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Patterns of Species Richness and Diversity of Insects Associated With Cucurbit Fruits in the Southern Part of Cameroon

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ABSTRACT. Patterns of species diversity and community structure of insects associated with fruits of domesticated cucurbits were investigated from January 2009 to 2011 in three localities from two agroecological zones in the southern part of Cameroon. Rarefaction curves combined with nonparametric estimators of species richness were used to extrapolate species richness beyond our own data. Sampling efforts of over 92% were reached in each of the three study localities. Data collected revealed a total of 66 insect morphospecies belonging to 37 families and five orders, identified from a set of 57,510 insects. The orders Diptera (especially Tephritidae and Lonchaeidae) and Hymenoptera (mainly Braconidae and Eulophidae) were the most important, in terms of both abundance and species richness on the one hand, and effects on agronomic performance on the other. Values for both the species diversity (Shannon and Simpson) and the species richness indices (Margalef and Berger–Parker) calculated showed that the insect communities were species-rich but dominated, all to a similar extent, by five main species (including four fruit fly species and one parasitoid). Species abundance distributions in these communities ranged from the Zipf–Mandelbrot to Mandelbrot models. The communities are structured as tritrophic networks, including cucurbit fruits, fruit-feeding species (fruit flies) and carnivorous species (parasitoids). Within the guild of the parasitoids, about 30% of species, despite their low abundance, may potentially be of use in biological control of important pests. Our field data contribute in important ways to basic knowledge of biodiversity patterns in agrosystems and constitute baseline data for the planned implementation of biological control in Integrated Pest Management.

Key Words: species diversity, species abundance distribution, fruit fly, parasitoid, ecological process

Pest insects are among the main constraints to fruit production in orchards and crop gardens in tropical regions. According to Scholtz and Mansell (2009), pest insects account for about 50% of crop losses in Africa, from plant establishment through growth, maturation, and storage. Although various studies deal with the feeding preferences of fruit-feeding insects (White 2006, Ndzana Abanda et al. 2008, Ngamo Tinkeu et al. 2010), the impact of these pests, which are responsible for millions of dollars in production losses each year (Scholtz and Mansell 2009), and strategies to manage them (Stonehouse et al. 2007, Jang et al. 2008), few have focused on the species diversity of insect communities in fruit-based food webs or on the taxonomic composition and characterization of these communities. Rigorous analysis may help identify ecological mechanisms underlying the dynamics of pest insect populations in agrosystems, so that they can be managed more effectively and with fewer adverse effects on human consumers and on the environment (Allwood 1996).

Hence, biodiversity inventories need to be designed around the use of effective sampling and estimation procedures, especially for “hyperdiverse” groups of terrestrial organisms such as arthropods (Colwell and Coddington 1994). Studies of ecological communities require ideally that individuals in a sample be properly identified to species level and counted (Gotelli 2004). However, this is not always possible, so that during identification, individuals are usually separated by morphotypes, treated as equivalent to species in species richness estimations (Magurran 2004, McGill et al. 2007). Species richness is difficult to quantify (Longino et al. 2002) but can be estimated by three different ways: 1) extrapolating species accumulative curves (SACs), 2) using nonparametric estimators to predict the number of ‘missing’ species, or 3) fitting statistical distributions such as species abundance distributions (SADs) (Colwell and Coddington 1994, Chao et al. 2009).

SACs allow measurement of within-inventory efficacy and completeness, and estimation of the minimum sampling effort required to reach a satisfactory level of completeness. Nonparametric estimators use the number of rare species in the community to predict the number of missing species (Moreno and Halfter 2000). Based on SACs, effort is thus the total number of individuals collected, or the number of pooled samples, necessary to reach the asymptotic species richness, whereas with species richness estimators, effort is the ratio between species richness observed and theoretical species richness. SADs capture the inequality of species abundances that characterizes ecological communities to highlight their structuring mechanisms (McGill et al. 2007). Based on ecological mechanisms shaping SADs, five biological models, including the broken stick or null model, niche preemption, lognormal distribution, Zipf, and Mandelbrot models are widely used. Species diversity, the most common representation of ecological diversity, uses mathematical indices broadly known as diversity indices, derived from combining information on richness and evenness (Hamilton 2005, Schowalter 2006).

In this study, diversity of ecological communities was assessed within habitat (α diversity) and compared between habitats or landscapes (β diversity) (Magurran 2004, Begon et al. 2006, Stireman 2008). This work aims to characterize patterns in the species composition, spatial distribution, and community structure of insects associated with fruits of domesticated cucurbits in the southern part of Cameroon, to provide ecological knowledge useful for the implementation of Integrated Pest Management strategies of these pests in crop gardens.

Materials and Methods

Sampling Period and Localities. The study was conducted from January 2009 to 2011 in three localities from two agroecological zones

in the southern Cameroon (Fig. 1). 1) Koutaba, situated in the Western Highlands, with a unimodal humid tropical rainfall regime; the experimental parcels were located in the domain of the Catholic Monastery; 2) the Campus of the University of Yaoundé I (hereafter termed Campus); and 3) Olembe, on the northern outskirts of Yaoundé. Sites 2 and 3 are both located on the Southern Plateau, with a bimodal humid tropical rainfall regime. The two agroecological zones differed in their topographic and climatic characteristics (Table 1), as well as in their agronomic systems. The plots of Olembe (surrounded by an old cocoa plantation, a swampy zone, and various market crop parcels) and Koutaba (surrounded by a mosaic of ornamental plantings, a strip of woodlands, and hedgerows) were located in agricultural landscapes and suffered less frequent disturbances by humans than did the Campus site (surrounded by buildings and grasslands), located in an urban landscape.

Experimental Design. In each locality, a trap garden made of 16 ridges of 8 m by 2 m each, separated by furrows 50 cm wide, was established during each cropping cycle. Each ridge supported 12 plants of a single cucurbit species. Each cucurbit species occupied two ridges.

Biological Material. Cucurbits are among the economically most important cultivated flowering plants worldwide (Dupriez and De Leener 1987, Matthews et al. 2003, Schippers 2004, Kocyan et al. 2007, Schaefer et al. 2009). In Cameroon, several species are cultivated for a diversity of purposes (nutrition, pharmacopoeia, artisanal, etc.) (Mbouemboue and Boyomo 1981, Dupriez and De Leener 1987). We studied eight market crops species belonging to the family of Cucurbitaceae, including 1) *Citrullus lanatus* (Thünberg) Matsumura and Nakai var. *egusi*, 2) *Cucumeropsis mannii* Naudin, 3) *Cucumis melo* L. var. *charantais*, 4) *Cucumis melo* L. var. *agrestis*, 5) *Cucumis sativus* L. var. *poinsett*, 6) *Cucurbita moschata* (Duchesne ex Lamarck) Duchesne ex Poiret, 7) *Lagenaria siceraria* (Molina) Standley, and 8) *Sechium edule* (Jacquin) Swartz (Supplementary material). The biological material was composed of 7,290 damaged cucurbit fruits unequally distributed among the three localities and the eight cucurbit species (Supplementary material).

Sampling Method. Samplings were conducted during sampling days, unequally distributed among the three localities of the study (Supplementary material). From the blooming stage up to the end of the fruiting period, plots were visited once a week to evaluate the number of fruits produced and the number affected by insects and/or diseases. Infected fruits were categorized as follows: 1) fruits attacked by fruit flies (Diptera: Tephritidae), characterized by the presence of exudates at the oviposition sites; 2) fruits attacked by sap-sucking insects (Hemiptera), recognized by the dried-out marks of the sucking points,

and 3) those attacked by Coleoptera and Lepidoptera, recognized by the areas removed by these chewing insects. Among affected fruits, those potentially damaged by fruit flies were individually carried in labeled plastic bags to the laboratory, where they were weighed, incubated in plastic boxes, and followed up to the emergence of adult insects. Insects collected were sorted, counted, and fixed in 70% ethanol.

Specimen Identification. Determinations were carried out at the Laboratory of Zoology of the University of Yaoundé I, at the Centre International de Recherche Agronomique pour le Développement/Centre de Biologie et de Gestion de Populations (CIRAD/CBGP) in Montpellier (France) and at the Musée Royale de l'Afrique Centrale (MRAC) at Tervuren (Belgium). Determinations were based on various documents, including the following: White (2006) and White and Elson-Harris (2004) for fruit flies; Wharton and Gilstrap (1983) and Wharton et al. (1992) for parasitoids; and Delvare and Aberlenc (1989) for insect families in general. The monographs by Bordat and Arvanitakis (2004) and Bordat and Daly (1995) were also used. Voucher samples are deposited in the collections of the three institutions cited above.

Data Analysis. To test any difference of abundance between taxonomical groups, the Kruskal–Wallis test computes in GraphPad Prism 5 was applied. The differences were significant at $P < 0.05$.

Various statistical tools were used to assess α diversity. Individual-based rarefaction and sample-based rarefaction, with 50 randomizations, were used to generate the SACs of “Mau Tao” estimates of

Table 1. Climatic and agroecological characteristics of the study localities in the southern part of Cameroon

Climatic parameters ^c	Agroecological zones		
	Southern plateau		Western highlands
Survey localities	Campus	Olembe	Koutaba
Latitude N	3° 51'28.9"	3° 57'46.3"	5° 38'47"
Longitude E	11° 29'52.2"	11° 31'51.4"	10° 48'20"
Altitude (m)	729	673	1,180
Annual rainfall (mm)	1,783.5 ^a –1,953.8 ^b		1,560.5 ^b
Mean temperature (°C)	24.63 ^a –24.46 ^b		18.66 ^b
Mean relative humidity (%)	80.17 ^a –76 ^b		70.09 ^b

^aData from the year 2009.
^bData from the year 2010.
^cClimatic data were obtained from the National Meteorological Service of Yaoundé and from the Koutaba airport services respectively.

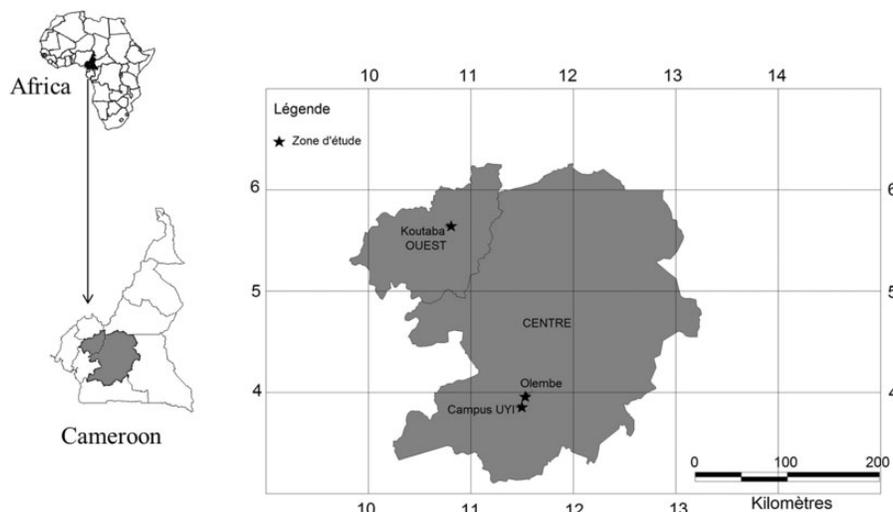


Fig. 1. Map of the study localities in the southern part of Cameroon. Reference system Transversal Mercator projection; Spheroid of Clarke 1981; author: Tadjoung Paulin.

species richness for each site. Application of SACs is highly recommended when comparing species diversity from different communities or landscapes, or from areas with different degrees of perturbation (Moreno and Halfiter 2000).

Three nonparametric abundance-based estimators ABE of species richness (abundance-based coverage estimator ACE, Chao 1, and Jackknife 1) and three nonparametric incidence-based estimators of species richness IBE (incidence-based coverage estimator ICE, Chao 2, and Jackknife 2) were used to estimate the potential number of species (observed + unseen) in the biological material of each study site. The combination of these measures, performed using EstimateS software version 9.0 (Colwell 2013), and the observed species richness allowed evaluation of the sampling effort in each locality.

The observation that species vary in abundance has promoted the development of statistical models such as species abundance models (Magurran 2004). Sometimes called dominance diversity curves, these models provide a graphical way of describing species richness and the relative abundance of species in communities (Morin 2011). This tool is important as it allows a quick and easy comparison of biological communities.

SADs, based on the inequality of species abundance that characterizes every ecological community, are used to study the structure of ecological communities by testing the fitting of data to theoretical models of relative species abundance (Green and Plotkin 2007, Pavoine and Bonsall 2011). Each distribution model has an underlying statistical distribution, which can be derived by making some assumptions about the way that species interact in the community (Magurran 2004, Morin 2011). We examined SADs for the insect communities we studied, choosing as the best model the one presenting the lowest value of the Akaike Information Criterion (AIC) (Henry et al. 2010) calculated with the rad.fit function through the diversity vegan package in the R 2.14.1 software (R Development Core Team 2004).

The diversity indexes of Shannon ($H' = -\sum_{i=1}^s \frac{ni}{N} \ln \frac{ni}{N}$) and Simpson ($D = \sum_{i=1}^s \frac{ni(ni-1)}{N(N-1)}$), as well as the evenness index of Pielou ($J = \frac{H'}{\ln S}$), were used to assess insect diversity within and between sites. In accordance with Magurran (2004), the unequal distribution of abundance between species allowed the use of the dominance index of Berger-Parker ($1/d = \frac{1}{N_{max}/N}$) to express the proportion of individuals accounted for by the most abundant species in each site. The species richness index of Margalef ($DMg = \frac{S-1}{\ln N}$) was used to highlight the most species-rich site. In these formulae, ni is the number of individuals of each of the i species in the sample; N the total number of individuals in the assemblage; S the number of species in the assemblage; N_{max} the number of individuals in the numerically dominant species in each locality; and \ln , the natural logarithm. All these indices, commonly used in ecological community studies (Magurran 2004), were calculated using PAST 2.12 (PAleontological STatistics) software (Hammer 1999-2011).

“Species turnover” focuses on changes in taxonomic composition between communities. The application of Sorensen’s coefficient ($Sc = \frac{a+b}{2c+a+b}$) permits quantification of specificity in the spatial distribution of insect species. Here, a and b represent the number of unique species, respectively, in the first and the second sites, while c is the number of shared species. Sorensen’s coefficient ranges in value from 0 (maximum β diversity, in which no species are shared between sites) to 1.0 (minimum β diversity; all species shared between sites) (Harrison and Berenbaum 2013). t -tests, computed in PAST, were used to compare diversity between sites and seasons.

Results

Taxonomic Composition of Insect Communities in the Study

Sites. In total, 66 insect morphospecies, belonging to five orders and 37 families, were identified from a set of 57,510 individuals collected in the three localities (Supplementary material). This included 60 morphospecies from 54 genera and 35 families on the Campus; 44 morphospecies from 40 genera and 30 families at Olembe; and 36 morphospecies from 32 genera and 25 families at Koutaba (Supplementary material).

At a taxonomic level, Diptera was the numerically predominant order ($P < 0.01$) and the most species-rich, followed by Hymenoptera (Fig. 2). These two orders present obvious agronomic interest, as their representatives include many species that can affect fruit production. Dipterans comprised both specialist and opportunistic fruit feeders. Most of the Hymenoptera species recorded were parasitoids (Supplementary material), including potential agents of biological control of fruit flies. Lepidoptera, Coleoptera, and Hemiptera, because of their low abundance and species richness (Fig. 2), were minor constituents of insect communities. They can be considered as minor fruit feeders in this system.

Composition of Diptera. All the 15 families of Diptera identified in the study were recorded on the Campus, while 13 were encountered, respectively, at Olembe and Koutaba (Fig. 3). In all the three sites, tephritids were numerically predominant among dipteran taxa ($P < 0.01$) (Fig. 3). They were represented by five species, including four of the genus *Dacus* (two in subgenus *Dacus* (*Dacus* (*Dacus*) *bivittatus* Bigot and *Dacus* (*Dacus*) *punctatifrons* Karsch and two in subgenus *Didacus* (*Dacus* (*Didacus*) *ciliatus* Loew and *Dacus* (*Didacus*) *vertebratus* Bezzi)) and one species of *Bactrocera* (*Bactrocera* (*Zeugodacus*) *cucurbitae* Coquillett) (Supplementary material). Although the *Dacus* spp. showed high population densities during the entire study period in all the three sites, *Bactrocera* was only observed during a single sampling day at Koutaba.

Composition of Hymenoptera. All the nine families of Hymenoptera identified were recorded on the Campus. Of these, three were also observed at Olembe, one at Koutaba, and four in both localities (Fig. 4). Consequently, Olembe hosted seven hymenopteran families and Koutaba five. Braconids were numerically predominant ($H = 8.2$; $ddl = 2$; $P = 0.02$) and the most species-rich family, with eight species (Fig. 4). Braconids and Eulophids, another family common in our samples, belong to the guild of parasitoids and thus have potential agronomic interest (Supplementary material). Among the braconids, *Diachasmimorpha* sp., *Foppius* spp., *Psytalia perproximus* Silvestris, *Phaenocarpa* sp., and an unidentified species coded Gen.18 sp.1 were found to be parasitoids of fruit flies, whereas *Apanteles* sp. and *Schoenlandella* sp. were found to be parasitoids of the Lepidopteran *Sphenarches anysodactylus* Walker (Supplementary material). In the Eulophidae, *Aprostocetus* sp., *Tetrastichus daccicidae*, and *Tetrastichus giffardianus* Silvestris were found to be fruit fly parasitoids. In addition, the ant *Pheidole megacephala* Fabricius (Formicidae) was observed preying on fruit fly larvae.

Trophic Activities of Insects. Three trophic groups of insects were identified: fruit feeders (carpophagous species and sap-suckers), carnivores (predators and parasitoids), and saprophagous (opportunistic fruit feeders that feed on decaying fruits) (Fig. 5). Carpophagous insects were numerically predominant (85.8% of all individual insects, representing 19 species), whereas saprophages were most species-rich (only 6.9% of the total number of individuals recorded but representing 24 species) (Fig. 5). Twenty-three species were parasitoids, which constituted 6.1% of all individual insects recorded.

Community Characterization.

Sampling Effort. On sample-based rarefaction curves, sampling effort necessary to reach the asymptotes was obtained, respectively, at the 87th day on the Campus, 39th day at Olembe, and 18th day at Koutaba, whereas on the individual-based rarefaction curves, asymptotes were reached at the pooled values of 29,600; 14,000; and 8,000 individuals, respectively (Fig. 6a and b). Also, there were strong significant positive correlations ($P < 0.01$) between the species richness observed and both the number of sampling days and the number of individuals collected in each community (Fig. 6a and b).

Computing the mean values obtained from the three abundance-based species richness estimators (64.4; 47.8 and 37.1) and the observed species richness generated by Mao tau (Table 2), estimated sampling effort was, respectively, 93.2, 92.1, and 97.2%. The incidence-based estimators gave similar results. This result reveals that few unseen species remain to be recorded in each community and that

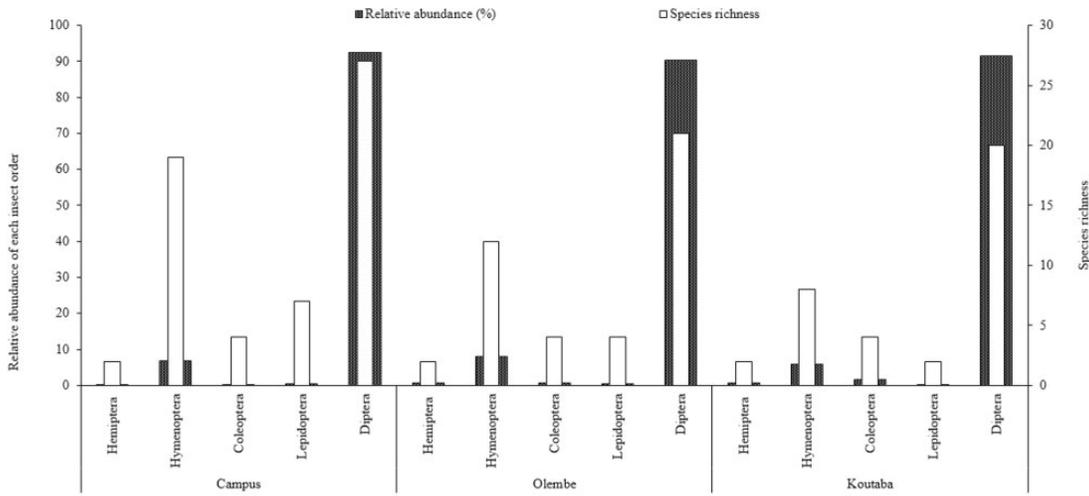


Fig. 2. Relative abundance and species richness of insect orders associated with fruits of eight cultivated cucurbit species in three localities of Cameroon, from January 2009 to 2011. Insect orders are arranged according to insect phylogenetic classification (Trautwein et al. 2012).

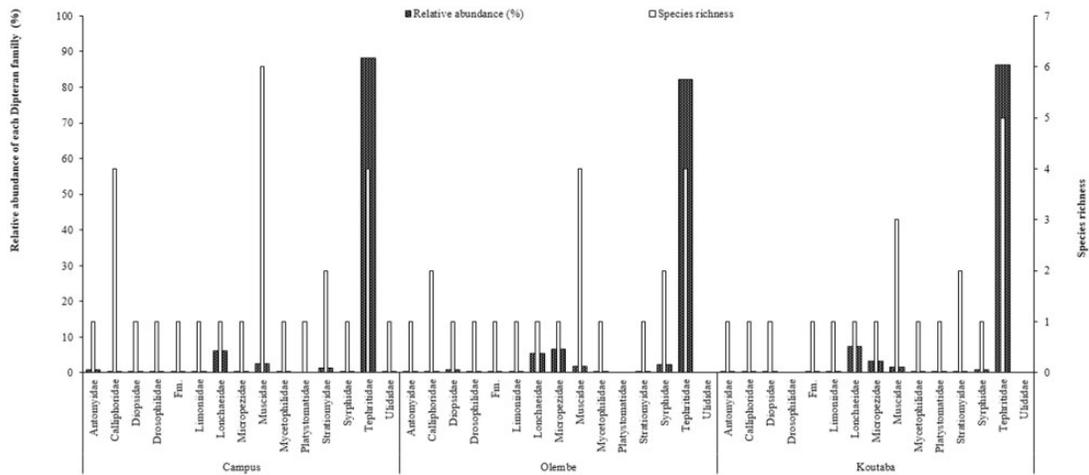


Fig. 3. Relative abundance and species richness of Dipteran families associated with fruits of eight cultivated cucurbit species in three localities of Cameroon, from January 2009 to 2011.

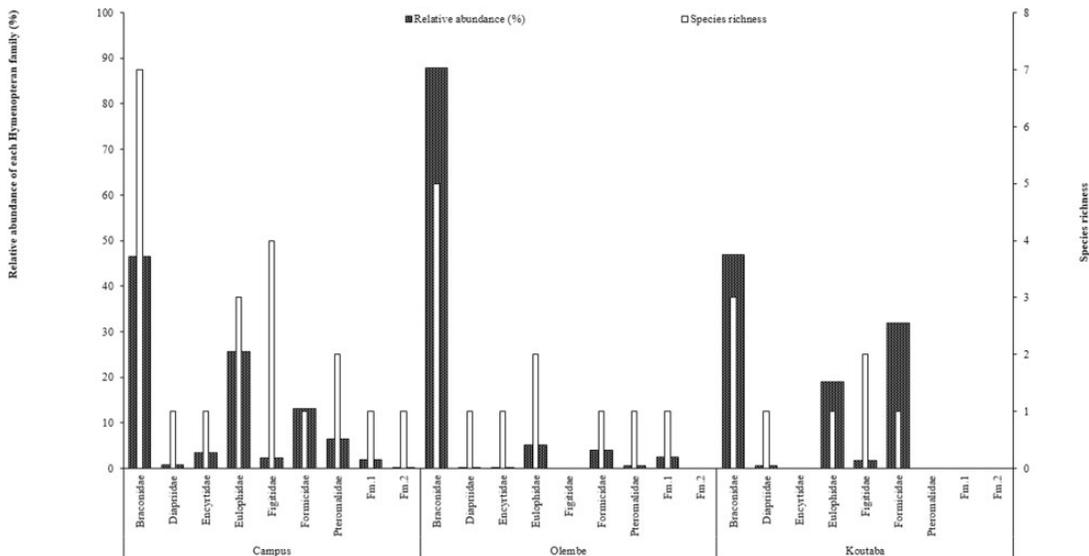


Fig. 4. Relative abundance and species richness of Hymenopteran families associated with fruits of eight cultivated cucurbit species in three localities of Cameroon, from January 2009 to 2011.

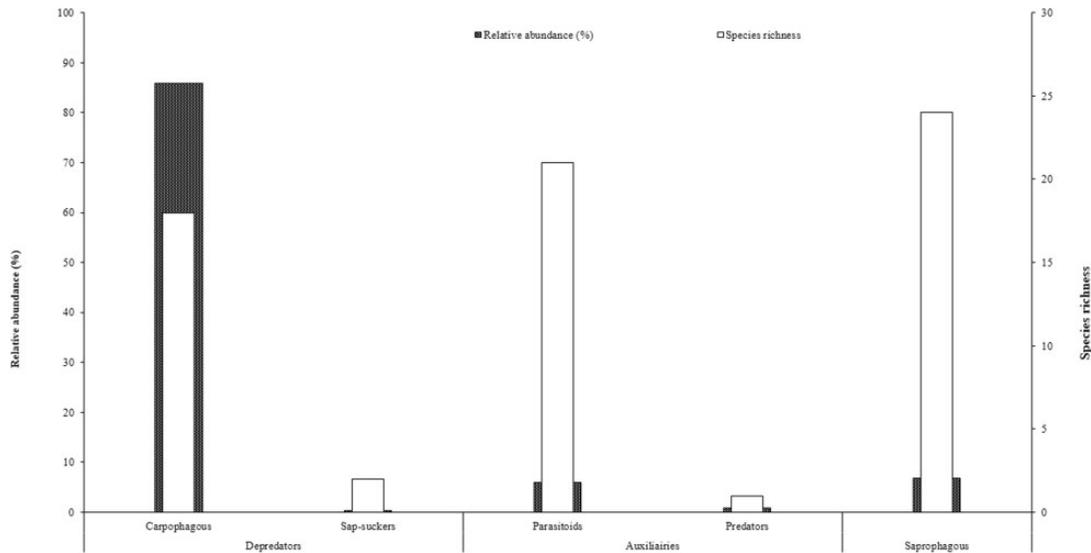


Fig. 5. Relative abundance and species richness of trophic groups of insects associated with fruits of eight cultivated cucurbit species in three localities of Cameroon, from January 2009 to 2011.

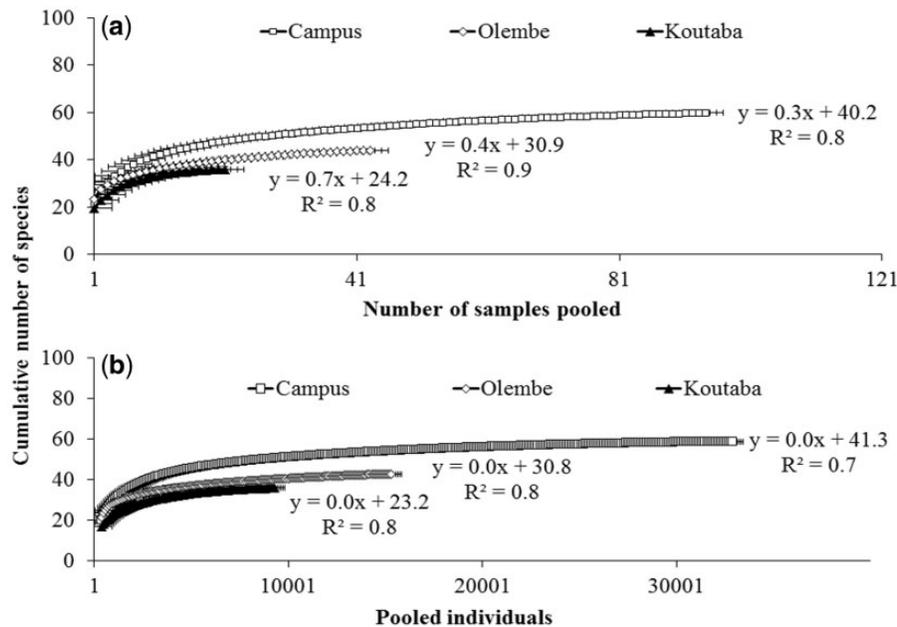


Fig. 6. Species accumulation curve based on the sampling days (a) and on the number of insect individuals (b) collected in three localities of Cameroon, from January 2009 to 2011.

sampling was sufficient for the use of asymptotic minimum species richness estimators.

Species Richness and Diversity. The highest species richness value was obtained on the Campus with 60 species recorded, followed by Olembe (44 species) and Koutaba (36) (Table 2). For the Margalef index values, there was no significant variation of species richness between Olembe and Koutaba, whereas both gave lower values than the Campus (Table 3). The Shannon and Simpson indexes both ranked the community of Koutaba as the most diverse. All the studied communities appeared weakly diversified when considering the value of the Shannon index in relation to the maximal diversity ($\ln S$) (Table 3). The values of the evenness index showed a nonsignificant difference in abundance distribution between Olembe and Campus, whereas both were different from Koutaba (Table 3). The Berger–Parker measure indicated the numerical predominance of the most abundant species in

each locality, with the highest value observed at Olembe and the lowest at Koutaba (Table 3).

Among the 66 identified insect morphospecies, 21 were found in only one site: 16 at the Campus, 3 at Olembe, and 2 at Koutaba, respectively (Supplementary material). Twenty-nine species were common to the three localities, whereas Campus and Olembe shared 11 other species and Campus and Koutaba four others (Supplementary material). No species was shared only by Olembe and Koutaba. Based on values of Sorensen's coefficient (S_c), these three communities were highly dissimilar: Campus/Olembe ($S_c = 0.2$), Campus/Koutaba ($S_c = 0.3$), and Koutaba/Olembe ($S_c = 0.3$).

Community Structure Model. Based on the values of AIC (Table 4) and the SADs (Fig. 7), community structures at the Campus and Olembe followed the Zipf–Mandelbrot model, while that of Koutaba followed the Mandelbrot model (Fig. 7). Both models characterize

Table 2. Estimators of species richness based on abundance of insects associated with fruits of eight cultivated cucurbit species in three localities of Cameroon, from January 2009 to 2011

Species richness estimators	Species richness generated (mean ± SE)		
	Campus	Olembe	Koutaba
Sobs (Mao Tau)	60 ^a (56.9–63.1) ^b	44 ^a (40.7–47.3) ^b	36 ^a (34.9–37.1) ^b
ACE mean	65.1 ± 0.6	48.5 ± 0.8	37.1 ± 0.8
Chao 1 mean	62.1 ± 2.5	46.0 ± 2.3	36.1 ± 0.5
Jack 1 mean	65.9 ± 2.4	48.9 ± 2.1	37.9 ± 1.3
Mean of the three ABE	64.4	47.8	37.0
ICE mean	64.7 ± 0.6	48.0 ± 0.8	37.1 ± 0.8
Chao 2 mean	61.9 ± 2.2	45.9 ± 2.5	36.1 ± 0.5
Jack 2 mean	65.0 ± 1.0	49.9 ± 1.4	34.6 ± 2.1
Mean of the three IBE	64.0	48.0	35.9

Sobs, species richness observed generated par Mao Tau in estimateS software.
^aMean value of Sobs.
^bLower–upper bound of the Sobs value.

Table 3. Species diversity and species richness indices calculated for insects associated with fruits of eight cultivated cucurbit species in three localities of Cameroon, from January 2009 to 2011

Localities	Campus	Olembe	Koutaba
Shannon_H'	1.6 ^a	1.4 ^b	1.7 ^c
LnS	4.1	3.1	3.6
Simpson_1-D	0.6 ^a	0.5 ^b	0.7 ^c
Evenness_J	0.4 ^a	0.4 ^a	0.5 ^b
Berger–Parker_d	0.6 ^a	0.7 ^b	0.5 ^c
Margalef_DMg	5.7 ^a	4.5 ^b	3.8 ^b

On a given line, values followed by the same letter are not significantly different among sites at $P < 0.05$ by the t-test comparing diversity in PAST software.

Table 4. Values of AIC for each rank-abundance distribution model of insects associated with fruits of eight species of cultivated cucurbits in three localities of Cameroon, from January 2009 to 2011

Species abundance models	AIC value in each survey locality		
	Campus	Olembe	Koutaba
Null	79,295.5	34,017	13,655
Preemption	17,832.6	13,645.3	1,738.7
Lognormal	1,181.7	2,473.2	483.1
Zipf	940.6 ^a	2,016.2 ^a	868.6
Mandelbrot	942.6 ^a	2,018.2 ^a	348.2 ^a

Values with a letter represent the lowest values of the AIC.

ecologically hierarchized communities in which colonization of space by a species is linked to the activity of the preestablished species with which it interacts.

SAD models underline the numerical predominance of *Dacus bivittatus*, which accounted for about 50% of all insect individuals in each of the three sites (Supplementary material). This fly emerged from fruits harvested during 90 out of 94, 40 out of 47, and 17 out of 21 sampling days, respectively, on the Campus, at Olembe, and at Koutaba. This species was followed in abundance by *Dacus ciliatus* (obtained on 85, 20, and 16 sampling days, respectively), *P. perproximus* (65, 29, and 15 d), *Dacus punctatifrons* (44, 12, and 13 d), and the unidentified species of Lonchaeidae coded as Gen.7 sp.1 (12, 24, and 10 d). These five

species accounted for about 80% of the whole sample (Supplementary material). *P. perproximus* was in our system a potential parasitoid of *Dacus* species, the principal fruit feeders. At Campus, 23 rare species (among which 34.8% were parasitoids of various pests), each accounting for no more than 10 individuals, were recorded, compared to 17 (35.3% of which were parasitoids) at Olembe and 17 (29.4%) at Koutaba.

Discussion

Taxonomic Composition of Insect Communities. This work is the first sampling of insect species from fruits of cultivated cucurbits in Cameroon. In total, 57,510 insect individuals, comprising 66 morpho-species belonging to five orders and 37 families, was collected. This sample revealed a hitherto unsuspected abundance and diversity of insects associated with cucurbit fruits in Cameroon and highlighted the richness of insects found in fruit-based agrosystems compared with previous studies focused on fruit pests (Nonveiller 1984, Tindo and Tamo 1999, Okolle and Ntonifor 2005, Fomekong et al. 2008, Ndzana Abanda et al. 2008, Ngamo Tinkeu et al. 2010).

Many ecologists have found it useful to group insects into guilds to study the ecological interactions between insects, their hosts, their natural enemies, and climate (Speight et al. 2008). Based on the feeding strategies of the insects observed, three guilds, phytophagous (carpophagous and sap suckers), saprophagous, and carnivorous (parasitoids and predators) were recognized. Globally, phytophagous insects were numerically predominant, representing >96.1% of the individuals collected. This guild accounts for at least 25% of all insects on earth (Strong et al. 1984). Several studies have emphasized their importance as pests on various crops, particularly the importance of carpophagous insects in fruit production (Appert and Deuse 1982, 1988; Reckhaus 1997).

An analysis by taxon revealed that Diptera and Hymenoptera were numerically preponderant and agronomically most important as well. A similar conclusion was reached by Djiéto-Lordon and Aléné (2006), who studied the fauna associated with various cultivated fruits in and around Yaoundé. Among Diptera, the family Tephritidae, mainly represented by species of the genus *Dacus*, were the main fruit feeders with respect to the feeding behavior of their larvae. These flies are known worldwide as key pests of fruits of economic importance in orchards and gardens (Tindo and Tamo 1999, Vayssières and Carel 1999, Da Silva et al. 2006, White 2006, Fomekong et al. 2008, Rwomushana et al. 2008, Copeland et al. 2009, Courtney et al. 2009, Virgilio et al. 2009, Rycckewaert et al. 2010). Concerning Hymenoptera, various species of the families Braconidae and Eulophidae were found to parasitize fruit flies and moths, while ants (Formicidae) preyed on fruit fly larvae.

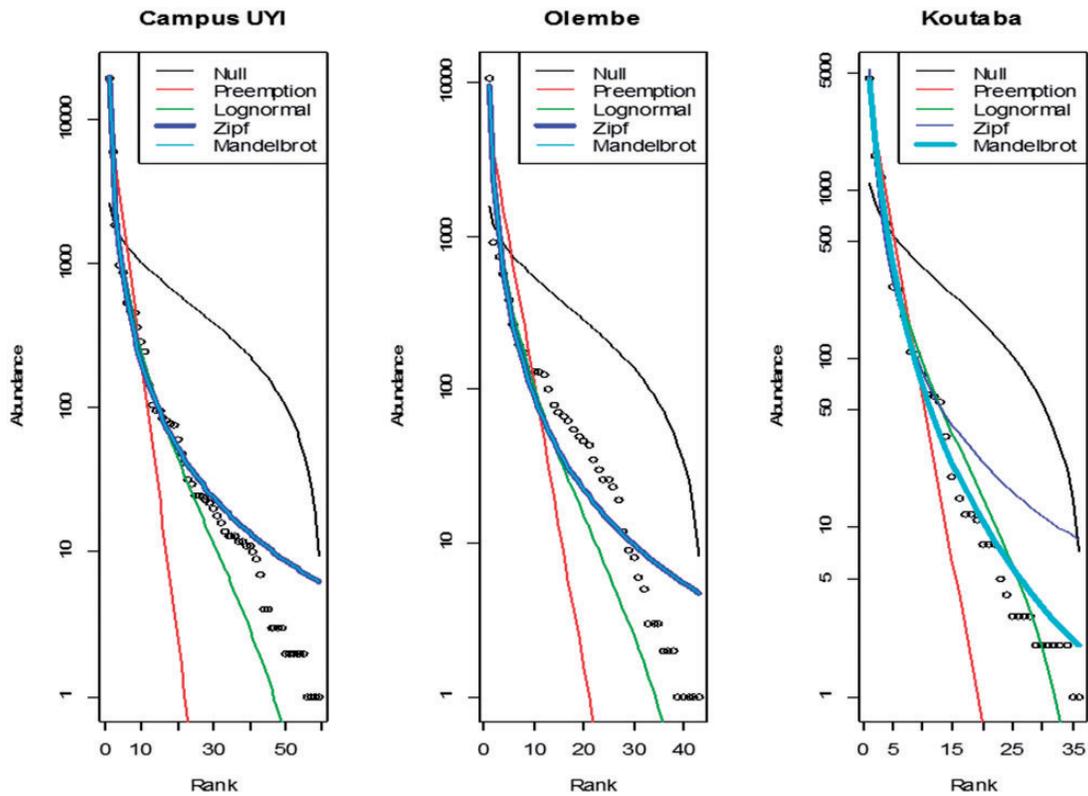


Fig. 7. SAD model of insect species associated with fruits of eight cultivated cucurbit species in three localities of Cameroon, from January 2009 to 2011.

Braconidae and Eulophidae are commonly cited as parasitoids of various crop pests (Huber 2009). Many parasitoid species are important in agriculture as agents of biological control (Wharton and Gilstrap 1983).

Community Characterization.

Sampling Effort. One important goal of sampling is the generation of a complete species list of a locality, along with an unbiased estimate of the abundance of each species (Longino and Colwell 1997). Statistical methods are widely used to estimate the asymptotic number of species present, including species not yet detected (Chao et al. 2009). Species richness estimators are based on the assumption that the observed species richness is lower than the true richness of the site (Colwell and Coddington 1994, Magurran 2004). In this study, six nonparametric estimators of species richness were used. The ratio of observed species richness to the average of abundance-based/sample-based species richness estimators revealed a powerful sampling effort higher than 92% in all cases.

Also, Gotelli and Colwell (2010) stated that the minimum number of samples needed for a representative sample in a specific habitat can be ascertained by graphing the curve of the number of species recorded as a function of the number of samples examined. These curves are based on the assumption that beyond a certain amount of effort, the species versus effort curve should reach an asymptote (Magurran 2004, Chao et al. 2005). That asymptote provides a reasonable estimate of the number of species present. Conventionally, the minimal sample size accepted for optimal sampling and efficient comparison of ecological communities is 20 samples (Agosti and Alonso 2000). In this study, SACs for each of the three localities were built on the base of, respectively, 32,981, 15,332, and 9,377 individuals per site, from 94, 47, and 21 samples per site. The saturation plateau was well established on all the three sites and indicated an acceptable quality of the sample in each site.

Species Richness and Diversity. The insect fauna associated with cucurbit fruits appeared to be species-rich in all the study sites. Based

on the values of Margalef's index, species richness was not significantly different between Olembe and Koutaba and, in both sites, was significantly lower than at the Campus. This finding indicates that the type of landscape, agricultural or urban, may have had a greater effect on species richness than the agroecological zone (unimodal vs. bimodal rainfall regime). Thus, species richness variation appeared more influenced by border effects than by climatic parameters. Based on values for Sorensen's index, composition of the studied communities at species level were dissimilar. As a result, no one community contains the same biodiversity as any of the others, even in rather homogeneous landscapes, due to site-specific characteristics of soil, topography, vegetation, weather, and other environmental factors that may govern each species settlement (Kim 2009).

Even though Koutaba appeared to be the most diverse of the three sites when considering the values of both Simpson and Shannon indices, evenness was low in each locality. An ecosystem exhibiting a low evenness is one in which a few sampled species dominate (Magurran 1988). In all the study sites, insect communities were dominated by the five most abundant species, which represent an average of >80% of the total abundance (89.0% on the Campus, 81.3% at Olembe, and 88.4% at Koutaba). These species governed diversity, productivity, and rates of energy or nutrient flux in fruit-based food webs. Also, the relatively short duration of availability of fruits as a resource (from infestation to complete decay) make them an unstable support. In market crop systems such as domesticated cucurbits, the above-demonstrated low diversity coupled with high densities of pest species heightens the need to implement management strategies that conserve beneficial species and the ecosystem services they provide.

Pattern of SADs. Any attempt to describe a complex community structure by one single attribute, such as richness or equitability, can be criticized because valuable information about community structure is lost (Begon et al. 2006). Based on the values from AIC, insect communities collected on the Campus and at Olembe are similar and followed

the Zipf–Mandelbrot model, while that of Koutaba followed the Mandelbrot model. The two models are closely related and constitute all the realistic models available for continuous data (Wilson et al. 1996), and provide a good statistical description of the structure and transformation of natural communities (Barangé and Campos 1991). The Zipf–Mandelbrot model supposes that there are specialist species, which cannot enter a community until generalist species have established (Frontier 1985). Also, the models postulate a rigid sequence of colonists, with the same species always present at the same point in the succession in similar habitats (Magurran 2004). The result is a few abundant species, with many minor species of comparable abundance. In our system, *D. bivittatus* was the predominant species, occurring on 90 out of 94, 40 out of 47, and 17 out of 21 sampling days, respectively, in the three localities and followed in similar ways by the four other species. The establishment of a species in a community is dependent on prior changes. The presence of a species can be seen as depending on previous physical conditions and on the presence of previously arrived species. This is the case of *P. perproximus*, a parasitoid species of *Dacus* spp., which required prior degradation of fruits by its hosts. Observations of the abundance of insects and their potential natural enemies can also be used to discover which natural enemy species are important in reducing the numbers of particular insect pest species (Speight et al. 2008). To a lesser extent, saprophagous insects also appeared to be late successional species as their presence requires decaying of the fruits. He and Reed (2006) suggested that there is a general tendency that locally abundant species are more widely distributed in space than rare species, leading to a positive distribution–abundance (or occupancy–abundance) relationship. For instance, insect communities associated with cucurbit fruits appeared to be hierarchical and structured as a tritrophic network, including fruits, true fruit flies or saprophagous insects and parasitoids.

This study aimed to characterize the structure of insect communities associated with cucurbit fruits in three localities situated in two agro-ecological zones in the southern Cameroon. Based on components of α diversity, the insect communities studied appeared species-rich, with a high preponderance of five main species including four pest species and a parasitoid, and a great number of rare species (23 on the Campus, 17 at both Olembe and Koutaba). SADs that range from the Zipf–Mandelbrot model on the southern Plateau to the Mandelbrot model on the western Highlands are closely related models. Apart from *P. perproximus*, a main parasitoid of *Dacus* species, our study reveals the importance of other potential parasitoid species of fruit flies found at low abundance. Such species are typically neglected in most studies. Also, our results point to some complexity in the composition and structure of insect communities associated with market crops and to the need to implement sustainable pest management strategies that preserve ecosystem integrity and services.

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