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Insect Fauna Associated With *Anacardium occidentale* (Sapindales: Anacardiaceae) in Benin, West Africa

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ABSTRACT. Cashew, *Anacardium occidentale* L. (Sapindales: Anacardiaceae), is an important cash crop in Benin. However, its production is threatened by several biotic factors, especially insects. In Benin, very few studies have focused on insects and just listed species commonly found on cashew worldwide. The present investigation fills this gap by presenting an exhaustive inventory of insect species associated with this crop in the country. The survey was carried out from September 2009 to August 2010 in 22 cashew orchards (5 young and 17 mature) distributed over three major agroecological zones where cashew is most produced in the country. Insects were collected using chemical knock-down technique and visual observation followed by capture with sweep net. In addition, infested plant organs were sampled and incubated to collect emerging insects. In total, 262 insect species were recorded and identified. Among them, the wood borer *Apate terebrans* Pallas, the leafminer *Eteoryctis gemoniella* Stainton, and the mirid bugs *Helopeltis schoutedeni* Reuter., and *Helopeltis anacardii* Miller., appeared as the most important insect species attacking cashew in Benin. Beneficial insects encountered included some predators, parasitoids, and pollinators. Few vertebrate predators were also recorded on the trees. Differences in agroecological conditions or in field cleanliness did not affect the number of insect species encountered in the cashew orchards. The results of this study represent an important baseline data for the design and implementation of strategies for cashew protection in Benin.

Key Words: *Eteoryctis gemoniella*, *Apate terebrans*, cashew, entomofauna, field cleanliness *Helopeltis schoutedeni*

Cashew, *Anacardium occidentale* L. (Sapindales: Anacardiaceae), is a perennial tree crop grown in about 32 countries worldwide, particularly in the tropics of America, Asia, and Africa, where climatic conditions are favorable for its economic cultivation (Pradeepkumar et al. 2008). It provides several products such as cashew apples, cashew nuts, and cashew nut shell liquid that are highly demanded on the international markets. The cashew tree is native to Brazil and was introduced into Africa by Portuguese traders in the 16th century (McLaughlin et al. 2008). The African continent represents currently 37% of the world's cashew nut production, covering an average of 45% of the total area harvested (Food and Agricultural Organization (FAO) 2010).

In Benin, cashew was initially introduced for soil preservation and reforestation. However, it gradually gained commercial importance with nut production that increased from 29,084 tons in 1998 to 69,700 tons in 2010, thus becoming the second most important cash crop for the country just behind cotton (Tandjiékpon 2007, Food and Agricultural Organization (FAO) 2010). In 2000, cashew nuts accounted for 9% of national exports, providing an annual income of 12 billion FCFA (∼US$ 24 million) (Joker 2003), and in 2008, it represented 8% of the total export value or 24.87% of agricultural export revenues (Tandjiékpon 2010).

Many factors are conducive to cashew production in Benin: the crop is well adapted to the prevailing climatic and edaphic conditions; it can be interplanted with food crops or other cash crops such as cotton; it can restore soils damaged by intensive cotton cultivation; its different parts can be used as medicine due to its pharmacological properties, and its wood can be used as firewood (Projet de Professionnalisation de l'Agriculture au Bénin (PPAB) 2004).

The demand for Benin cashew on the international markets resides in its high quality, especially its good taste, and the absence of pesticide residues. In fact, until recently cashew plantations in Benin were considered less attacked by insect pests, and very few pesticide applications were carried out in cashew fields (Tandjiékpon et al. 2005).

Unfortunately, many constraints—abiotic as well as biotic—have arisen in recent years that interfere with the good prospects for this crop. It is acknowledged elsewhere that insect pests are a major source of crop losses in many cashew-growing areas (Azam-Ali and Judge 2004, Hammed et al. 2008). In West Africa, 170 insect species were associated with this crop in Ghana (Dwomoh et al. 2008) and 141 in Nigeria (Asogwa et al. 2009), but only a few of them cause economic damage to the crop (Omole 1972, Martin et al. 1997).

In Benin, however, of the many studies initiated to investigate the cashew cropping system (Trepko 2003, Lemaître et al. 2004, Programme d'Amélioration Des Systèmes d'Exploitation and Institut National des Recherches Agricoles du Bénin (PADSE and INRAB) 2004, Tandjiékpon et al. 2005, Tandjiékpon 2010), very few have focused on insects, and some just contain a list of insect species commonly found on cashew worldwide, without any scientific evidence of their presence in Benin. Such country-specific data constitute, however, a prerequisite for the development of an environmentally sound control strategy against the most economically important cashew insect pest species in Benin.

This study aimed at filling this gap by compiling an inventory of insect species associated with different cropping stages of cashew in Benin and determining their functional status such as pests, predators, parasitoids, pollinators, or visitors. In addition, how the entomofauna composition is affected by the level of field cleanliness (i.e., clean vs. weedy) as well as agroecological zones was investigated.

Materials and Methods

Study Area. The study was conducted from September 2009 to August 2010 in the most important cashew production zones in Benin. These zones were located within the belt that ranges between Abomey (latitude 7° 10 N) in the south, to Natitingou and Gogounou (latitude 10° 25 N) in the north (Tandjiékpon et al. 2005). Within this so-called

cashew belt in Benin, the annual rainfall varies between 800 and 1,200 mm. These zones are characterized by three types of climates, which can be merged together into two major rainfall regimes, unimodal and bimodal. The unimodal rainfall regime occurs in the northern part of the country with a rainy season that begins in May and ends in October. The bimodal rainfall regime occurs in the southern and central parts of the country, with a short rainy season that lasts from October to November and a long rainy season occurring from April to July. The rainfall pattern exhibits a declining gradient from south to north.

Orchards Selection and Spatial Distribution. In August 2009, a preliminarily survey was conducted throughout the country, especially in the most suitable zones for cashew production, to identify and select sample orchards. The cashew production area in Benin falls in three of the eight agroecological zones defined by Ministère de l'Environement et de la Protection de la Nature (MEPN)/United Nations Development Programme (UNDP) (2008). Those three cashew-producing agroecological zone are described as follows: agroecological zone III (South-Borgou, located between longitude 1° 32 to 3° 48 E and latitude 9° 25 to 10° 36 N) and characterized by an unimodal rainfall pattern with annual rainfall varying between 700 mm and 1,600 mm and averaging 1,200 mm. The main crops grown here are yam, cotton, maize, and groundnut); agroecological zone IV (West-Atacora, located between longitude 0° 45 to 3° 08 E and latitude 9° 29 to 11° 26 N), and characterized by an unimodal rainfall pattern with annual rainfall varying between 700 mm and 1,800 mm averaging 1,200 mm. The main crops grown here are cereals in its northern part (supplemented by yam in its southern part); and agroecological zone V (Central Benin located between Longitude 1°38 to 2°46 E and Latitude 6°57 to 9°25 N), and characterized by a bimodal rainfall pattern with annual rainfall varying between 700 mm and 1,600 mm and averaging of 1,100 mm. Beside cotton, cereals, yams, and grain legumes (i.e., cowpea, pigeon pea, and soybean) are the main crops grown here.

In each zone, cashew field selection was based on the following criteria:

- The age of the orchards should be at most 20 yr.
- The size of the selected field should exceed 1 ha, therefore having at least 100 cashew trees.
- The fields should be easily accessible throughout the year.
- The distance between two selected orchards should exceed 20 km.

Apart from two orchards located in the south of the Central Benin where the distance criterion has not been met due to the scarcity of plantations in this area, all the other plantations fit well to the criteria. Thus, orchards were distributed among the three agroecological zones sampled as follows: agroecological zone III, 5 mature orchards (N'dali, Banhounkpo, Kassakpéré, Kouandé, and Makrou) and 2 young (prefruiting) orchards (Becket-Bourame, Biro); agroecological zone IV, with 2 mature orchards (Pabegou and Vanhoui); and agroecological zone V, 10 mature orchards (Dan 1, Dan 2, Hoko, Gbéré, Gouka, Okoutaossé, Kikélé, Korou, Bakpérou, and Parakou) and 3 young (prefruiting) orchards (Kikele, Agboro-Kombon, and Ouoghi). Throughout the country, a total of 22 cashew orchards were selected including 17 mature and 5 young orchards. Inside each orchard, cashew trees were planted at spacings ranging from 6 by 6 m to 10 by 10 m. Cashew tree varieties were defined by the color of the apples even though there are local variety "TK" and introduced varieties "TS" (Le Roux 2000). Unfortunately, distinction among cashew varieties based on morphological characteristics (i.e., color, shape, and size) remains problematic in Benin as many variants of each characteristic can be found without any clear link with variants of another characteristic (e.g., apple color and shape, physical shape of the nut, their color or texture, and their size). To lighten the field selection process, we therefore considered only the apple color. In that respect, two cashew varieties are mainly grown in Benin: the yellow apple variety and the red one. Between these two, there are, however, several intermediate varieties resulting certainly from a cross between the yellow and red varieties or from mutations linked to local conditions or to the physiological state of the apples (Sedjro and Sanni-Agata 2002). All these varieties were found inside the same orchard and over the different surveyed zones. No fertilizers or chemical pesticides were applied in any of the sampled orchards. Geographical coordinates of each field (i.e., sample) site were recorded using a handheld Global Positioning System (GPS 320 by Magellan. Manufacturer: Magellan; Released: 1999). The spatial distribution map of the sample orchards is given in Fig. 1.

Insect Collection. For the insect collection, two methods were used, depending on whether it was a young prefruiting orchard or a mature orchard.

Young Prefruiting Orchards. Each month, 20 trees were randomly selected per orchard and carefully checked for the presence of insects or their damage symptoms. All damage symptoms observed on the leaves and stems were recorded. Whenever possible, insects encountered were captured with nets or by hand and transferred to plastic vials containing 70% ethanol, except for the butterflies that were transferred to standard glassine envelopes. Leaves with caterpillars or mines were collected and placed in plastic boxes (17.5 cm by 11 cm by 13.5 cm) where the insects were reared until adult stage.

Mature Orchards.

Collection of Insect Species Inhabiting Leaves and Flushes. Each month, 10 trees were randomly selected and labeled per orchard. Each tree was sprayed thoroughly with 50 EC Cypermethrin using a motorized mist-blower STIHL SR 420 (Chinagros International Corporation limited, Zhejiang, China), as described in Dwomoh et al. (2008). Thirty minutes after applying the insecticide, the sample trees were vigorously shaken to allow all the dying insects to drop on a 5- by 5-m white cloth that was spread underneath the trees for this purpose. The insects were then collected and transferred to plastic vials containing 70% alcohol and brought to the laboratory for identification. In addition, direct collection through visual observation was made on 20 other randomly selected trees to collect foliage and flushes inhabiting insects. The

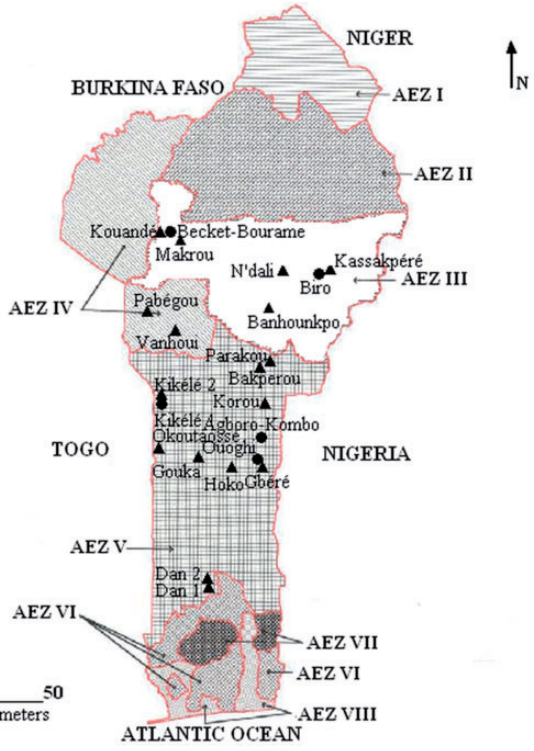

Fig. 1. Sampling sites for the inventory of cashew insect species in Benin, West Africa. AEZ, agroecological zone. ▲, Mature orchard; ●, Young orchard.

chemical knock down technique was, however, not maintained during the flowering and fruiting phases of the trees.

Collection of Stem Borers. For stem borers, 30 trees were randomly selected per month in each orchard. The main stems and the branches of each tree were carefully inspected for the presence of feeding holes or other damage symptoms and for their physical presence on or inside the tree. For this purpose, we defined three types of attack holes for *Apate terebrans* Pallas (Coleoptera: Bostrichidae), the most well-known cashew stem borer in Benin: 1) the old attack holes or old holes marks representing attack points already closed; 2) very recent entry points (holes) that were about to close and from which no sawdust was coming out; and 3) the freshly bored or active holes, from which sawdust was still coming out, providing evidence that the beetle was boring inside the hole. Thus, on each tree, the number of old attack holes (i.e., >1-yr old), inactive attack holes (i.e., <1-yr old) and active or freshly bored holes were recorded. To be sure of the identity of the insect species present in the holes, some of the fresh attack holes were sprayed with commercial aerosol insecticide named Rambo (1% propoxur, 1% dichlorvos, and 0.04% cyfluthrin), and after about 15–30 min, the insects that came out were collected and preserved in 70% alcohol, as described previously, and brought to the laboratory for their identification.

Effects of Field Cleanliness on the Composition of Insect Communities. The 17 mature orchards could be ranged into two groups based on the cultural practices: clean and well-maintained fields, and weedy and poorly maintained fields. Eight fields were well maintained, whereas nine fields were weedy (Table 1). The number of insect species and orders recorded in each field were pooled per field status (i.e., clean vs. weedy fields) and compared between the two groups of fields using the Student's *t*-test (Proc T-TEST) in SAS (SAS Institute 2009). Similar analysis was conducted also to compare the species composition of the three most numerous insect orders between clean and weedy orchards.

Effects of Agroecological Zones on the Composition of Insect Communities. The distribution of the 17 mature orchards surveyed within the three agroecological zones yielded five fields in the agroecological zone III, two fields in the agroecological zone IV, and 10 fields in the agroecological zone V (Table 1). Average number of insect species and orders recorded within each field were compared among the three agroecological zones using the analysis of variance (Proc GLM) in SAS (SAS Institute 2009). When analysis of variance showed significant among agroecological zone differences ($P < 0.05$), agroecological zone means were compared using Tukey's honest significance test in SAS. To correct for homogeneity of the variances, count data were transformed using square root ($x + 0.5$) before their use in the statistical analyses. This analysis on agroecological zone differences was also performed for the three major insect orders pooled together per field.

Results

During this survey, 262 different insect species were recorded that belonged to the orders Hemiptera, Coleoptera, Hymenoptera, Diptera, Orthoptera, Lepidoptera, Isoptera, Neuroptera, Dermaptera, Odonata, and Thysanoptera (Fig. 2). The insect species identified were distributed among 79 insect families, as presented in Annex 1. A comparison of the insect species composition between young and mature cashew orchards (Table 2) showed that the entomofauna on mature orchards

Table 1. Distribution of mature cashew orchards among agroecological zones and between maintenance quality

Orchard maintenance status	Agroecological zones			
	Agroecological zone III	Agroecological zone IV	Agroecological zone V	Total
Clean	N'dali	Vanhoui	Dan 2, Hoko, Korou Parakou, Okoutaossé Bakpérou	8
Weedy	Banhounkpo, Kouandé, Makrou, Kassakpéré	Pabegou	Dan 1, Kikélé, Gouka, Gbéré	9
Total	5	2	10	17

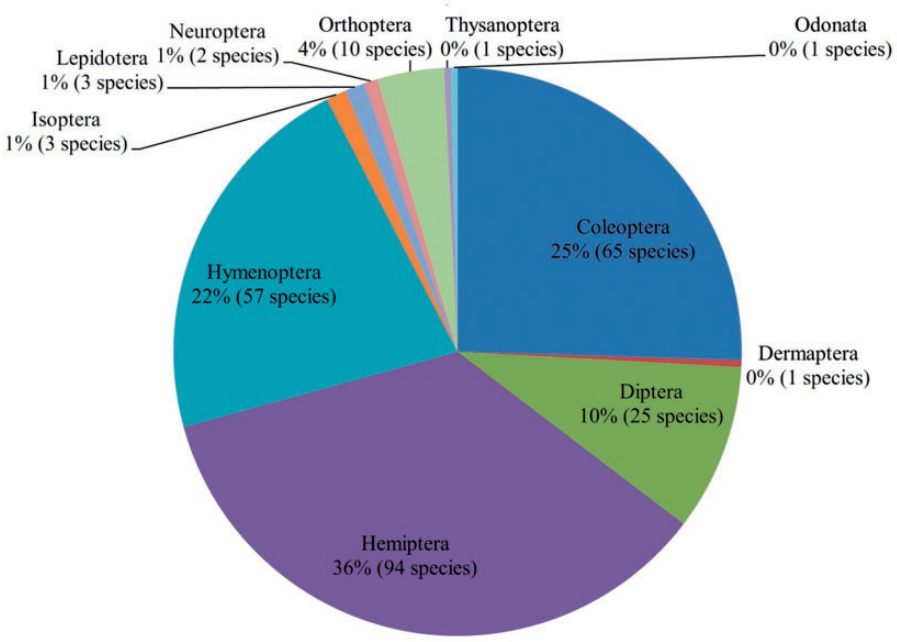

Fig. 2. Relative importance of insect orders associated with cashew trees in Benin Republic (cropping season 2009–2010), West Africa.

Table 2. Insect orders, numbers of species, and relative abundance (%) in young and mature cashew orchards during insects survey in Benin (2009–2010)

Orchard status	Insect orders	Number of species	Relative abundance (%)
Young orchards	Lepidoptera	1	1.75
	Isoptera	1	1.75
	Orthoptera	2	3.51
	Diptera	3	5.26
	Hymenoptera	11	19.3
	Coleoptera	16	28.08
	Hemiptera	23	40.35
	Dermaptera	1	0.38
	Odonata	1	0.38
	Thysanoptera	1	0.38
	Neuroptera	2	0.76
	Isoptera	3	1.15
Mature orchards	Lepidoptera	3	1.15
	Orthoptera	10	3.82
	Diptera	25	9.54
	Hymenoptera	57	21.76
	Coleoptera	65	24.81
	Hemiptera	94	35.87

Table 3. Insect community composition throughout the different agroecological zones surveyed in Benin Republic (cropping season 2009-2010), West Africa

Insect orders	Agroecological zone III	Agroecological zone IV	Agroecological zone V
Hemiptera	73[a]	45	94
Coleoptera	53	39	64
Hymenoptera	45	31	57
Diptera	14	8	25
Orthoptera	7	3	10
Isoptera	1	1	3
Lepidoptera	2	2	3
Neuroptera	1	0	2
Dermaptera	1	0	1
Odonata	1	1	1
Thysanoptera	1	1	1

[a]The value in the cells represents the number of insect species (not the number of the individuals or specimens) in the corresponding insect order.

was more diversified than that on the young orchards. Over the three survey zones taken together, the insect orders Hemiptera, Coleoptera, and Hymenoptera contained, in a decreasing order, the higher number of insect species (Table 3). The phytophagous insect species encountered comprised foliage, flower, apple, and nut feeders as well as stem, branch, and trunk borers or girdlers. Apart from termites, no insect species were recorded from roots.

Overview of the Most Important Insect Pest Species. The cashew leafminer *Eteoryctis gemoniella* Stainton (Lepidoptera: Gracillariidae), the cashew stem borer *A. terebrans*, and the mirid bugs *Helopeltis schoutedeni* Reuter, and *Helopeltis anacardii* Miller (Hemiptera: Miridae) appeared to be the major insect pests of cashew trees in Benin due to their damage potential and their wide distribution over the Benin cashew belt (Annex 1). The longhorn beetle *Analeptes trifasciata* F. (Coleoptera: Cerambycidae) was found in only one of the 22 cashew fields surveyed, causing serious damage on mature cashew trees in non-managed orchards in the southern part of the country during periods of intense rainfall.

E. gemoniella Stainton. E. gemoniella (falsely called *Acrocercops syngramma* Meyrick*)* is a small lepidopteran of the Gracillariidae family attacking cashew trees during their vegetative growth period. The larvae cause damage to the tender leaves of seedlings, young, or mature cashew trees by mining into the epidermal layer of the upper surface of leaves. This leads to thin and tortuous mines. Later on, the thin mines swell up and take a grayish-white color, induced by the desiccation of the detached leaf epidermis. The resulting large round or elliptical mines are generally full of dark grains of frass. If the attack occurs on young leaves, they get stunted and deformed, and sometimes fall off precociously thereby reducing the photosynthetic activity of the trees. On mature leaves, the damage is characterized by big cracks left at the place of the mines. This minute lepidopteran has been recorded in all the surveyed cashew orchards in Benin.

A. terebrans Pallas (Coleoptera: Bostrichidae). *A. terebrans* is commonly referred to as the black borer or branch and twig borer. The adult beetle is black in color, elongated, and somewhat cylindrical in shape. The head is directed downward, rarely visible from above and covered by a hook-like thorax, whereas the larva has a curved body, yellowish in color, with the beginnings of three pairs of thoracic legs. Measurements of the body length of 60 adult females and 60 adult males chosen randomly in one cashew orchard are as follows: male 17.1–29.8 mm (mean ± SD: 26.1 ± 1.89 mm) and female 25.2–31.5 mm (mean ± SD: 28.09 ± 1.36 mm). The adult female is distinguished from the male by a large tuff of yellow hairs with two triangular teeth called tubercles on the frons. Both male and female adults bore into branches and trunks of cashew, leaving the trees with longitudinal tunnels (up to 50 cm in length) that are entangled in some places and a layer of fine sawdust under the trees. The entry points are located from the tree basis at ground level right to the extreme end of the main stem or under the lateral branches, and many different entry points can lead to the same gallery. Most of the holes observed (i.e., attack points) on a tree are entry points for the adults, and only few of them are probing holes. By boring holes and galleries, *A. terebrans* weakens the tree, frequently resulting in the breaking-off of the branches and sometimes in the death of the trees. This beetle was prevalent in all the mature cashew orchards surveyed in Benin. Moreover, we found it attacking other plants in the vicinity of surveyed sites. These plants included *Albizia lebbeck* (L.) Bentham (Fabaceae), *Azadirachta indica* Juss. (Meliaceae), *Parkia biglossia* Jacq. (Fabaceae), *Khaya senegalensis* Desr. A. Juss (Meliaceae), *Khaya grandifolia* Thompson (Meliaceae), and *Terminalia mantaly* Perrier (Combretaceae). The typical damage symptoms caused by this beetle were also observed on *Daniella oliveri* (Rolfe) Hutch & Dalz. (Leguminoseae), *Combretum adenogonium* Steud (Combretaceae), and *Citrus sinensis* (L.) Osbeck (Rutaceae), without the physical presence of the beetle.

H. anacardii Miller (Hemiptera: Miridae) *and H. schoutedeni* Reuter (Hemiptera: Miridae). These two mirid bugs were recorded in cashew orchards in Benin. They are generally referred to as cashew bug or tea mosquito bug, due to their mosquito-like shape and their occurrence on tea plant. Adults of *H. schoutedeni* are slender, measuring 7–10 mm in length, red in color with prominent eyes, long legs, and black antennae that are longer than the body. For *H. anacardii,* adults are more orange–brown, smaller than *H. schoutedeni,* measuring 4–6 mm in length with transparent wings extending beyond the tip of the abdomen. Adults of both species feed on tender shoots, inflorescences, immature nuts, and apples, causing the drying-off of tender shoots, blighting of inflorescences, and fall-off of immature nuts. The presence of their feeding lesions can result in a reduced price for the nuts. Their damages are most serious and noticeable during the flushing and flowering season and vary from 1 yr to another. Both *H. anacardii* and *H. schoutedeni* are prevalent in Central and Northern Benin (e.g., N'dali, Ouoghi, and Okoutaossé).

Overview of the Most Important Beneficial Insect Species. In young cashew orchards, most beneficial insects encountered belonged to Hymenopteran order among which the ant community deserves particular attention. In total, 15 ant species representing 13 genera and 5 subfamilies were recorded on cashew trees in Benin. Though the list is not exhaustive, the most common species were *Oecophylla longinoda* (Latreille), *Pheidole* sp., *Camponotus sericeus* (F.), *Camponotus* sp.,

and *Crematogaster* sp. (Annex 1). These ant species are known as predators. In mature cashew orchards, besides the above mentioned species, other ant species were also found. The pollinating insect species recorded there included *Apis mellifera* andersonii Latreille (Hymenoptera: Apidae) that is found feeding not only on very ripe and nearly rotting apples but also on just ripe cashew apples at many survey sites, *Anthidium* sp. (Hymenoptera: Megachilidae) and *Meliponula bocandei* (Spinola) (Hymenoptera: Apidae).

Other beneficial insects included the Hymenopteran parasitoids *Apanteles* sp. (Hymenoptera: Braconidae), *Chelonus* sp. (Hymenoptera: Braconidae), and *Trathala* sp. (Hymenoptera: Ichneumonidae) recovered from *E. gemoniella*-infested cashew leaves.

Overall, the guild of parasitoids, pollinators, and predatory insect species observed on cashew trees was diverse and distributed over all agroecological zones surveyed (Annex 1). Among the 13 families to which these beneficial insects belonged, the Braconidae was the most diversified and in which taxonomic identification was conducted up to the genus level. Genera identified included *Spathious* sp., *Iphiaulux* sp., *Ascogaster* sp., *Bassus* sp., *Phanerotoma* sp., *Braunsia* sp., and *Xanthopimpla* sp. Many mantids (Mantodea: Mantidae), dragonflies, and damselflies (Odonata: Libellulidae), known as generalist predators, were also collected but have not yet been identified.

It is worth mentioning that not only insects were present on cashew trees many other arthropods such as spiders and centipedes, as well as small vertebrates like snakes, whitish and yellowish toads or frogs were also observed. All these organisms are predatory and may play a role in regulating pest populations.

Effects of Field Cleanliness on the Composition of Insect Communities. On average (mean ± SE), 7.78 ± 0.22 insect orders and 50.78 ± 4.39 insect species were recorded in clean cashew orchards against 7.25 ± 0.25 insect orders and 42.63 ± 3.79 insect species in weedy cashew orchards. The statistical analyses did not reveal any significant differences between clean and weedy cashew orchards neither for the number of insect orders (df = 15, $t = 1.58$, $P = 0.1341$) nor for the number of insect species (df = 15, $t = 1.39$, $P = 0.1854$).

The comparison of the insect species composition of the three dominant insect orders (i.e., Coleoptera, Hemiptera, and Hymenoptera) resulted in 13.67 ± 4.24 Coleopteran species in clean cashew orchards against 10.50 ± 3.89 in weedy cashew orchards; 16.67 ± 2.40 Hemipteran species in clean cashew orchards against 15.75 ± 2.36 in weedy cashew orchards; and 10.56 ± 0.84 Hymenopteran species in clean cashew orchards against 9.50 ± 1.20 in weedy cashew orchards. For any of these insect orders, statistical analyses did not reveal any significant differences between clean and weedy cashew orchards ($P > 0.05$).

Effects of Agroecological Zones on the Composition of Insect Communities. On average (mean ± SE), 7.20 ± 0.37 insect orders and 56.80 ± 7.21 insect species were recorded in agroecological zone III versus 7.50 ± 0.50 insect orders, and 43.00 ± 2.00 insect species were recorded in agroecological zone IV and 7.70 ± 0.25 insect orders and 42.80 ± 2.86 insect species in agroecological zone V. The statistical analyses did not reveal any significant differences among the three agroecological zones neither for the number of insect orders (df = 2, $F = 0.72$, $P = 0.4730$) nor for the number of insect species (df = 2, $F = 2.70$, $P = 0.1018$).

The comparison of the insect species composition for the three dominant insect orders (i.e., Coleoptera, Hemiptera, and Hymenoptera) resulted in 15.00 ± 1.41 Coleopteran species in agroecological zone III versus 9.50 ± 3.5 in agroecological zone IV, and 11.30 ± 1.36 in agroecological zone V; 22.40 ± 3.91 Hemipteran species in agroecological zone III versus 16.00 ± 5.00 in agroecological zone IV, and 13.20 ± 1.02 in agroecological zone V; and 12.00 ± 1.71 Hymenopteran species in agroecological zone III versus 11.00 ± 1.00 in agroecological zone IV, and 8.90 ± 0.67 in agroecological zone V.

The statistical analyses did not reveal any significant differences among agroecological zones for Coleoptera (df = 2, $F = 1.93$, $P = 0.1813$) and Hymenoptera (df = 2, $F = 2.00$, $P = 0.1720$). In contrast, there were significant differences among agroecological zones for the species composition of Hemiptera (df = 2, $F = 4.14$, $P = 0.0386$). The Tukey's Studentized Range [Honestly Significant Difference (HSD)] test showed that the Hemipteran species were significantly more diversified in agroecological zone III than in the two other agroecological zones between which no significant differences were observed.

Discussion

This countrywide survey of the insect fauna associated with cashew trees is the first one ever carried out in Benin. Previous reports were largely based on a literature search of cashew pests worldwide (e.g., Tandjiékpon et al. 2005), without the possibility of verifying in the field that the reported species do really occur in Benin. Of the 13 insect species reported by Tandjiékpon et al. (2005) only four species (*Selenothrips rubrocinctus* Giar, *H. schoutedeni*, *H. anacardii,* and *A. terebrans*) were encountered in our intensive survey.

Our results show that across the different agroecological zones, cashew trees are very attractive to a wide diversity of insect species, ranging from pests to beneficials. Besides these species for which we could establish the exact role (pests or beneficials), a large number of species were collected in the orchard and thus associated with it. However, their exact relationship with regard to the cashew tree remains unclear and requires further investigation. The majority of insect species encountered in the three different agroecological zones where cashew is produced fall into three major insects composed of Coleoptera, Hemiptera, and Hymenoptera. The orders Coleoptera and Hemiptera were represented mostly by pest species such as stem borers, apple feeders, leaf feeders and suckers, and flower feeders.

In this study, 262 insect species were identified among which the cashew stem borer *A. terebrans,* the mosquito bugs *H. schoutedeni* and *H. anacardii*, and the leaf miner *E. gemoniella* appeared as the most important insect pests due to their damage potential and their wide distribution throughout the Benin cashew belt. These four species and other species such as *Pseudotheraptus wayi, An. trifasciata, S. rubrocinctus, O. longinoda, Crematogaster* sp. *Polyrhachis* sp., or *Dysdercus* spp. have also been reported in other West African cashew growing countries such as Nigeria, Ghana, Côte d'Ivoire, Guinea Bissau, and Guinea (Eguagie 1972, Topper et al. 2001, Dwomoh et al. 2008). Occurrence of these four insect pest species in Western Africa constitutes a real threat to the cashew production system, especially nowadays that this cash crop is gaining importance in the national gross product of this subregion. It is, therefore, mandatory to develop control strategies to maintain population densities of theses pest species below the economic threshold level.

The composition of the insect fauna varied, however, both with age and growth stage of cashew trees in the orchards. Fewer insect species were encountered on young immature trees than in mature cashew orchards. As an example, the cashew stem borer *A. terebrans* was exclusively encountered in mature orchards although it attacks cashew trees or stems diameters ranging between 7 and 77 cm (mean ± SD: 18.06 ± 7.75 cm). Similarly, the sucking insect species, such as the mosquito bugs *H. schoutedeni* and *H. anacardii,* were generally more abundant at the beginning of the dry season when cashew trees produced new flushes of leaves prior to flowering. The cashew stem borer *A. terebrans* showed up in cashew orchards during the last quarter of the year until the first quarter of the following year, thereby reaching its peak by December to January (C. A, personal observations). In contrast, the cashew leafminer *E. gemoniella* infested cashew trees in the second half of the year, immediately following production of new leaves by the trees after cashew nut harvest. However, as soon as the dry season got established and cashew trees started flowering, it became difficult to observe *E. gemoniella* in the cashew orchards.

In contrast, the number of insect species and orders was not affected by the cleanliness (i.e., clean vs. weedy) of the orchards. This is more so when we considered the species composition of the three most

important insect orders, Coleoptera, Hemiptera, and Hymenoptera. These results are, however, a bit surprising as it is generally admitted that the diversity of insect species is affected by the complexity of the plant community (Siemann 1998, Kruess and Tscharntke 2002). Similarly, the number of insect species and orders on cashew trees did not differ among the three agroecological zones. This is more so when we considered the species composition of the three most dominant insect orders, except for Hemiptera that was more diversified in the agroecological zone III. However, the environmental conditions that could explain this relative prevalence of these hemipteran bugs remained unknown, except that around those orchards, there were many shrubs that are known as host plants to some of the bugs.

Among the major insect species found on cashew during this survey, the cashew stem borer *A. terebrans* was, beside the weaver ants *O. longinoda,* the most well-known insect species by cashew growers in Benin (Programme d'Amélioration Des Systèmes d'Exploitation and Institut National des Recherches Agricoles du Bénin (PADSE and INRAB) 2004, C. A, personal observations). Some cashew growers commonly call it "carpenter," due to the enormous quantity of sawdust produced by this insect while boring into the cashew stems. Besides attacking cashew trees, *A. terebrans* was recorded, during our study, on several other host trees. This result confirms the polyphagous status of *A. terebrans* and is in agreement with previous studies reporting this wood borer on coffee, citrus, cocoa, guava, cotton, and other host plants (Hill and Waller 1988, Food and Agricultural Organization (FAO) 2007, de Souza et al. 2009). The presence of this insect on different host plants suggests that *A. terebrans* is a constant threat to cashew and other crops. In fact, insects with a wide host range will be able to multiply on a number of host plants and when most plants in a mixed system are palatable to a polyphagous pest, then it is likely that the insect will stay longer and become more numerous, causing greater damage (Speight 1983, Singh-Rathore 1995). However, as we do not yet know the exact dynamics of *A. terebrans* on the other plants, it is not possible to rule out that some of them might actually act as trap plants. More research is needed to verify this assumption. It is noteworthy that during the survey, *Apate monachus,* the sister species of *A. terebrans*, was recovered at two sites not only on cashew trees but also on the teak *Tectona grandis* L. f. located close to cashew orchards.

Other insect pest species that deserve attention were *Agonoscelis versicolor* F. (syn *Agonoscelis pubescens* Thunberg) (Hemiptera: Pentatomidae), *Agonoscelis haroldii* Bergroth (Hemiptera: Pentatomidae), also called cluster bugs, and *Pachnoda* spp. (Coleoptera: Cetoniidae). The adults of *Agonoscelis* are shield-shaped bugs measuring up to 14 mm in length and 7 mm in width (Bijlmakers and Verhoek 1995). The upper side has a straw of yellow to reddish brown color with many brown punctures. These insects were seen at a number of orchards surveyed, feeding in large groups on cashew leaves, apples, nuts, and stems. They are generally known as major pests of sorghum and sesame in southern and eastern Africa and secondarily found on cowpea, soybean, and pigeon pea (Bijlmakers 1990, Mohamed and Bilal 2011, Poutouli et al. 2011). In Benin, they have been mentioned sometimes on mango (J. F. Vayssieres, personal communication). Because of their feeding habit (sap sucking), they should be regarded as a potential disease vectors. As for the cetonids, *Pachnoda marginata* Kolbe*, Pachnoda cordata* Drury*,* and *Pachnoda interrupta* (Olivier), often found in groups, they prefer mature apples on which they feed and copulate. They were also encountered on mango trees in Benin, especially when the trees are flowering or fruiting (C. A, personal observations). Although *P. interrupta* was recorded as a major insect pest of sorghum in Ethiopia, *P. marginata* was not considered as a major pest for any crop (Yitbarek and Hiwot 2000). Although a particular insect species might not be a problem in a given location in the past, the sporadic nature of insect pests does not prevent them from becoming damaging in the future (Topper 2008). In fact, the expanding cashew growing areas coupled with increased anthropogenic activities creating ecological disturbances might induce changes in the status of some of the above insect pests, which needs to be monitored closely in the future.

Among the beneficial insect species which may regulate insect pest populations, we observed a diversity of ant species, some of which have already been reported by many authors in Benin, Ghana, Nigeria, and Tanzania, on cashew trees and other plants (Van Mele et al. 2007, Dwomoh et al. 2008, Asogwa et al. 2008). These included *C. sericeus*, *Camponotus* sp. *Crematogaster* spp, *O. longinoda*, *Pheidole megacephala,* and *Pheidole* sp., whose relationships with the herbivores inhabiting the cashew ecosystem will need more investigations, even though ants are known as predators or cryptic herbivores (Stacy and Inge 2006).

The most common ant species in this study was *O. longinoda,* reported as a biological control agent by many authors (Dejean 1991, Peng et al. 2004, Dwomoh et al. 2009). However, the leaves used by this African weaver ant to construct their nests generally cover the new shoots and buds that end up dying, as this hampers the photosynthetic activity and thus productivity of the cashew trees. In addition, the black spots left on the nuts by the weaver ants through foraging may decrease the commercial quality of the nuts. Special investigations are needed to clarify the status of the weaver ants in cashew orchards in Benin and in West Africa in general.

Finally, the diversity of parasitoids and predators recorded for the first time on cashew tree in Benin is noteworthy. This may offer a potential for biological control strategy against the economically important cashew pests if populations of these natural enemies are more investigated, preserved, and enhanced.

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Appendix

Annex 1. Insect species associated with cashew trees; orders, families, species, agroecological zone/distribution in Benin (2009-2010)

Order	Family	Species	Agroecological zone/distribution
Coleoptera			
	Alleculidae	*Alogista serricorne* Kolbe	V
	Anthribidae	*Araecerus fasciculiatus* (De Geer)	V
	Apionidae	*Apion* sp.	III, IV, V
		Cylas punticollis Boheman	III, V
		Piezotrachelus sp.	III, IV, V
	Attelabidae	*Parapoderus fuscicornis* F.	III, V
	Bostrichidae	*Apate monachus* (F.)	III, V
		Apate terebrans Pallas	III, IV, V
		Sinoxylon transvaalense Lesne	III, V,
		Xyloperthella picea (Olivier)	V
	Bruchidae	*Callosobruchus maculatus* F.	III, IV, V
		Caryedon sp.	III, IV, V
	Buprestidae	*Sphenoptera* sp.	III, IV, V
	Cerambycidae	*Analeptes trifasciata* F.	V
		Ceroplesis aestuans guineensis Hintz	III, V
		Coptops aedificator (F.)	III, IV, V
		Corus collaris Chevrolat	III, IV, V
		Niphona appendiculata Gerstäcker	V
		Philematium festivum (F.)	III, IV, V
		Zographus regalis Brown	III, IV, V
	Cetoniidae	*Charadronota pectoralis* Bainbridge	III, IV, V
		Charadronota quadrisignata (Gory & Percheron)	III, IV, V
		Pachnoda marginata (Drury)	III, IV, V
		Pachnoda cordata (Drury)	III, IV, V
		Pachnoda sp.	III, IV, V
		Uloptera burgeoni Bourgoin	III, IV, V
	Chrysomelidae	*Acrocrassis roseomarginata* (Boheman)	III, IV
		Asbecesta transversa Allard	III, IV, V
		Aspidimorpha dissentanea Boheman	III, V
		Aspidimorpha sp.	III, V
		Aulacophora foveicollis (Lucas)	III, V
		Buphonella nigroviolacea Allard	V
		Cassida sp.	III, V
		Cryptocephalus sp.	III, V
		Gynandrophthalma sp.	III, IV, V
		Lema armata (F.)	III, V
		Lema sp.	III, IV, V
		Medythia quaterna Fairmaire	III, IV, V
		Monolepta duplicata Sahlberg	III, IV, V
		Monolepta goldingi Bryant	III, IV, V
		Monolepta sp.	III, IV, V
		Ootheca mutabilis (Sahlberg)	V
		Peploptera sp.	III, IV, V
		Syagrus calcaratus (F.)	III, IV, V
	Coccinellidae	*Cheilomenes vicina* (Mulsant)	III, IV, V
		Exochomus troberti Mulsant	III, V
		Scymnus sp.	V
	Curculionidae	*Alcidodes* sp.	III, IV, V
		Hadromerus sagittarius Olivier	V
		Lixus sp.	III, IV, V
	Elateridae	*Melanotus* sp.	III, V
	Histeridae	*Atholus* sp.	III, V
		Teretrius sp.	III, IV, V
	Lycidae	*Lycus sinuatus* Schoenherr	III, IV, V
	Meloidae	*Coryna hermanniae* (F.)	V
	Melyridae	*Melyris abdominalis* (F.)	III, IV, V
	Nitidulidae	*Carpophilus dimidiatus* (F.)	V
		Carpophilus hemipterus (L.)	III, IV, V
	Scarabaeidae		
		Trochalus sp.	III, V
	Staphylinidae	*Paederus sabaeus* Erichson	III, IV, V
	Tenebrionidae	*Endustomus senegalensis* (Laporte)	III, IV, V
		Heterotarsus bogosicus Marseul	V
		Luprops sp.	III, V
		Lagria cuprina Thomson	III, IV, V
		Paramarygmus curvipes Gebien	III, IV, V
Dermaptera			
	Forficulidae	*Diaperasticus erythrocephalus* (Olivier)	III, V
Diptera			
	Asilidae	*Ommatius* sp.	III, IV, V
	Calliphoridae	Chrysomya sp.	III, V

(*continued*)

Annex 1. Continued

Order	Family	Species	Agroecological zone/distribution
	Diopsidae	*Diopsis apicalis* Dalman	III, V
		Diopsis sp.	III, IV, V
	Micropezidae	*Mimegralla tessmanni* Enderlein	V
	Muscidae	*Lucilia* sp.	III, IV V
	Platystomatidae	*Paryphodes tigrinus* Enderlein	V
		Peltacanthina sp.	V
		Plagiostenopterina westermanni Hendel	V
		Rivellia sp.	III, IV, V
	Smuliidae	*Simulium* sp.	III, V
	Stratiomyidae	*Hermetia pennicornis* Bezzi	V
		Hermetia sp.	V
		Sternobrithes sp.	III, V,
	Syrphidae	*Graptomyza* sp.	V
		Ischiodon aegyptius (Wiedemann)	III, V
		Paragus sp.	III, V
	Tabanidae	*Chrysops* sp.	V
		Tabanus sp.	III, IV, V
	Tephritidae	*Bactrocera cucurbitae* (Coquillett)	V
		Bactrocera invadens Drew et al.	III, IV,V
		Dacus sp.	V
		Dacus vertebratus Bezzi	III, V
		Leucotaeniella guttipennis Bezzi	III, IV, V
		Perilampsis sp.	III, IV, V
Hemiptera			
	Alydidae	*Mirperus jaculus* Thunberg	III, IV, V
		Mirperus sp.	V
		Stenocoris southwoodi Ahmad	III, IV, V
		Tupalus fasciatus (Dallas)	III, IV, V
		Tenosius proletarius Schaum	III, IV, V
	Aphrophoridae	*Poophilus* sp.	V
		Ptyelus sp.	V
	Berytidae	*Coelidia* sp.	III, V
	Cicadellidae	*Nephotetix* sp.	V
	Coreidae	*Acanthocoris collarti* Schouteden	III, V
		Anoplocnemis curvipes F.	III, IV, V
		Anoplocnemis tristator F.	III, IV, V
		Clavigralla shadabi Dolling	III, IV, V
		Clavigralla tomentosicollis Stål	III, IV, V
		Cletus fuscescens Walker	III, IV, V
		Cletus pronus Berger	III, V
		Cletus sp.	III, IV, V
		Leptoglossus australis F.	III, IV, V
		Myla sp.	III, IV, V
		Pephricus pellucida (Westwood)	III, IV. V
		Pseudotheraptus devastans Distant	III, IV, V
	Derbidae	*Proutista fritillaris* Boheman	III, V
		Proutista sp.	III, IV, V
	Lygaeidae	*Aspilocoryphus fasciativentris* Stål	III, IV, V
		Oxycarenus hyalinipennis (Costa)	V
		Oxycarenus sp.	III, IV, V
		Dieuches albostriatus F.	V
		Dieuches sp.	III, IV, V
		Graptostethus servus F.	III, V
		Paromius paraclypeatus Scudder	III, IV, V
		Spilostethus furculus (Heinrich-Schaeffer)	V
		Spilostethus rivularis Germar	III, V
		Spilostethus sp.	III, V
		Stalagmostethus lagonensis Distant	III, V
	Miridae	*Helopeltis anacardii* Miller	III, V
		Helopeltis schoutedeni Reuter	III, IV, V
		Proboscidocoris sp.	III, IV, V
	Pentatomidae	*Acoloba lanceolata* (F.)	III, V
		Acrosternum acutum (Dallas)	III, V
		Aeliomorpha griseoflava (Stål)	III, V,
		Afrius purpureus (Westwood)	III, IV, V
		Agonoscelis haroldi Bergroth	III, IV, V
		Agonoscelis versicolor (F.)	III, IV, V
		Aspavia acuminata Montandon	III, IV, V
		Aspavia armigera (F.)	V
		Aspavia sp.	III, IV, V
		Atelocera raptoria Germar	III, IV, V
		Atelocera spinulosa (Palisot de Beauvois)	III, IV, V
		Bathycoelia horvathi Schouteden	III, V
		Boerias ventralis (Dallas)	III, IV, V
		Carbula marginella (Thunberg)	III, IV, V
		Carbula sp.	V

(*continued*)

Annex 1. Continued

Order	Family	Species	Agroecological zone/distribution
		Cyptocoris lundii (F.)	V
		Damarius splendidulus F.	V
		Diploxys floweri Distant	III, V
		Durmia fei blackae (Villiers)	III, IV, V
		Dymantis plana (F.)	III, V
		Eysarcoris sp.	III, V
		Macrima sp.	V
		Macrorhaphis acuta Dallas	V
		Myrochea aculeata (Westwood)	III, V
		Nezara viridula (L.)	III, IV, V
		Piezodorus pallescens (Germar)	III, IV, V
		Piezodorus rubrofasciatus (F.)	III, V
		Planopsis sp.	III, V
		Platynopus septemdecimmaculatus (Palisot de Beauvois)	V
		Plautia elegans Linnavuori	III, V
		Tessaratoma? afzelii (Stål)	III, IV, V
	Plataspidae	*Brachyplatys testudonigra* De Geer	III, V
		Coptosoma nubila (Germar)	V
		Coptosoma sp.	III, IV, V
	Pyrrhocoridae	*Dysdercus voelkeri* Schmidt	III, IV, V
		Dysdercus sp.	III, IV, V
	Reduviidae	*Acanthaspis vidua* Stål	III, V
		Cosmolestes pictus Klug	III, V
		Endochus binotatus Bergroth	III, V
		Harpagocoris katangae fasciatus Villiers	III, V
		Lopodytes armatus Villiers	V
		Nagusta praecatoria F.	III, IV, V
		Peprius nodulipes (Signoret)	III, V
		Platynopus parvus Distant	V
		Rhaphidosoma truncatum Jeannel	III, IV, V
		Rhynocoris albopilosus Signoret	III, IV, V
		Tribelocephala tristis Breddin	V
		Vadimon comedo Bergroth	III, V
		Vestula lineaticeps (Signoret)	V
		Vestula sp.	V
	Rhopalidae	*Leptocoris hexophthalma* (Thunberg)	III, IV, V
	Scutelleridae	*Sphaerocoris annulus* (F.)	III, IV, V
		Steganocerus multipunctatus Thunberg	III, V
	Tingidae	*Ammianus* sp.	III, V
	Coccidae	*Saissetia* sp.	III, V
	Aphididae	*Melanaphis sacchari* (Zehntner)	III, IV, V
		Toxoptera odinae (van der Goot)	V
Hymenoptera			
	Apidae	*Meliponula bocandei* (Spinola)	V
		Meliponula togoensis (Stadelman)	III, IV, V
		Meliponula sp.	III, IV, V
		Apis mellifera andersonii Latreille	III, IV, V
	Braconidae	*Aleiodes* sp.	III, IV, V
		Apanteles sp.	III, IV, V
		Ascogaster sp.	III, IV, V
		Bracon sp.	III, V
		Braunsia sp.	III, V
		Bassus sp.	III, IV, V
		Chelonus sp.	III, IV, V
		Iphiaulax rubrinervis Cameron	III, V
		Iphiaulax sp.	III, IV, V
		Phanerotoma sp.	III, IV, V
		Spathius sp.	V
		Trathala sp.	III, IV, V
	Chalcididae	*Antrocephalus* sp.	III, IV, V
		Brachymeria sp.	III, IV, V
		Epitranus sp.	V
	Crabronidae	*Dasyproctus bipunctatus* Lepeletier & Brullé	III, IV V
		Dasyproctus sp.	III, IV, V
	Eumenidae	*Rhynchium* sp.	V
		Synagris sp.	III, V
	Eupelmidae	*Anastatus* sp.	III, IV, V
	Eurytomidae	*Eurytoma* sp.	V
	Formicidae	*Camponotus sericeus* (F.)	III, IV, V
		Camponotus spp.	III, IV, V
		Cataulacus sp.	III, IV, V
		Crematogaster sp.	III, IV, V
		Dorylus nigricans Illiger	V
		Lepisiota sp.	III, IV, V

(*continued*)

Annex 1. Continued

Order	Family	Species	Agroecological zone/distribution
		Myrmicaria opaciventris Emery	III, IV, V
		Myrmicaria sp.	III, IV, V
		Odontomachus troglodytes (Santschi)	III, V
		Oecophylla longinoda (Latreille)	III, IV, V
		Pachycondyla tarsata (F.)	III, V
		Paratrechina longicornis Roger	III, V
		Pheidole sp.	III, IV, V
		Polyrhachis militaris (F.)	III, IV, V
		Polyrhachis sp.	III, IV, V
		Tetraponera anthracina (Santschi)	III, IV, V
		Tetraponera sp.	III, IV, V
	Ichneumonidae	*Charops* sp.	V
		Enicospilus sp.	III, V
		Pimpla sp.	III, V
		Xanthopimpla sp.	III, V
	Leucospidae	*Leucospis* sp.	III, V
	Megachilidae	*Anthidium* sp.	V
	Pompilidae	*Pepsis* sp.	V
	Sphecidae	*Tachytes* sp.	III, V
		Trypoxylon sp.	V
	Vespidae	*Belonogaster juncea* (F.)	V
		Polistes marginalis (F.)	V
		Polistes sp.	III, IV, V
		Ropalidia cincta (Lepeletier)	III, IV, V
		Ropalidia sp.	III, V
		Vespula sp.	III, V
Isoptera			
	Termitidae	*Amitermes* sp.	V
		Macrotermes bellicosus Smeathmann	V
		Nasutitermes sp.	III, IV, V
Lepidoptera			
	Syntomidae	*Euchromia lethe* F.	V
	Gracillariidae	*Eteoryctis gemoniella* Stainton	III, IV, V
	Pieridae	*Mylothris chloris* (F.)	III, IV, V
Neuroptera			
	Hemerobiidae	*Micromus* sp.	V
	Myrmeleontidae	*Nosa tigris* (Dalman)	III, V
Odonata			
	Coenagriidae	*Ceriagrion* sp.	III, IV, V
Orthoptera			
	Euschmidtiidae	*Euschmidtia congana* Rehn	III, V
	Acrididae	*Gastrimargus africanus* (Saussure)	III, V
		Oecanthus pellucens (Scopoli)	III, V
	Gryllidae	*Homoeogryllus tessellatus* Audinet-Serville	V
	Pyrgomorphidae	*Zonocerus variegatus* (L.)	III, IV, V
	Tetrigidae	*Paratettix* sp.	III, IV, V
		Xerophyllium sp.	V
	Tettigoniidae	*Cymatomera* sp.	V
		Zabalius sp.	III, V
	Tridactylidae	*Tridactylus* sp.	III, IV, V
Thysanoptera			
	Thripidae	*Selenothrips rubrocinctus* (Giard)	III, IV, V

NB. Others species have been identified only at family level, e.g., Cosmopterigidae, Carabidae, Limacodidae, Laguiriidae, Meloidae, Bombyliidae, Drosophilidae, Sarcophagidae, Delphacidae, Issidae, Bethylidae, Libellulidae, and Mutilidae.