Hitching a ride on a scorpion: the first record of phoresy of a myrmecophile pseudoscorpion on a myrmecophile scorpion

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Hitching a ride on a scorpion: the first record of phoresy of a myrmecophile pseudoscorpion on a myrmecophile scorpion

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Abstract. An observation of phoresy by pseudoscorpions on a scorpion host is recorded for the first time worldwide. Pseudoscorpions of the endemic species *Nannowithius wahrmani* (Beier, 1963) (Pseudoscorpiones: Withiidae) were observed phoretic on the endemic scorpion species *Birulatus israelensis* Lourenço, 2002 (Scorpiones: Buthidae) in Israel. Both are myrmecophiles of harvester ants of the genus *Messor* Forel, 1890.

Keywords: *Birulatus*, *Messor*, myrmecophily, *Nannowithius*, Withiidae

Zusammenfassung. Mitfahrt auf einem Skorpion: Der erste Nachweis von Phoresie eines myrmekophilen Pseudoskorpions auf einem myrmekophilen Skorpion. Zum ersten Mal weltweit wurde Phoresie eines Pseudoskorpions auf einem Skorpion als Wirt festgestellt. In Israel wurden Pseudoskorpione der endemischen Art *Nannowithius wahrmani* (Beier, 1963) (Pseudoscorpiones: Withiidae) phoretisch auf der endemischen Skorpionart *Birulatus israelensis* Lourenço, 2002 (Scorpiones: Buthidae) beobachtet. Beide leben myrmekophil zusammen mit Ernteameisen aus der Gattung *Messor* Forel, 1890.

תקציר. לתפוס טרמפ על עקרב: תיעוד ראשון של נשיאת-הפצה של זוט-עקרב נמלים על-גבי עקרב-נמלים. תצפית של נשיאת-הפצה (phoresy) של זוט-עקרב על גבי עקרב מתועדת לראשונה בעולם. זוט-עקרבים מהמין האנדמי לישראל *Nannowithius wahrmani* (Beier, 1963) (Pseudoscorpiones: Withiidae), נצפו בישראל נישאים על גבי עקרב, שגם הוא ממין אנדמי לישראל - עקרב-נמלים הירדן *Birulatus israelensis* Lourenço, 2002 (Scorpiones: Buthidae). שני המינים נמצאים בקשר צוותאות עם נמלים (myrmecophily) מהסוג נמלת-הקציר *Messor* Forel,1890.

Phoresy is a common symbiotic association among numerous species of pseudoscorpions that cling onto the host to disperse into new habitats (Poinar et al. 1998). Phoresy of pseudoscorpions has been recorded on mammals, birds, nine insect orders (Coleoptera, Diptera, Hemiptera, Hymenoptera, Lepidoptera, Mecoptera, Odonata, Orthoptera and Plecoptera) and even on the arachnid orders harvestmen and spiders (Hetešová & Christophoryová 2022, Poinar et al. 1998). While pseudoscorpions usually grasp the host by their chela, on larger carriers they can ride without grasping, and the chelae can be used to feed on micro-arthropods, especially mites (Poinar et al. 1998). Phoresy has been documented in nine out of 25 contemporary pseudoscorpion families: Atemnidae, Cheiridiidae, Cheliferidae, Chernetidae, Garypinidae, Geogarypidae, Larcidae, Sternophoridae and Withiidae (Benavides et al. 2019, Harms & Dunlop 2017, Poinar et al. 1998, Xing et al. 2018).

The pseudoscorpion family Withiidae Chamberlin, 1931 comprising 37 genera and 170 species, is found in many regions of the world (WPC 2022). They are most abundant in tropical and sub-tropical biotopes and most diverse in Africa and South America showing strong biogeographic fidelity (Harvey 2015a). Most withiid species occur in leaf litter, under bark or under stones, but the genera *Nannowithius* Beier, 1932 and *Termitowithius* Muchmore, 1990 were considered inquilines with social insects (Harvey 2015b). *Termitowithius* species are reported to live with termites, while some *Nannowithius* species were found with ants (Harvey 2015b). In most species of *Nannowithius* eyes are absent, except two species with rudimentary eye spots, and this was suggested as a further indication to obligate occurrence with social insects (Harvey 2015b).

The genus *Nannowithius* comprises seven species (six are endemics) and its distribution extends from Pakistan through the Middle East to western Africa (WPC 2022).

Nannowithius wahrmani was known until recently from only two localities in Israel. The first specimens of *N. wahrmani* were collected in 1952 from a nest of the ant *Messor semirufus* (André, 1883) in its type locality Nahal Lavan in the Negev desert, in south-west Israel, and described as *Myrmecowithius wahrmani* Beier, 1963, whereas other specimens were found under a stone without recorded association with ants in Mt. Arbel near the Sea of Galilee, in north-east Israel (Beier 1963, Mahnert 1974). *Nannowithius pakistanicus* specimens were also found in nests of ants (*Messor* sp.) (Beier 1978), thus it is likely that all species of *Nannowithius* are associated with ants (Harvey 2015b).

Myrmecophily refers to various types of symbiotic associations of organisms with ant colonies and nests including mutualistic, commensal or parasitic interactions. This association was reported in at least 39 orders of arthropods, among them: pseudoscorpions, spiders, mites, millipedes, isopods and about a hundred families of insects (Rocha et al. 2020). Myrmecophily of pseudoscorpions has been reported for over 200 years (Wheeler 1911), with twenty-four records of associations with ant nests in eighteen species of sixteen genera and seven families of pseudoscorpions: Atemnidae, Cheiridiidae, Chernetidae, Chthoniidae, Ideoroncidae, Olpiidae and Withiidae (Martinez et al. 2021). As a result of the association with ants, pseudoscorpions gain a predator-free environment, while being richer in potential prey items and a sheltered stable environment with favourable temperature and humidity (Cole et al. 1994). They can hide in narrow inaccessible crevices to evade attack by ants, and possibly employ chemical mimicry of the surface cuticle (Červená et al. 2020). In many cases these interactions are restricted to a single ant host genus or species (Martinez et al. 2021).

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The ant genus *Messor* is a species-rich genus spread in the Palearctic, Afrotropical, and Oriental regions, with 85 species and subspecies in the Mediterranean region (Salata & Borowiec 2019). In the genus *Messor*, workers are polymorphic, and many Mediterranean species that have been mistakenly proposed are actually synonyms of the same species representing various casts and morphs. Therefore, taxonomic revisions of the *Messor* species groups are necessary (Salata & Borowiec 2019).

In a recent study, myrmecophily was reported for the first time for a scorpion (Zvik 2017). *Birulatus israelensis* has been found in the Jordan Valley, in the eastern part of Israel, exclusively on active foraging trails of the ant species *Messor ebeninus* Santschi, 1927, or coming in and out of the nests many times, disregarded by the ants. When aggressive interactions did occur, they ended with no visible harm to the ants or the scorpions (Zvik 2022). The genus *Birulatus* Vachon, 1974, is found in Jordan, Israel and Syria, comprising four described species. It is characterized by a small body size, up to two cm long, and reduced lateral eyes, but only *B. israelensis* was studied for its ecology and biology and was reported as a myrmecophile (Lourenço et al. 2021, Zvik 2017).

Here we present the first record of a pseudoscorpion phoretic on a scorpion, while both are myrmecophiles of an ant species belonging to the genus *Messor*.

Methods

A thorough study of *Birulatus israelensis* has been conducted since 2016 by the second author (Zvik 2022). It included field surveys and specific nest monitoring every year between March–November, field observations, and video recordings in the vicinity of the ant nests between August–November. Surveys were performed in a semi-desert region along the eastern part of Israel from southern Golan and the Sea of Galilee in the north, to the Dead Sea area and Central Negev in the south. Monitoring started towards dusk and continued until midnight using UV torches, mainly in the vicinity of ant nests and along ant trails, but also in their surrounding area (Zvik 2022). While scorpions glow under UV light, these pseudoscorpions do not. This enabled their detection during night time as dark shades on the scorpion's glowing body. These scorpions were collected with the pseudoscorpions adhering to their dorsum or metasoma for laboratory identification using a Nikon SMZ25 motorized stereomicroscope and Beier's (1963) key for the pseudoscorpion fauna of Israel. The specimens are deposited at the Israel Arachnid National Natural History Collection (NNHC) at the Hebrew University of Jerusalem (HUJ).

Results

Over a thousand observations of *Birulatus israelensis* were documented in hundreds of monitoring events during the seven years of the study. However, *Nannowithius wahrmani* pseudoscorpions were observed on only two dates, both in late spring, at two localities in the main study area in the northern part of the Jordan valley ca. 20 km south of Bet She'an: Givat Salit 32.3628°N, 35.5071°E and Rotem 32.3438°N, 35.5162°E, (Fig. 1a). On 7. May 2018 a single *B. israelensis* individual was collected with two pseudoscorpions on its dorsum. On 27. Apr. 2023 out of eleven *B. israelensis* specimens

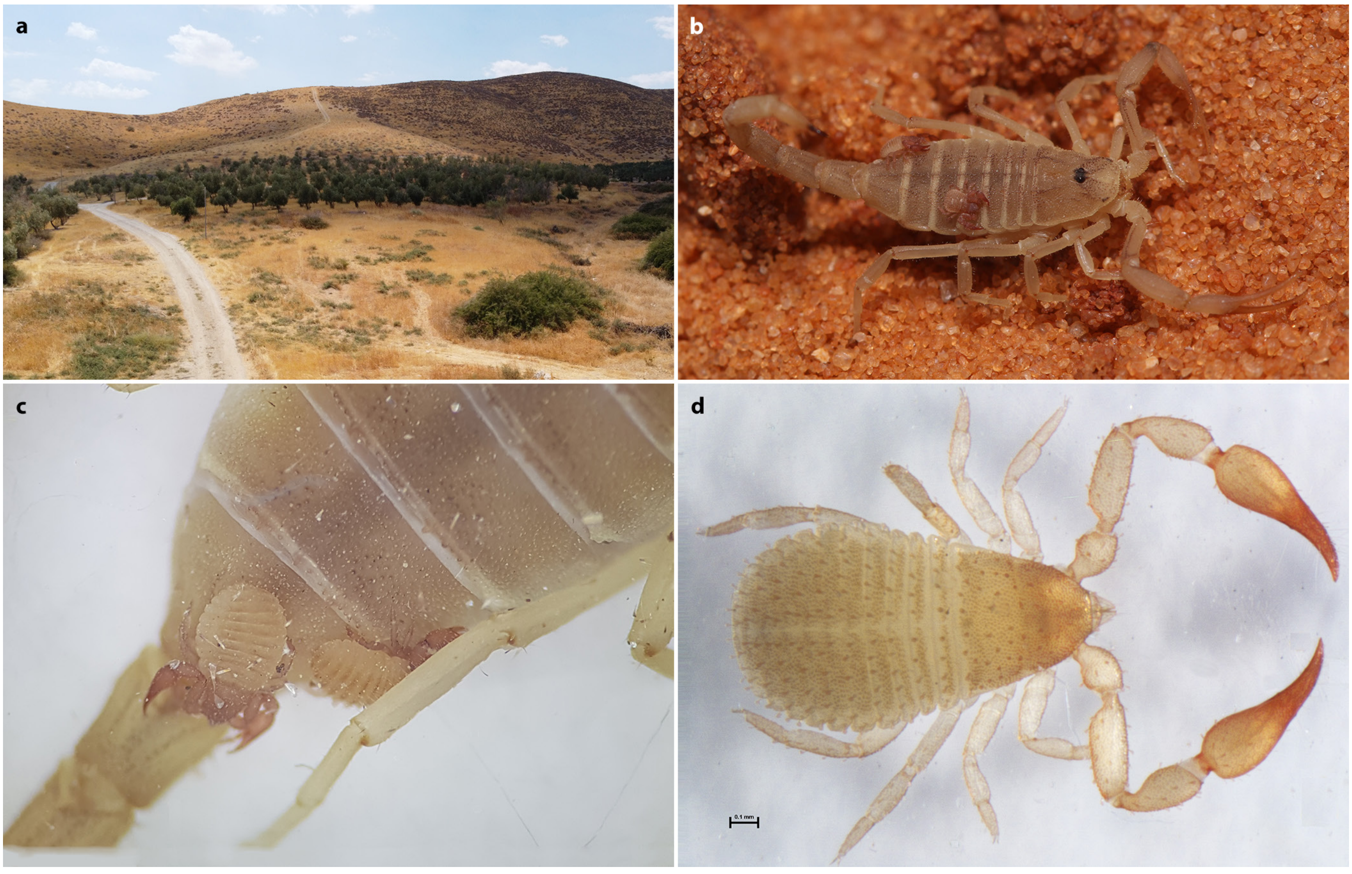

Fig. 1: a. The main study area in the northern part of the Jordan valley, where *Birulatus israelensis* and *Nannowithius wahrmani* were found; **b-c.** *Nannowithius wahrmani* phoretic on a *Birulatus israelensis*; **d.** *Nannowithius wahrmani* (Photo a. and c. by Y. Zvik, b. by S. Aharon, d. by S. Warburg)

detected in one monitoring event, seven were collected with two to six pseudoscorpions on the scorpion's dorsum (Fig. 1b-d). Three of these scorpions were found on the same ant trail as in May 2018, and the rest were from three different ant nests. In captivity, after being collected, some of the pseudoscorpions remained on the scorpion's dorsum for over three weeks.

Discussion

It is unclear exactly when phoresy evolved in pseudoscorpions for the first time. It may have developed independently up to five times within the pseudoscorpions, yet, it is unlikely that the extinct fossil family Dracochelidae was phoretic (Harms & Dunlop 2017). However, withiid species were recorded from Baltic amber from the Eocene, 49 Ma ago, and are known to be phoretic as early as 16 Ma ago, from fossil evidence from the Miocene in Dominican amber, on ambrosia beetles (Harms & Dunlop 2017, Poinar et al. 1998).

We here describe the first record of phoresy of pseudoscorpions on a scorpion as a host. The pseudoscorpions were adhering to the scorpion's dorsum or metasoma presumably using their tarsal claws and arolia, and not grasping it with their pedipalpal chelae, which is common when the carrier is large, and not flying (Poinar et al. 1998). The most common way for a phoront and a host to make contact is when they occupy the same habitat and have the same activity and dispersal season (Poinar et al. 1998). Both the pseudoscorpion *N. wahrmani* and the scorpion *B. israelensis* are myrmecophilous generalist predators living in the same ant nests. *Birulatus israelensis* was recorded outside *M. ebeninus* nests, among the foraging ants and as aggregates in the upper chambers of the nest, usually two-three scorpions per chamber (Zvik 2022). It can feed on various prey items available inside the nest or around it, but based on laboratory experiments *B. israelensis* may favour ant larvae, when this food source is available and within reach. However, the scorpion was never observed to feed on mature ants (Zvik 2022). *Nannowithius wahrmani* is around one mm long and therefore it probably exploits a different ecological niche in the nest, and feeds on smaller prey such as soil mites and collembolans (Cole et al. 1994).

The co-evolution of a phoront and a host has probably developed over a long period of time creating an effective dispersal mechanism which is related to the phoront's survival strategy (Poinar et al. 1998). This co-evolution results in sophisticated capabilities of sensing the signal for dispersion and the cues of arrival. *Nannowithius wahrmani* pseudoscorpions were observed phoretically on *B. israelensis* scorpions walking along ant trails, both in 2018 and in 2023, at the same time of the year, during late spring. This is the season with high foraging activity of the *Messor* ants, and the observations reported here may suggest that late spring is also the dispersal season for both myrmecophilous species: *B. israelensis* and *N. wahrmani.* It is possible that the high foraging activity of the *Messor* ants during this season, which enables an easy deviation from the initial ant trail to an intersecting trail of a different ant nest, and thus dispersal to a new nest, triggers these myrmecophiles to disperse.

Another compelling indication supporting the hypothesis that this phoretic behaviour serves as a means of dispersal between ant nests, can be derived from the observation that certain pseudoscorpions persisted on the scorpion's dorsum for over three weeks. Additionally, in one case, four pseudoscorpions did not abandon a deceased scorpion, further implying that the pseudoscorpions were potentially awaiting a particular cue, possibly indicating the presence of a desirable habitat, before disengaging from their host scorpion. The cue may involve certain conditions that can be found within the nest chambers. The phoront and the host both being predators, with no observation of predation during that period, may also support the hypothesis that the purpose of this phoresy interaction is dispersal, rather than exploitation of the host by the phoront.

Over twenty pseudoscorpion species were documented from ant nests by Beier (1948), who suggested that the dispersal of the pseudoscorpions from nest to nest is performed by phoresy. While at least in two cases pseudoscorpions have been documented phoretic on Formicidae species, in South America and in Asia (Poinar et al. 1998), *N. wahrmani* pseudoscorpions were not observed phoretically on ants. We suggest several possible explanations: 1. It is harder to cling onto the fast-moving ant's smooth body. 2. The ant might easily notice the uninvited passenger and get rid of it or attack it. 3. Ants have chemical repellent that is avoided by the pseudoscorpions. 4. The scorpion can carry several individuals and do so for a long period, while ants' potential capacity is more limited. 5. An ant returns to its nest after foraging, while a dispersing scorpion can be exploited to get a ride to a different colony.

Many questions arise for further research of the symbiotic interactions between these partners in the ant nest ecosystem and their coevolution. For instance: How do they elude the ants or are they recognized by them as nest mates? How do the pseudoscorpions disperse in absence of scorpions, and what are their alternative hosts? What is the signal for the scorpions and the pseudoscorpions to set out of the nest and disperse and, finally, what are the cues for the pseudoscorpions to get off the scorpion's back?

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Author contribution

SW and YZ contributed equally to the manuscript. Conceptualization: YZ, SW and EG-R; investigation: YZ and SW; writing – original draft preparation: SW and YZ; writing – review and editing: EG-R, SW and YZ; funding acquisition: EG-R.

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