

Cooperative foraging of *Paratemnoides nidificator* (Balzan, 1888) (Pseudoscorpiones: Atemnidae) on two species of ants (Hymenoptera:Formicidae) in the tropical dry Forest, Colombian Caribbean

Forraje cooperativo de *Paratemnoides nidificator* (Balzan, 1888) (Pseudoscorpiones: Atemnidae) sobre dos especies de hormigas (Hymenoptera:Formicidae) en el bosque seco tropical, Caribe colombiano

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Abstract

Key words:
ecology; diet; Pseudoscorpiones;
ant, Sucre; Colombia

Two new cases of cooperative foraging by *Paratemnoides nidificator* (Balzan, 1888), in ants *Atta cephalotes* (Linnaeus, 1758) and *Dolichoderus bispinosus* (Olivier, 1792) are documented. These events were observed in the locality of Santa Inés, municipality of San Marcos, Department of Sucre, Colombian Caribbean. It is the first record of this kind of food-searching behavior in this social species of pseudoscorpions, that preys on the above-mentioned ant species. This means an increase in the number of species that are known as preys, and that constitute the diet of this pseudoscorpion.

Resumen

Palabras clave:
ecología; dieta; Pseudoscorpiones;
hormigas; Sucre; Colombia

Dos nuevos casos de forrajeo cooperativo por parte de *Paratemnoides nidificator* (Balzan, 1888) en hormigas *Atta cephalotes* (Linnaeus, 1758) y *Dolichoderus bispinosus* (Olivier, 1792) son documentados. Estos eventos se observaron en la localidad de Santa Inés, municipio de San Marcos, departamento de Sucre, Caribe Colombiano. Esto representa el primer registro de este comportamiento de búsqueda de alimento en estas especies de hormigas por esta especie social de pseudoescorpiones. Se incrementa el número de especies conocidas como presas y que forman parte de la dieta de este pseudoescorpion.

Social behavior and long-term cooperation among conspecifics are relatively rare, the best-known examples are social insects such ants, bees, and termites (Wilson, 1971; 1975; Viera and Agnarsson, 2017). In such societies, individuals are often morphologically specialized, and most contribute to different tasks in the colony (Whitehouse and Lubin, 2005; Viera and Agnarsson, 2017). Generally, pseudoscorpions are solitary animals, but there are a few social species. Recently, social behavior was observed in *Paratemnoides nidificator* (Balzan, 1888) (Weygoldt, 1969; Tizo-Pedroso and Del-Claro, 2005, 2007; Fernandes *et al.*, 2018). Other animals can be strictly asocial; agonistic

interactions are more common than cooperation among conspecifics, most spiders are solitary and aggressive, often cannibalistic, and cooperation is absent (Avilés, 1997; Foelix, 2011; Bilde and Lubin, 2011; Viera and Agnarsson, 2017). Therefore, *P. nidificator* is a suitable model species to investigate the general characteristics of social pseudoscorpions (Tizo-Pedroso and Del-Claro, 2007). In this sense, subsociality is maternal care that includes several juvenile instars, rather than few (Agnarsson, 2004), and the sociability is characterized by the absence of dispersal of nestmates (Aguar and Bührnheim, 1998; Viera and Agnarsson, 2017; Tizo-Pedroso and Del-Claro, 2018).

Sociality is an uncommon phenomenon among arachnids (Avilés, 1997; Choe and Crespi, 1997; García *et al.*, 2016), the most complex cases of sociability occur among spiders and pseudoscorpions, where examples of cooperative species are found (Zeh and Zeh, 1990; Avilés, 1997; Del-Claro and Tizo-Pedroso, 2009; Yip and Rayor, 2014; Viera and Agnarsson, 2017). While cooperative behavior has evolved repeatedly in spiders, it is found only in a small fraction of species (less than 0.05 %), of spider species (Agnarsson *et al.*, 2006; Avilés, 1997; Bilde and Lubin, 2011; Viera and Agnarsson, 2017). In spiders, food is a critical determinant of sociability, as group size and structure are regulated by the prey size and availability (Whitehouse and Lubin, 2005; Lubin and Bilde, 2007; Guevara *et al.*, 2011; García *et al.*, 2016).

Pseudoscorpions are arachnids present in all terrestrial ecosystems, except polar zones, having cryptic sizes and habits (Weygoldt, 1969; Del-Claro and Tizo-Pedroso, 2009; Tizo-Pedroso and Del-Claro, 2018). Commonly, these animals can be found inhabiting the litter, under rocks, bark of trees and decomposing trunks (Hoff, 1959; Gabbutt, 1962; Weygoldt, 1969; Lee, 1979; Mahnert and Schuster, 1981; Del-Claro and Tizo-Pedroso, 2009; Harvey, 2009; Harvey, 2013; Mahnert, 2014; Bedoya-Roque, 2015; Judson, 2016). Pseudoscorpions can be found in many microhabitats such as bat guano, ants and bee nests, and parts of plants (like the Bromeliaceae); also, they are known by their phoretic behavior with birds, insects and mammals (Weygoldt, 1969; Zeh and Zeh, 1992a, b; Cole *et al.*, 1995; Poinar *et al.*, 1998; Aguiar and Bührnheim, 2003; Francke and Villegas-Guzmán, 2006; González *et al.*, 2007).

Likewise, they are generalist predators, they also take advantage of animals smaller than themselves, however, *P. nidificator* has developed hunting strategies to take advantage of large prey (Zeh and Zeh, 1990; Tizo-Pedroso and Del-Claro, 2007; 2018; Filgueiras *et al.*, 2018). Previous studies on diet and feeding behavior in *P. nidificator*, showed that this species can feed on larger prey and capture them (Brach, 1978; Zeh and Zeh, 1990). This species of pseudoscorpion prefers a large variety of prey, mainly insects, but also other arachnids, isopods, and myriapods; all these preys of variable size (table 1) (García *et al.*, 2016; Tizo-Pedroso and Del-Claro, 2007; 2018; Fernandes *et al.*, 2018). Currently, we only have a poor understanding of how *P. nidificator* forages and feeds on different prey items (table 1) (Tizo-Pedroso and Del-Claro, 2018). We described two different cases of foraging on two different ant species by *P. nidificator*.

Table 1. Ant species used as prey by *Paratemnoides nidificator* (Balzan, 1888) (Atemnidae). New reports of prey for the diet (*)

Order	Family	Species	References
Hymenoptera	Formicidae	<i>Acromyrmex octospinosus</i>	García <i>et al.</i> , 2016
		<i>Acromyrmex</i> sp.1	Tizo-Pedroso and Del-Claro, 2007
		* <i>Atta cephalotes</i>	This investigation
		<i>Camponotus</i> 3 spp.	Tizo-Pedroso and Del-Claro, 2007
		<i>Camponotus</i> cf. <i>brevis</i>	García <i>et al.</i> , 2016
		<i>Camponotus</i> cf. <i>substitutus</i>	García <i>et al.</i> , 2016
		<i>Camponotus crassus</i>	Filgueiras <i>et al.</i> , 2018
		<i>Camponotus mus</i>	Filgueiras <i>et al.</i> , 2018
		<i>Camponotus</i> sp.	García <i>et al.</i> , 2016
		<i>Cephalotes atratus</i>	Zeh and Zeh, 1990
		<i>Cephalotes</i> sp.1	Tizo-Pedroso and Del-Claro, 2007
		<i>Cephalotes clypeatus</i>	
		<i>Crematogaster</i> sp.	García <i>et al.</i> , 2016
		* <i>Dolichoderus bispinosus</i>	This investigation
		<i>Ectatomma tuberculatum</i>	García <i>et al.</i> , 2016
		<i>Odontomachus</i> sp.	García <i>et al.</i> , 2016
		<i>Pachycondyla</i> sp.	Tizo-Pedroso and Del-Claro, 2007
		<i>Pseudomyrmex</i> sp.	García <i>et al.</i> , 2016
		<i>Pseudomyrmex</i> sp.1	Tizo-Pedroso and Del-Claro, 2007

We observed and described a series of cases of cooperative foraging that took place in the Protective Forest Reserve “Bosque Santa Inés”, located at $8^{\circ}42'43,8''N$ and $75^{\circ}13'39,3''W$, municipality of San Marcos, Department of Sucre, Colombian Caribbean (figure 1a). Commonly, this area is part of the tropical dry forest’s ecosystem (figure 1b). Between the months of March and April of 2018, night sampling was carried out systematically (20: 00 - 23: 00 h).

For three days, the method of collecting unrestricted free was used for each sampling, the bark of live trees and of decomposing trunks was examined, in order to record cases of foraging by pseudoscorpions. The registered cases of foraging were photographed, and the specimens were collected and preserved in 70 % ethanol, and subsequently, examine them in the laboratory. Additionally ecological data was recorded.

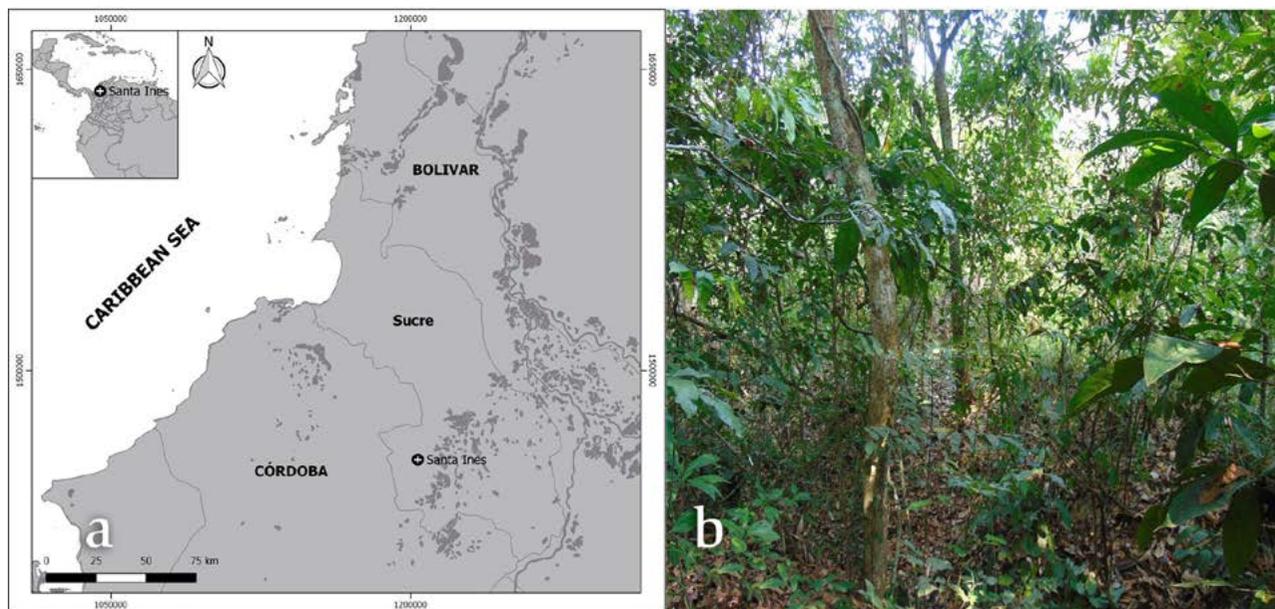


Figure 1. Cooperative foraging of *Paratemnoides nidificator* (Balzan, 1888): a. Locality where the cases of cooperative foraging were recorded. b. Dry forest of Santa Inés, Department of Sucre, Colombian Caribbean.

These cases were observed in the loose bark of five trees, with a diameter of 50 mm, in areas surrounding the tree where several colonies of pseudoscorpions were present. The specimens collected were dissected, a leg I and IV, a chelicera and a pedipalp, of which the chela was separated. The dissected portions were collected in a MicroVial and preserved in 70 % ethanol in the same vial as the rest of each specimen. The specimens were studied using temporary mounts on glycerin, a process carried out in the Entomology laboratory of the University of Sucre. The specimens were studied with the help of a microscope Carl Zeiss, plus Axiostar, Germany. Multifocal photographs were taken in the Microscopy laboratory of the Universidad de Cordoba, with an HD digital camera attached to the Carl Zeiss stereomicroscope, Axiostar, and then put together using the image stacking

software AxioVision Carl Zeiss (Rel.4.8.2. SP3). The specimens of pseudoscorpions collected were identified as *Paratemnoides nidificator* (figure 2 a y b), using the taxonomic keys for families and genera of Harvey (1992); Mahnert and Adis (2002) and the descriptions made by Balzan (1890); Beier (1932); Klausen (2005). The ants were identified as *Atta cephalotes* (Linnaeus, 1758) and *Dolichoderus bispinosus* (Oliver, 1792) (figure 3 a y b), using the taxonomic keys proposed by Mackay and Mackay (1989), Bolton (1994);(2003), Hölldobler and Wilson (1990), Palacio and Fernández (2003) and Ortíz and Fernández (2011). All collected specimens were deposited in the Collection of The Entomology Laboratory, Universidad de Sucre, Colombia (LEUS) with the voucher number LEUS-C010 (Pseudoscorpiones), and LEUS-F102 (Ants).



Figure 2. Specimens collected: a. Habitus, *Paratemnoides nidificator* female, dorsal view. b. Habitus, male, dorsal view.



Figure 3. Ants, specimens collected: a. Habitus, *Atta cephalotes*, lateral view. b. Habitus, *Dolichoderus bispinosus*, lateral view.

Ants are eusocial organisms, characterized by cooperative care of young, which coincides with generations of workers in the colony and the development of an advanced caste system (Wilson, 1971). In this sense, *A. cephalotes*, commonly known as pruning ant, forager or leaf cutter, is considered to be one of the most widely dispersed ants in Colombia's forests and agrarian systems (Villanueva *et al.*, 2016). It is considered to be a plague as it causes defoliation (Della Lucia, 2011; Montoya-Lerma *et al.*, 2012; Villanueva *et al.*, 2016). Its diet is varied and it uses the material of the plant for the growth of the fungus *Leucoagarycus gongylophorus* (Escobar *et al.*, 2002; Villanueva *et al.*, 2016). Likewise, *D. bispinosus* is one of

the most widely dispersed species of genus *Dolichoderus* in Colombia (Ortíz and Fernández, 2007), and it has a certain preference for canopies, which are particularly abundant in isolated areas, for instance, treetops (Harada and Adis, 1998; Cuezco, 2003; Chacón *et al.*, 2014). While these ants were gathering food, three *P. nidificator* males (located outside the bark) attacked an individual (ant) of *A. cephalotes*, (figure 4a), holding it strongly by the legs; once the prey was neutralized, it was dragged by its legs by two pseudoscorpions, and it was held by two more individuals who were under the bark (figure 4b). Finally, several pseudoscorpions came out from under the bark and began feeding on the ant; the colony was composed

by several individuals of different stages of nymph and adults (of different sex), 4 protonymphs, 5 tritonymphs, 5 females, and 5 males, respectively.

Likewise, it was observed in the loose bark of five trees, two to three colonies of *P. nidificator* on average (with 3 to

4 males out of colonies), they attacked several ants of the species *D. bispinosus*, holding them strongly by their legs, and finally when immobilizing the prey, it was dragged into the refuge (figure. 4 c-d). In the same tree where this event was observed, we observed between two to three colonies performing the same behavior.

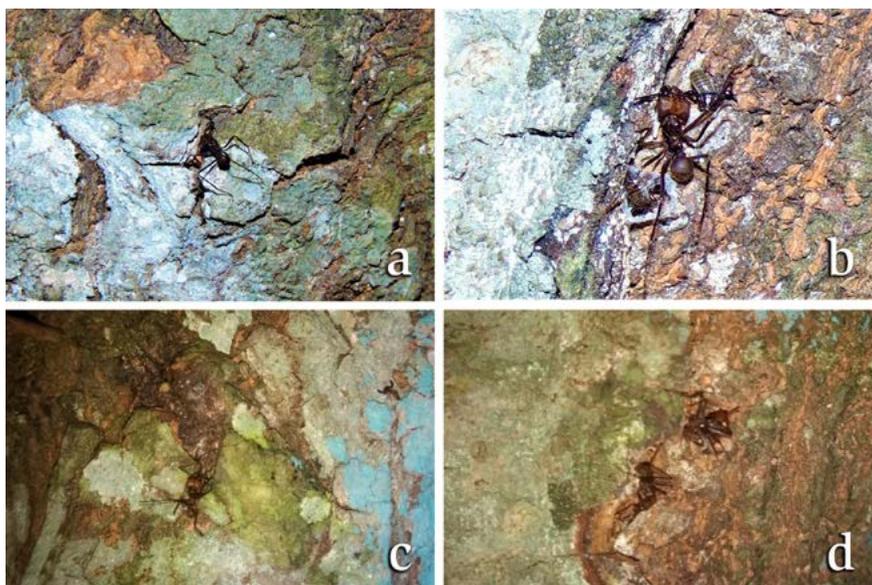


Figure 4. Cooperative foraging on *Atta cephalotes* L. and *Dolichoderus bispinosus* O.: a. Shot of the prey. b. Immobilization captured prey. c. Dragging the ant. d. Introducing the ant inside the colony.

The species *P. nidificator* is considered a widely dispersed species in America, and lives in Central and South America, in the bark of decomposing trunks and living trees (Harvey, 2013). It is considered to be the only social species of pseudoscorpions: it lives in large colonies maintained by a high intraspecific tolerance and exhibit cooperative behaviors (Hahn and Matthiessen, 1993; Tizo-Pedroso and Del-Claro, 2018; Fernandes *et al.*, 2018). In general, it exhibits cooperative parental care and division of labors in the colonies (Tizo-Pedroso and Del-Claro, 2005, 2007, 2011; Del-Claro and Tizo-Pedroso, 2009).

Some authors, such as Zeh and Zeh (1990), and Tizo-Pedroso and Del-Claro (2018), suggest that this species of pseudoscorpion is a generalist predator. It feeds on a great variety of prey and in contrast to other groups of pseudoscorpions, it includes large preys in their diet. In addition, the plasticity of food is directly related to the cooperative search (Tizo-Pedroso and Del-Claro, 2007; 2011); they can subdue and capture preys almost four times larger than them in body size. Some authors, such as Tizo-Pedroso and Del-Claro (2007), (2018); Fernandes

et al. (2018), and Filgueiras *et al.* (2018), who studied the foraging ecology and social life of *P. nidificator*, documented the use of more than 60 different preys in 15 taxonomic groups, including dangerous organisms, such as ants and spiders. Likewise, García *et al.* (2016), evaluated how selective *P. nidificator* is of its prey. He determined there are 14 preys in 7 taxonomic groups. Similarly, Fernandes *et al.*, (2018) evaluated the selectivity of prey using ants of the genus *Camponotus*. In spite of the above-mentioned information, the fact that the species *Atta cephalotes* and *Dolichoderus bispinosus*, is a part of the diet of *P. nidificator* (table 1).

Cooperative hunting not only increases the chances *P. nidificator* has of catching prey, but also its chances of catching a large prey, which allows mutual tolerance between individuals of the same colony, and is presented as an important step in the evolution of the prey, non-territorial permanent and social behavior (Zeh and Zeh, 1990; Tizo-Pedroso and Del-Claro, 2007). In small colonies, such as those observed in this research, it usually involves few individuals; the feeding process tends to favor the juveniles

because the prey is dragged to the colony (Tizo-Pedroso and Del-Claro, 2018). Adults are mainly dedicated to capturing and subduing small preys and then give them to the nymphs as food (Tizo-Pedroso and Del-Claro 2005, 2007, 2018). This behavior was evident in the documented cases of the two species of ants *A. cephalotes*, and *D. bispinosus*, which was dragged to the interior of the colony, under the bark. The adults remain in a defensive position, while the nymphs are feeding on the prey, and tend to wait for the nymphs to leave the prey to approach it and feed on it, as well (Tizo-Pedroso and Del-Claro 2005; 2007). The combination of tasks related to food and parental care is considered to be essential for the division of labor, and a key effort for maintaining the proper growth of the colonies and the development of new individuals who will act as workers in the colonies (Tizo-Pedroso and Del-Claro 2011; 2018).

This species of social pseudoscorpion has been classified as an euryphagous predator. Additionally, it has been noted that it feeds selectively on some species of ants of *Camponotus* and *Acromyrmex* genera (Zeh and Zeh, 1990; Hahn and Matthiesen, 1993; García *et al.*, 2016; Fernandes *et al.*, 2018; Tizo-Pedroso and Del-Claro, 2018), which suggests that ants are an important part of the diet of this social group of arachnids. Therefore, these cases, that were observed and documented, constitute the first case of cooperative foraging of individuals of *P. nidificator* in ants *A. cephalotes*, and *D. bispinosus*. This a new contribution to the knowledge of the diet of this social pseudoscorpion.

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