Research Article

Associated pseudoscorpions (Arachnida: Pseudoscorpiones) with waste heaps of *Atta colombica* (Guérin-Méneville, 1844) (Hymenoptera: Formicidae) in Panama

Pseudoescorpiones (Arachnida: Pseudoscorpiones) asociados con vertederos de *Atta colombica* (Guérin-Méneville, 1844) (Hymenoptera: Formicidae) en Panamá

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Abstract. Waste heaps of *Atta* are host to an extraordinary diversity of myrmecophiles insects and other arthropods. In this study, the presence of four species of pseudoscorpions is recorded in two *Atta colombica* waste heaps in the years 2016 and 2017. Two of these species, *Cordylochernes scorpioides* and *Lustrochernes carolinensis* are new records in waste heaps and except for the deutonymphs of *L. carolinensis*, the others all stages of post-embryonic development were present in the studied heaps, which could indicate that these two species carry out their entire life cycle in these waste mounds and live there permanently.

Key words: Ant nests; Atemnidae; Cheiridiidae; Chernetidae; symbiosis.

Resumen. Los vertederos de *Atta* albergan una extraordinaria diversidad de insectos mirmecófilos y otros artrópodos . Este estudio registra la asociación entre *Atta colombica* y cuatro especies de pseudoescorpiones recolectadas en dos vertederos en 2016 y 2017. Dos de estas especies, *Cordylochernes scorpioides* y *Lustrochernes carolinensis* son nuevos registros en vertederos, y con excepción de las deutoninfas de *L. carolinensis*, las demás etapas de desarrollo post-embrionario estuvieron presentes en los vertederos estudiados, lo que podría indicar que estas dos especies llevan a cabo todo su ciclo de vida en estos lugares viviendo allí permanentemente.

Palabras clave: Atemnidae; Cheiridiidae; Chernetidae; nidos de hormigas; simbiosis.

Introduction

Myrmecophily is a biological concept that describes casual or intimate associations of various organisms with ants (Rocha *et al*. 2020). It refers to mutualistic associations, though in its more general use the term may also refer to commensal or even parasitic interactions

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(Hölldobler and Wilson 1990; Hughes *et al*. 2008). Some arthropods have close associations with ant species, often living alongside the ants or within the ant colonies (Cushing 2012). Many species across diverse taxa thrive in large numbers in the ant waste heaps attracted by the enrichment of organic material, ideal climatic conditions, and constant supply of nutrients (Parmentier 2016). They may feed on the stored food supplies of ants or consume waste materials in the waste heaps, such as dead ants, dead larvae, or fungi growing in the nest while others are predatory on ant eggs, larvae, or pupae. Others benefit the ants by providing a food source for them (Hölldobler and Wilson 1990). This association is reported in several genera of isopods, pseudoscorpions, many spiders, mites, millipedes, and about 100 families of insects (Hölldobler and Wilson 1990). Underground refuse chambers are frequent in most *Atta* Fabricius, 1805 ants (Stahel and Geijskes 1939; Autuori 1947; Moser 1963), but some species dispose of their refuse material on a single waste heap above ground (Weber 1972) at a safe distance from the colony. These waste heaps are host to a high diversity of insects and other arthropods, among the most common being mites and staphylinid beetles (Rojas 1989; Hölldobler and Wilson 1990). One group of arachnids associated with waste heaps of *Atta* are pseudoscorpions, who are predominantly solitary animals that can live in the ground substratum, in the vegetation, or in both. Beier (1948) and Muchmore (1971) recognized six different categories of relationships between pseudoscorpions with other animals. One of them was the relationship established by those species found in the waste heaps of social insects such as ants (Christophoryová *et al*. 2017; Červená *et al*. 2020).

Twenty-four records of associations with ant nests were found in 18 species of 16 genera and seven families of pseudoscorpions (Table 1). There are 10 records of associations with the genus *Camponotus* Mayr, 1861 while on *Atta* there are four records and only one species of pseudoscorpion related with *A. colombica* (Table 1).

Table 1. Reported pseudoscorpions associated with nests of ants.

Family	Species	Host	Reference
Atemnidae	*Paratemnoides nidificator* (Balzan)	*Cephalotes atratus* (L.)	Torres *et al*. 2018
Cheiridiidae	*Cryptocheiridium mairae* Bedoya-Roqueme & Quirós-Rodríguez	*Atta colombica (*Guérin-Méneville)	Bedoya-Roqueme & Quirós-Rodríguez 2015
Chernetidae	*Allochernes deceuninckorum* Henderickx & Vets	*Camponotus* (*Tanaemyrmex*) *sylvaticus* (Olivier)	Henderickx & Vets 2003
	Allochermes wideri (C.L. Koch)	*Formica* Linnaeus, 1758 & *Lasius* Fabricius, 1804	Leclerc & Heurtault 1979
	Americhernes eidmanni (Beier)	*Atta* Fabricius, 1804	Harvey 1991
	Chernes vicinus (Beier)	*Lasius fuliginosus* (Latreille)	Cooreman 1947
	Incachernes mexicanus (Beier)	*Atta mexicana* (F. Smith)	Reyes-Castillo & Hendrichs 1975
	Lustrochernes communis (Balzan)	*Camponotus rufipes* (Fab.)	Beier 1970
	Marachernes bellus Harvey	*Iridomyrmex* Mayr	Harvey 1992
		Iridomyrmex Mayr	Harvey 2015
		Anonychomyrma biconvexa Clark	Harvey 1992

	Myrmochernes Tullgren, 1907	*Camponotus maculatus* (Fab.)	Harvey 1994
		Camponotus rufipes (Fab.)	
		Acromyrmex lundii (Guérin-Méneville)	
		Camponotus africanus Santschi	Newlands 1978
	Sphenochernes camponoti Beier	*Camponotus rufipes* (Fab.)	Beier 1970
	Xenochernes caxinguba Feio	*Acromyrmex lundii* (Guérin-Méneville)	Harvey 1994
		Camponotus rufipes (Fab.)	
Chthoniidae	*Pseudochthonius brasiliensis* Beier	*Camponotus rufipes* (Fab.)	Beier 1970
	Tridenchthonius mexicanus Chamberlin & Chamberlin	*Atta mexicana* (F. Smith)	Reyes-Castillo & Hendrichs 1975
Ideoroncidae	*Ideoroncus lenkoi* Beier	*Camponotus rufipes* (Fab.)	Beier 1970
Olpiidae	*Pachyolpium crassichelatum* (Balzan)	*Camponotus rufipes* (Fab.)	Muchmore 1971
	Pachyolpium isolatum (Chamberlin)	*Labidus coecus* (Latreille)	
Withidae	*Nannowithius wahrmani* Beier	*Messor semirufus* (André)	Beier 1963

From Panama, there have been reported associations of *Pachyolpium* Beier, 1931 and *Lustrochernes* Beier, 1932 pseudoscorpions with *Labidus coecus* and *Eciton hamatum* (Fabricius, 1782) ants respectively (Muchmore 1971). The status of the pseudoscorpions found in the nests of ground-living social insects is difficult to ascertain because most of the pseudoscorpion collections consist of only one or two specimens associated with other animals. There is no data on the frequency with which certain species associate with insects and there is no information about what pseudoscorpions do in ants' nests (Muchmore 1971; Hölldobler and Wilson 1990) and some of the recorded species of pseudoscorpions associated to ants might have simply landed accidentally in the mounds (Parmentier 2016). In this study, is recorded the presence of four species of pseudoscorpions in two *Atta colombica* waste heaps.

Materials and Methods

The study was carried out in the Parque Natural Metropolitano (PNM) that comprises an area of 270 ha located adjacent to a capital city (8°59'28" N - 79°32'46" W). It is characterized by shallow soils with presence of gravel, low natural fertility, and high susceptibility to pluvial erosion, a very humid climate, and an average temperature of 27 °C. During last 80 years the PNM has reverted from abandoned pasture to a secondary dry, deciduous, lowland in which there are 284 species of plants with 80 families and 228 genera (ANAM 2007)

Pseudoscorpions were collected in two waste heaps of *Atta colombica* in two years, 2016 (November) and 2017 (February). The sampling sites were approximately one kilometer apart and were selected for their accessibility and size of their waste heaps. At each site

three samples of ant waste of approximately 300 cm^3 each were collected (900 cm^3 total per sampling site) separated 50 cm from each other to ensure that we captured representative diversity of the site. The samples were placed into labeled plastic bags (Rojas 1989) and transported to the Laboratory of Biological Studies of Arthropods at the University of Panama (LEBA-UP) where they were checked under the stereoscope to collect any visible pseudoscorpions, and then the material was placed in a Berlese funnel (Gabbutt 1970) to collect the rest of the specimens that were hidden. Pseudoscorpions were processed using Hoff's (1949) technique, modified following Wirth and Marston (1968). Organisms were measured in millimeters using Chamberlin's (1931) method, modified by Benedict and Malcolm (1977). The terminology follows Chamberlin (1931), Muchmore (1991), Harvey (1992) and Judson (2007). The specimens were deposited in the Museum of Invertebrates of the University of Panama.

Results

A total of 55 specimens were obtained from the samples collected from waste heaps of *A. colombica* in both sampling sites within the PNM in 2016 and 2017. These specimens belonged to three families, four genera and four species (Table 2). Only *Lustrochernes carolinensis* Muchmore, 1991 was collected in both years. Two of the species collected (*Cryptocheiridium* sp. and *Paratemnoides nidificator* Balzan, 1888) were represented by one male each. Nevertheless, the other two species (*Cordylochernes scorpioides* (Linnaeus, 1758) and *Lustrochernes carolinensis*)) were quite abundant in these two waste heaps of *A. colombica* when samples were taken.

Table 2. Species of pseudoscorpions associated to debris of *Atta colombica* in Parque Natural Metropolitano in Panama. P= protonymph, D= deutonymph, T= Tritonymph.

Family	Species	♀	♂	P	D	T	Total	Date
Chernetidae	*Cordylochernes scorpioides* (Linnaeus)	1	4	1		3	9	2-3-2017
	Lustrochernes carolinensis Muchmore	17	13	2	3	8	44	11-2-2016 2-3-2017
Cheiridiidae	*Cryptocheiridiu*m sp.		1				1	2-3-2017
Atemnidae	*Paratemnoides nidificator* (Balzan)		1				1	2-3-2017

Except for the deutonymphs of *C. scorpioides* (Linnaeus, 1758) the other post-embryonic development stages of *C. scorpioides* and *L. carolinensis* were present in the studied waste heaps, which could indicate that these two species carry out their entire life cycle in these waste piles and might live there permanently (Table 2). *L. carolinensis* was observed feeding on staphylinides and *C. scorpioides* on mites during the sorting process under the stereomicroscope. The absence of *C. scorpiodes*, *Cryptocheiridium* and *P. nidificator* from the collection sites in 2016 could be due to inadequate sampling during the first year of study or evidence of an ecological succession occurring in these waste heaps. Additional and longer studies are needed to determine if there is a sequence in which pseudoscorpions arrive to these *Atta* waste piles.

Discussion

From de four species of pseudoscorpions (*C. scorpioides*, *L. carolinensis*, *Cryptocheiridium* sp., and *P. nidificator*) found in the waste heaps of *A. colombica*, one of the species (*P. nidificator*) had already been previously recorded in nests of *Cephalotes atratus* ants (Table

1). *C. scorpioides* and *L. carolinensis* are registered for the first time in ant nests. *L. carolinensis* is distributed around 100 meters or less above sea level, from North Carolina to Panama (Muchmore 1991; Martínez *et al*. 2019). This species has been found under the bark of *Quercus* L., *Enterolobium cyclocarpum* (Jacq.), *Avicennia germinans* (L.) L. and under the elytra of cerambycid and carabid beetles (Muchmore 1991; Martínez *et al*. 2019). *C. scorpioides* is distributed throughout the tropical forests of Central and South America living in decaying trees and it is frequently found under the elytra of cerambycid beetles (Beier 1948; Muchmore 1971; Zeh and Zeh 1991, 1992).

Despite the importance of leaf-cutting ants in natural ecosystems (Haines 1978) and in agricultural systems, waste management has received little attention (Hart and Ratnieks 2002). Unlike most leaf-cutting ants, which have underground waste dumps, the leaf-cutting ant *A. colombica* dumps waste in an external heap placed down-hill of foraging entrances of the nest. Large colony size results in large quantities of waste, including old fungus garden, culture medium, and dead workers (Weber 1972). Therefore, the constant supply of nutrients in these waste heaps may lead to an increase in the abundance and richness of soil biota, such as a diverse bacterial community (Lewin *et al*. 2016). As result, a large number of species across diverse taxa may feed on this organic material and a complex trophic web might gradually evolve from producers to predators of different levels. This creates a suitable and attractive environment for the establishment of a high diversity of other arthropods (Hölldobler and Wilson 1990).

Therefore, the environmental conditions of these waste heaps and the presence of food necessary for their development are the probable reasons for the presence of pseudoscorpions there. These arachnids feed on mites, springtails, beetle larvae and other small arthropods (Muchmore 1971; Kistner 1979; Hölldobler and Wilson 1990; Harvey 1992). There are 18 species of pseudoscorpions associated with ant nests, although the nature of their relationships with ants has not been clarified, many of these records are considered debatable, however in this study nine individuals of *C. scorpioides* and 44 of *L. carolinensis* were found including stages of their post-embryonic development. This indicates that these organisms live permanently in these ant waste heaps and carried out their entire life cycle there, therefore we do not consider their presence circumstantial but rather well-established although additional studies are necessary to demonstrate it. The presence of only one specimen of *Cryptocheiridium* Chamberlin, 1931 and *P. nidificator* (Balzan, 1888) in the waste heaps could be considered accidental, fortuitous, or temporary (Harvey 2015). The species *P. nidificator* deserves a special mention, since it lives in rough barks of trees in groups of 2 to 175 individuals and sometimes more than 200 organisms (Tizo-Pedroso and Del-Claro 2007; Del-Claro and Tizo-Pedroso 2009) and perhaps was in the surroundings when samples were taken. This record of its presence in the waste heap of *A. colombica* is one of the earliest. The genus *Cryptocheiridium* has already been recorded in nests of *A. colombica* (Bedoya-Roqueme and Quirós-Rodríguez 2015), so it may be a common inhabitant of these micro habitats.

The fact that some pseudoscorpions were observed feeding on some small arthropods such as mites and staphylinides that coexist in the waste heap is a preliminary evidence that these external dumpsters may be envisioned as collections of species that are organized into food chains and webs in which each species is a consumer of resources and is itself a resource for other consumers (Schmitz *et al.* 2008).

In this preliminary study, there were no observations of aggressive responses from any member of the *A. colombica* colony towards pseudoscorpions or other arthropods. The waste heap placement down-hill, seems to reduce interactions between *Atta* waste transporters and the waste heap community.

The relationships established by the pseudoscorpions with different organisms must be studied to understand how they are carried out and what factors affect them, especially

in nests where they share micro habitats with a wide variety of species with which they are related to in many ways.

Waste heaps of *Atta* nests and the communities thriving in there may have an important impact on neotropical rainforest because of their effect in the soil and between ants and pseudoscorpions, therefore more research needs to be done to answer the following questions:

- How long arthropods remain in abandoned *Atta* nests after the colony moves to another site?
- What is the role of these waste heaps communities in the health of soil ecosystems in tropical rainforests?
- What is the degree of dependence between the organisms that live in these waste heaps and the continuous supply of organic matter from the nest?
- How ecological succession occurs in these waste heaps?
- What benefits if any, ants derive from the community that thrives in the waste heap?

Author contributions

RJM, GAVG, DIQ, and DE wrote the first draft and identified the collected material. Collaborated in writing the manuscript and corroborating the identification of the pseudoscorpion.

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Conflict of interest

The authors declare that there is no conflict of interest.

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