Kiefer 1978a; Dussart and Defaye, 2002) without providing any drawing or precise locality data; furthermore, extensive limnological surveys carried out in the island (e.g., Stella 1970; Stella et al. 1972; Stella and Margaritora 1975/1976; Fadda et al. 2011; Marrone and Stoch, *unpublished data*) only recorded the presence of the congeneric species *A. salinus* and *A. wierzejskii*, and no evidence of the presence of *A. similis* s.l. was ever collected. Thus, the report of the presence of the species in Sardinia is almost certainly erroneous, and the species is currently not considered part of the Italian copepod fauna (Stella 1984; Ruffo and Stoch 2005). The Israeli populations of *A. similis* s.l. studied by us could be split into two parapatric groups (Table 3), differing in the chaetotaxy of the left male antennule (Figure 2C,G) and in the mtDNA Cyt-b sequences (Figure 3).

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

A. similis was described by Baird (1859) based on specimens raised from dried mud collected in the pool of Gihon in Jerusalem (now Birket Mamilla pond). Later on, Kiefer (1930) described *D. wierzejskii palaestinensis* based on specimens collected in Birket Mamilla, but this taxon was later synonymised, by the author himself, with *A. similis* (see Kiefer 1974 for an annotated list of the synonyms of the species). In the same work, Kiefer (1974) stressed the variability of the ornamentation and chaetotaxy of the male antennule and established two infrasubspecific *formae* based on the presence of two *versus* one setae on the 13th, 15th, and 17th segments of the left male antennule (*forma saetosior*) and on the presence of a rod-like instead of claw-like process of the antepenultimate segment of the right male antennule (*forma irregularis*). Based on this last character, and on the presence *versus* absence of a tooth on the 14th segment of the right male second antenna, Dimentman and Por (1985) established the subspecies *Arctodiaptomus similis irregularis*, whose type locality lies in Birket Bab el Hawa, on the Golan Heights. However, it has to be stressed that several authors (Richard 1893; Petkovski 1961; Kiefer 1974, 1978a) reported the presence of a pronounced intra-populational morphological variability for the morphological characters which, according to Dimentman and Por (1985), should allow unequivocal assignment of each population to one or the other subspecies.

In good accordance with Richard (1893) and Petkovski (1961), the *A. similis* s.l. populations studied by us showed a noteworthy variability in the morphology of the right male antennule; although the populations from the Golan Heights show, as a rule, a smaller tooth on the 14th segment (Figure 2D) and a blunter process on the antepenultimate segment of the antennule (Figure 2B), exceptions and intermediate forms were observed. Conversely, the number of setae on the 15th and 17th segments of the left male antennule allowed us to soundly distinguish the specimens collected throughout the country in two groups (Table 3). This observation is in sharp contrast with Kiefer (1974, 1978a), who stressed a significant variability for the chaetotaxy of the segments 13th, 15th, and 17th both at intra- and inter-population level.

The two groups of populations singled out based on the number of setae present on the 15th and 17th segments of the left male antennule (Figure 2C,G) are parapatric and in good accordance with the observed molecular clustering in two clades of the studied populations (Figure 3). The molecular distance observed between the two groups is of the same order of magnitude of those observed among different lineages deserving the status of cryptic species within other diaptomid species, like *Skistodiaptomus pallidus* (14.3% to 17.2%, Thum and Harrison 2009), *Hemidiaptomus ingens* (18%, Marrone et al. 2010), and *Onychodiaptomus sanguineus* (22%, Thum and Derry 2008); furthermore, a high sequence similarity was observed within each of the two clades.

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

Arctodiaptomus similis (Baird, 1859)

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

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

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

The two taxa *Arctodiaptomus similis* var. *smirnovi* Brehm, 1938 and *Arctodiaptomus spectabilis* Mann, 1940 are junior synonyms of *A. similis* s.l. (cf. Kiefer, 1974), but at the current state of knowledge, it is impossible to soundly ascribe them to, or differentiate from, either *A. similis* s.s. or *A. irregularis*. The distribution of these two taxa in the Middle East and Eastern Europe is in fact to date unknown. Interestingly, a parapatric distribution of two distinct lineages similar to that within *A. similis* has also been observed in Israeli populations of the cladoceran *Daphnia* (*Ctenodaphnia*) *chevreuxi* Richard, 1896: one lineage was only detected in lowland pools in the Mediterranean coastal plain, while a genetically distinct lineage was widespread in the Golan Heights but not found elsewhere (A. Petrusek, *unpublished data*).

Conclusions

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

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

The possible presence of an allochthonous species in the country is in accordance with the ever-growing number of successful biological invasions affecting the freshwater zooplankton in the last decades. Such phenomenon is becoming increasingly important in the Western Palaearctic region, where the records of allochthonous calanoid copepods are increasing at a fast pace (e.g., Ferrari et al. 1991; Rossetti et al. 1996; Alfonso and Belmonte 2008; Brandorff 2011; Alfonso et al. 2014).

Competing interests
The authors declare that they have no competing interests

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

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