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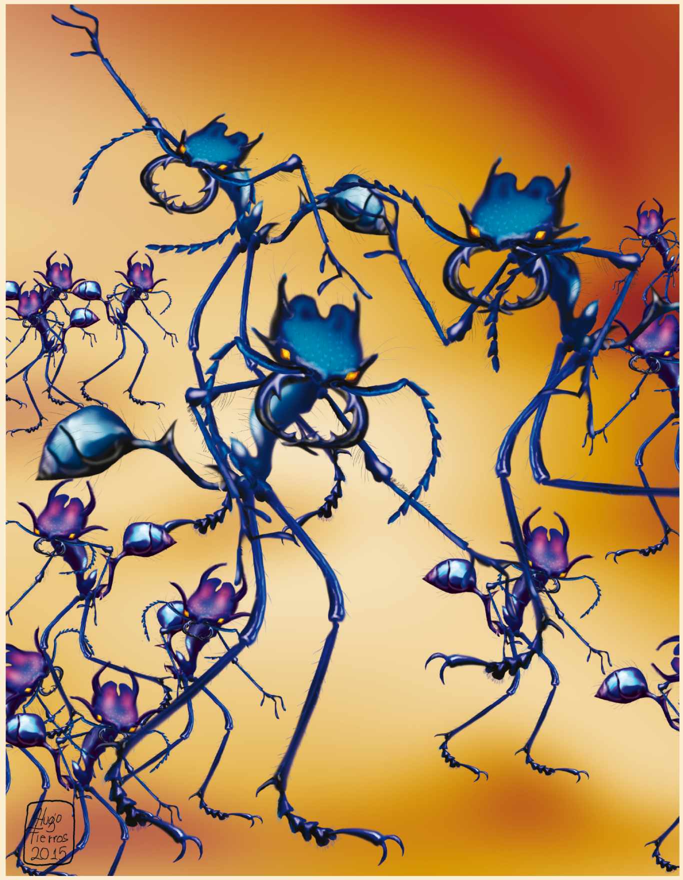

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The ant community and their accompanying arthropods in cacao dry pods: an unexplored diverse habitat

La comunidad de hormigas y sus artrópodos acompañantes en frutos secos de cacao: un hábitat diverso no explorado

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ABSTRACT

Dry pods of cacao are an important habitat exploit by different ant species to establish their nest, and by their conditions, diverse organisms associated to them also occupied such nests. We studied the composition of ant assemblage and their accompanying arthropods in fall and hanging cacao pods from experimental areas in Ilhéus, Bahia, Brazil. A total of 34 dry cacao fruits were reviewed. The hanging fruits were occupied by six species of ants, with *Neoponera villosa* as the commonest, while in fallen fruits eight species nested, with *Camponotus cingulatus* occupying most of the 50% of them. A total of 42 taxa were founded accompanying the ants in the nest, 37 in the fallen fruits (15 exclusive) and 26 in the hanging (seven exclusive). Groups as Mollusca, Myriapoda (Diplopoda, Chilopoda and Symphyla) and Opilionida, were found only in the fallen fruits. Some groups of predators, as Reduviidae and Schizomidae, were found only in nests from hanging fruits. The community composition in both types of fruits was different, more detritivorous groups were found in the fallen fruits, while in the hanging fruits were found more predators. The complexity of interactions established between nest suggests the importance of this environment to ecosystem function and conservation diversity in the cacao plantations.

Key words: Ants nests, diversity, interactions, trophic guilds.

RESUMEN

Los frutos de cacao secos o en descomposición constituyen un hábitat explotado por distintas especies de hormigas para establecer sus nidos, generando un ambiente particular que a su vez es explotado por una diversidad de organismos que se establecen en asociación con tales nidos. Se estudió la composición de la comunidad de hormigas y artrópodos acompañantes en nidos de cacao en áreas experimentales en Ilhéus, Bahía, Brasil, comparando tanto frutos caídos como frutos retenidos en la planta. Un total de 34 frutos secos de cacao fueron revisados. Los frutos colgados estuvieron ocupados por seis especies de hormigas, con *Neoponera villosa* como la más común, mientras que en los frutos caídos habitaron ocho especies, con *Camponotus cingulatus* ocupando más del 50% de ellos. Un total de 42 taxa fueron encontrados acompañando a las hormigas en los nidos, 37 en los caídos (15 exclusivos) y 26 en los colgados (siete exclusivos). Grupos como Mollusca, Myriapoda (Diplopoda, Chilopoda y Symphyla) y Opilionida, fueron encontrados sólo en los nidos de frutos caídos. Algunos grupos de depredadores como Reduviidae y Schizomidae, sólo se encontraron en los nidos de frutos colgados. La composición de la comunidad en ámbos tipos de frutos fue diferente, con más detrítívoros encontrados en los frutos caídos y más depredadores en los colgados. Las complejas interacciones que se establecen en los nidos en los frutos sugieren la importancia de este ambiente para el funcionamiento del ecosistema y el mantenimiento de la biodiversidad en los cultivos de cacao.

Palabras clave: Nidos de hormigas, diversidad, interacciones, gremios tróficos.

Cacao culture together with coffee plantations are the most extended cultures in tropical areas, cover more than 20 million of ha in the World according with data from 2007 (FAOSTAT 2011). Due the climatic and environmental conditions needed to growth of cacao trees, this shaded culture is considered as having a low impact for the natural environment and is an important ecosystem for maintaining biodiversity for numerous groups of vertebrates and invertebrates (Rice and Greenberg 2000, Faria *et al*. 2006, Delabie *et al*. 2007, Moço *et al*. 2010, Castaño-Meneses *et al*. 2014).

The cacao farms with shadow management, offer conditions and resources that can be used for maintaining a great diversity of organisms, representing a biological corridor favorable to the species which live in, both the original vegetation and the modified agroecosystem. The fauna associated to that culture can occupy different habitats including the canopy of shaded trees, soils, litter as well the living and dried cacao pods. For many organisms, fruits represent an ephemeral resource similar to dung or carrion, since they represent organic matter at different stages of decomposition associated with a characteristic fauna (Van Klinken and Walter 1996, Lukasik and Johnson 2007). Changes in the composition of their associated communities have been recognized as corresponding to a heterotrophic succession (Hanski 1987). Invertebrates involved into this process in different fruits include groups withn an especially great diversity, such as Coleoptera, Hymenoptera and Diptera which dominate (Souza-Silva and Lopes, 2004), but are also very common arachnids such mites, spiders and harvestmen (Oliveira *et al*. 1995, Machado and Pizo 2000), snails and few other organisms (Mason 1970, Van Klinken and Walter 1996). Nevertheless, there are few studies focused into the dried cocoa pods on the tree or on the floor, that can be used by many organisms for sheltering or nesting, as has been found for many ant species (Fowler, 1993). Due the nest ants are in general stable environment diverse organisms are associated to them and can used these resources. Ants are a very important element in the ecosystems and in cocoa farms have been well studied by their ecology, diversity and functional role (Fowler and Delabie 1995, Delabie *et al*. 2007, Wielgoss *et al*. 2010). Moreover, the nests of ants are stable microhabitats in time and space, containing many resources available to fauna that can live into them, which included parasites and symbionts with different association degree, show a great abundance and diversity, including almost all invertebrate groups as well vertebrates as reptiles (Vaz-Ferreira *et al*. 1970, Kistner 1982, Kronauer and Pierce 2011). Mites and Staphylinoidea beetles are the most frequently recognized groups inhabiting in ant nest due to their abundance and species richness (Eickwort 1990, Lapeva-Gjonova 2013).

Thus, nests of ants are an important element in the maintaining of the global biodiversity and in many cases the interactions between the groups of associated fauna are poorly known (Pérez-Lachaud and Lachaud 2014).

The cacao pods are affected by different factors and pathogenic agents that can produce their lost and abortion (Bos *et al*. 2007), and that pods can be retained on the tree or well fall to the soil and drying. These pods are a resource for many species of ants and are available to them to install their nests, foraging or shelter (Fowler 1993, Fernandes *et al*. 2013), as well are a biotope attractive to many organisms that can establish and explore the resources available into the nests of ants. Nevertheless, there are few information about that fauna, their relationships and diversity.

There are important differences in the microenvironment along the tree height, with high values of humidity and temperature near of soil, and into the crown, nevertheless in the crow the evaporation rates are highest (Castellanos *et al*. 1999, Almeida and Valle 2007, Parra *et al*. 2009).

Studies about the vertical distribution of ants and other arthropods shows important differences in community composition, with species that can be present along the vertical gradient, while others are found on the floor or only in the higher strata on the trunk of cocoa trees. In most of cases, the soil and litter had the high diversity (Brühl *et al*. 1998, Basset *et al*. 2003, Cutz-Pool *et al*. 2010).

The southern of Bahia State is the main cacao production region of Brazil, and the dominant production system is the named *cabruca* (Araujo *et al*. 1998), which is shaded with native trees and promotes the conservation of many species of the tropical forest (Delabie *et al*. 2007, Schroth *et al*. 2011).

The Cocoa Reserch Center (CEPLAC) in Ilhéus, Bahia, Brazil possesses experimental areas with shaded plantations. There the ant fauna has been studied for the last 30 years, and shows a great diversity and complexity (Delabie *et al*. 2007). We review fallen and hanged dried cacao pods in plantation areas of CEPLAC in order to verify the presence of ant nests as well as their accompanying fauna, and to infer about the probable relationships between them, according with the trophic guilds to which belong the recorded groups. We expected that fallen pods were used by a upper number of ant species for nesting, as well as the cohort of their accompanying fauna, because the litter fauna is available to colonized this habitat.

MATERIAL AND METHODS

The CEPLAC experimental areas (14° 45'S – 39° 13'W) are located in relict fragments of the South American Coastal Atlantic Forest at Ilhéus, Bahia, Brazil. The climate is characteristic of the humid tropics, classified as AF by Köppen (1936), with annual average temperatures ranged between 20° and 25°C and annual precipitation between 2000 and 2400 mm, soils are mainly sandy clay and altitude about 60 m asl (Santana *et al*. 2003).

Two areas were selected into the experimental plots of the CEPLAC, the named E' and F', in order to have a repetition. In each one, a team of four persons reviewed during two hours dry pods of cacao, hanging and fall, in order to found nest ants in them. Pods were carefully open, in order to confirm the presence of ants nesting in them. The presence of ant queens and brood was used as evidence of ants nesting. When the ant nesting was confirmed, pod was put in a plastic bag and carried to laboratory, where was reviewed on a tray, and the larger specimens were caught with forceps and preserved in 70% ethanol. Then the nests were put during 28 h in Berlesse funnels. The obtained fauna was sorted under stereoscopic microscope.

The abundance and composition (at upper taxonomic levels) of the accompanying fauna, was recorded in each nest. The effect of the localization of fruit (hanged or fallen) on the accompanying fauna abundance was tested by one way ANOVA test, using STATISTICA software ver. 6.0 (Statsoft 1995).

RESULTS

A total of 34 dry cacao fruits were obtained with nests of ants in the two areas. Fifteen of them were collected hanging in the cacao tree and the 19 remaining were collected fallen on the floor. In most of the pods, a single ant species, between nine species, has established its nest, as reproductives and brood were located into the fruits. Nevertheless in some nests second ant species was nesting or foraging (Table 1). The hanging fruits were occupied by six species of ants (a single species per pod), with *Neoponera villosa* as the commonest, while in fallen fruits eight species nested, with *Camponotus cingulatus* occupying most of the 50% of them (Fig. 1). In the hanged fruits were found an average (±SE) of 25±4.9 individual/nest of accompanying fauna, while in the fallen fruits the average was 108±3. The ANOVA one way test show a significant effect of the localization of fruit (hanging or fallen) on the abundance of accompanying fauna ($F_{1,31}$= 6.01; p=0.02).

There were found 42 taxa accompanying to the nest, 37 in the fallen pods (15 exclusive) and 26 in the hanging ones (seven exclusive). Groups such as Mollusca, Myriapoda (Diplopoda, Chilopoda and Symphyla) and Opilionida, were found only in the fallen pods, maybe because these can be colonized also by litter fauna which depends to the ants and the nest environment. Some groups of predators, such as Reduviidae and Schizomida, were found only in nests from hanging fruits.

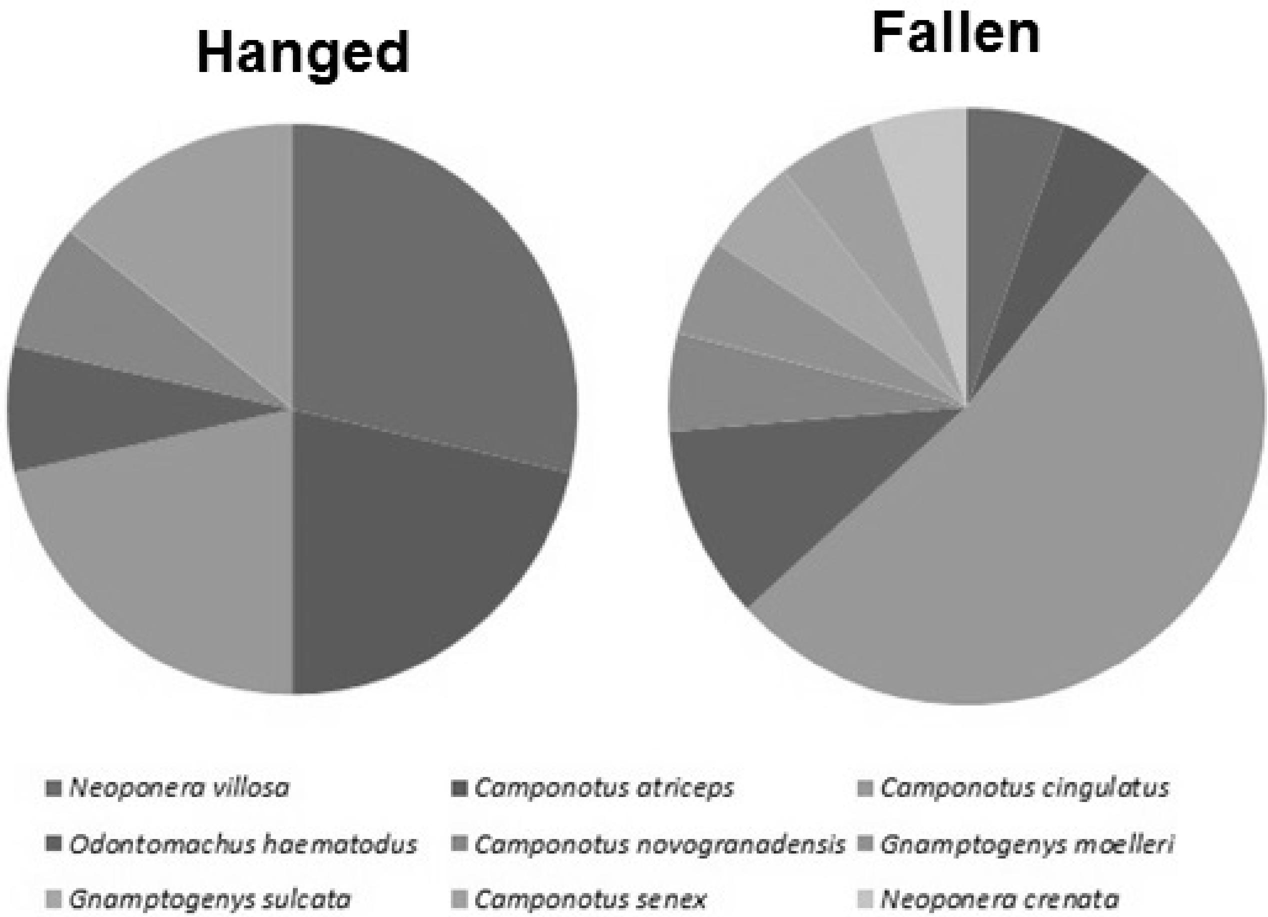

Figure 1. Composition of species of ants nesting in hanged and fallen dry pods of cacao, Ilhéus, Bahia, Brazil.

DISCUSSION

The composition of arthropod community in both type of pods were different, more detritivorous groups were found in the fallen fruits, as expected, while in the hanging fruits were found predators that were not recorded in the fallen pods, as Schizomida (Fig. 2).

The studied dried cacao pods show that they are a very important resource and habitat used for a diversity of organisms, also when these fruits remain retained hanged to the tree trunk. The diversity of groups and their trophic guilds, suggest the complexity of interactions that can be establish into the nests environment. Most abundant groups were detritivorous as springtails, oribatid and uropodid mites, nevertheless other groups of predator mites, mainly mesostigmatid and prostigmatid, were also abundant. The presence of predator of second level as pseudoscorpions, staphylinid beetles and centipeds, show that nests or the immediate environment provided by the decomposing pod offer the necessary resources to maintain complex interactions and the stability of the system (Thébault and Loreau 2005).

Fowler (1993) studied the use of the fallen pods of cacao by ants looking for nesting in Caraguatatuba, São Paulo, Brazil. He found 17 species, with *Gnamptogenys striatula* Mayr and *Carebara* sp. as dominant, but no information about their accompanying fauna was provided. We found nine ant species nesting in pods, plus other eleven companion species nesting or foraging also in the same nest, for a total of 20 species of ants using dry fruits for nesting or other activities. In the nest of omnivorous ants nesting in the soil, as *Camponotus*, were found more ant species accompanying, with some species whit specific feeding habits, such those of *Strumigenys* genus, with many species specialist springtail predator (Hölldobler and Wilson 1990). The occurrence of these ants in the pods is certainly more related with the soil environment that with the pod conditions.

There are important and significant differences between the nesting ants assemblage established in fallen or hanged dry pod, due the conditions into both types of pods are different too, due the humidity, decomposition process and resources availability. In fallen pods, the ephemeral nature of this kind of resource is especially evident, due to the conditions of humidity that accelerate the decomposition process, promoted the presence of more detritivorous groups, release some resources that can be exploded for other groups, increasing also the biodiversity (Wardle 2006).

More ant species occupied the fallen cacao pods than the hanged ones, and were dominated by omnivorous groups such as species of *Camponotus* genus. In other hand, also were found more ant species in the accompanying fauna from the fallen fruits, where were recorded 10 species, with *Solenopsis* sp. and *Wasmania auropunctata* as dominant, while in hanged pods five species were found only, with *Monomorium floricola* and *Pheidole* sp. as the commonest nesting species.

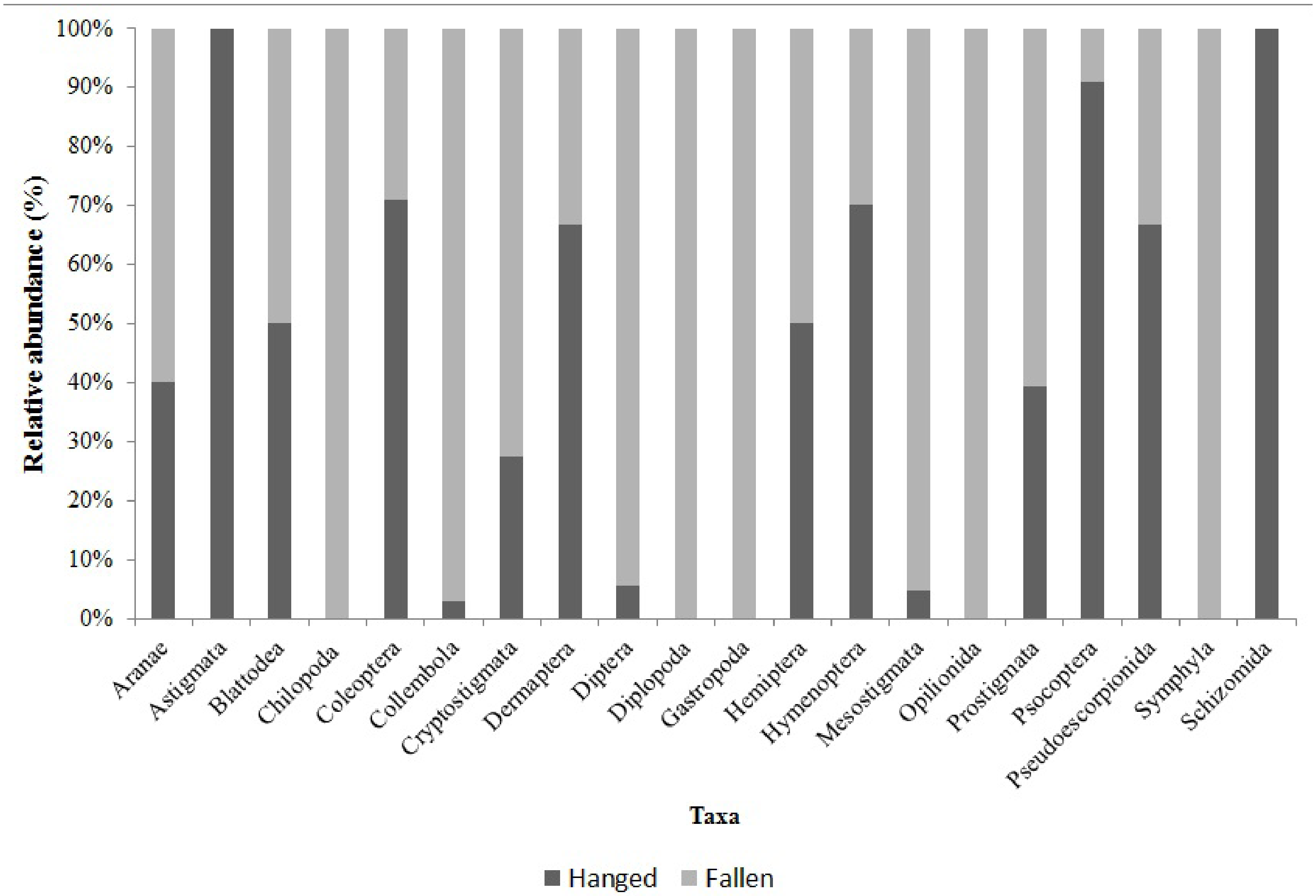

Figure 2. Composition and relative abundance of accompanying fauna at ant nests in hanging and fallen dry pods of cacao, Ilhéus, Bahia, Brazil.

The accompanying fauna in hanged pods results to be less diverse than in fallen pods, probably due to the less rich resources and environment since hanged pods are less accessible and offer restriction to be colonized by groups with low dispersion or vertical movements. Comparative studies made in hanged and fallen fruits in the tree *Alibertia edulis* (Rubiaceae), have shown that there is also more diversity of associated fauna in the fallen fruits than on the tree, because the edaphic fauna is available to colonizing the fallen fruits (Souza-Silva and Lopes 2004). Nevertheless, we found a particular fauna, with groups normally considered as uncommon in such environment, as schizomids, that are frequently found in tropical soils, but has been recorded also associated with ant nest (Reddell and Cokendolpher 1995) and in abandoned arboreal termite nest in cocoa plantations also in Brazil (Santos *et al*. 2008).

The ant nest are recognized by supporting a great diversity of fauna (Kistner 1982, Rettenmeyer *et al*. 2011). Nevertheless has been put few attentions on their relationships and the importance of that environment in global biodiversity and ecosystem function. A recent study on three nest of arboricolous Neotropical weaver *Camponotus senex* show the presence the different groups, including new species of parasitoids and new records of spiders associated to ants, and suggest that due to the importance of that habitat in conservation they would be considered as “hot-points” of biodiversity (Pérez-Lachaud and Lachaud 2014). The particular conditions of the nests in cacao pods, which can be considered less stable than nest in other biotopes, due their relative ephemeral nature, may facilitate the colonization of certain groups of organisms than can support and use this habitat, and constitute particular assamblages specialized not only in promoting decomposition processes and make more efficient the energy flux in the systems, also positively participate to the biodiversity conservation in the ecosystem.

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Table 1. Associated fauna to ant nest in dried cacao fruits fallen and hanging in cacao CEPLAC experimental areas, Ilhéus, Bahia, Brazil. Numbers in brackets indicate the number of nest reviewed.

Species ant	**Associated fauna**	
	Fallen	**Hanging**
Camponotus atriceps (Smith)	(1) Acari: Mesostigmata (Uropodidae, Laelapidae, Ascidae); Cryptostigmata (Galumnidae) Collembola: Cyphoderidae (*Cyphoderus* sp.) Insecta: Psocoptera, Coleoptera (Staphylinidae), Diptera	(3) Acari: Mesostigmata (Uropodidae); Cryptostigmata (Oppidae) Pseudoscorpionida Insecta: Hemiptera, Dermaptera, Hymenoptera (Brachonidae; Formicidae: *Braychymyrmex* sp., *Solenopsis* sp.); Coleoptera (Staphylinidae)
Camponotus cingulatus Mayr	(10) Acari: Mesostigmata (Uropodidae, Ascidae, Laelapidae, Undeteminated); Prostigmata (Cunaxidae, Undeterminated); Cryptostigmata (Oppidae, Galumnidae, Undeterminated); Pseudoscorpionida, Opilionidae (Laniatores): Araneae Myriapoda: Chilopoda, Diplopoda Collembola: Brachystomellidae, Isotomidae (*Folsomides* sp., I*sotomodes* sp.), Cyphoderidae (*Cyphoderus* sp.) Insecta: Blattodea, Hemiptera, Dermpatera, Hymenoptera (Undeterminated; Formicidae: *Crematogaster* sp., *Monomorium floricola* (Jerdon), *Carebara* sp., *Solenopsis* sp., *Strumigenys* sp., *Wasmannia auropunctata* (Roger), *Pheidole* sp.); Diptera, Coleoptera (Scarabaeidae, Staphylinidae, Undeterminated)	(3) Acari: Prostigmata, Cryptostigmata (Oppidae, Galumnidae) Collembola: Cyphoderidae (*Cyphoderus* sp.) Insecta: Psocoptera, Dermpatera, Hymenoptera: Formicidae (*Crematogaster* sp., *Monomorium floricola*, *Solenopsis* sp.); Diptera, Coleoptera (Staphylinidae)
Camponotus novogranadensis Mayr		(1) Insecta: Hemiptera (Reduvidae); Hymenoptera: Undetermined; Formicidae (*Pheidole* sp., *Solenopsis* sp.)
Camponotus senex (Smith)	(2) Acari: Mesostigmata (Uropodidae, Laelapidae, Undeterminated); Prostigmata, Cryptostigmata Myriapoda: Diplopoda Collembola: Brachystomellidae, Isotomidae, Cyphoderidae (*Cyphoderus* sp.) Insecta: Dermpatera, Hymenoptera: Formicidae (*Nylanderia* sp., *Solenopsis* sp.); Coleoptera, Diptera	(2) Acari: Mesostigmata (Ascidae), Prostigmata (Cunaxidae); Cryptostigmata (Oppidae, Galumnidae, Undetermined) Insecta: Psocoptera, Hymenoptera: Undeterminated, Formicidae (*Crematogaster* sp.); Coleoptera

Odontomachus haematodus (L.)	(2) Acari: Mesostigmata (Laelapidae, Ascidae, Undeterminated); Cryptostigmata Myriapoda: Symphyla Collembola: Brachystomellidae, Isotomidae, Entomobryidae, Cyphoderidae (*Cyphoderus* sp.) Insecta: Hemiptera, Dermaptera, Hymenoptera: Formicidae (*Nylanderia* sp., *Solenopsis* sp., *Strumigenys* sp., *Pheidole* sp.); Diptera	(1) Acari: Astigmata, Mesostigmata (Laelapidae) Insecta: Hymenoptera: Formicidae (*Pheidole* sp.)
Neoponera villosa (Fabricius)	(1) Mollusca: Gastropoda Acari: Mesostigmata (Uropodidae, Ascidae, Laelapidae, Undeterminated); Prostigmata (Bdellidae, Cunaxidae, Undeterminated); Cryptostigmata (Galumnidae, Undeterminated) Opilionida (Laniatores) Collembola:Isotomidae, Cyphoderidae Insecta: Dermaptera, Hymenoptera: Undeterminted, Formicidae (*Pheidole* sp.); Coleoptera (Staphylinidae, Undeterminated)	(5) Acari: Mesostigmata (Uropodidae, Ascidae); Prostigmata (Anystidae, Bdellidae); Cryptostigmata Schizomida Araneae Pseudoscorpionida Collembola: Isotomidae, Cyphoderidae Insecta: Blattodea, Hemiptera, Psocoptera, Hymenoptera: Undeterminated, Formicidae (*Crematogaster* sp., *Pheidole* sp., *Solenopsis* sp.); Coleoptera (Staphylinidae, Undeterminated); Diptera
Neoponera crenata (Roger)	(1) Acari: Mesostigmata Araneae Collembola: Brachystomellidae, Isotomidae (*Folsomides* sp.); Cyphoderidae Insecta: Hemiptera, Hymenoptera: Formicidae (*Solenopsis* sp., *Strumigenys* sp.); Coleoptera	
Gnamptogenys moelleri (Forel)	(1) Acari: Mesostigmata, Prostigmata, Cryptostigmata Collembola: Cyphoderidae (*Cyphoderus* sp.) Insecta: Hymenoptera: Formicidae (*Pheidole* sp., *Solenopsis* sp.); Coleoptera (Staphylinidae, Undeterminated); Diptera	
Gnamptogenys sulcata (Smith)	(1) Mollusca: Gastropoda Acari: Mesostigmata (Uropodina); Cryptostigmata (Galumnidae) Collembola: Brachystomellidae, Isotomidae, Entomobryidae Insecta: Hemiptera, Hymenoptera: Formicidae (*Hypoponera* sp.); Diptera, Coleoptera (Staphylinidae, Undeterminated)	