

Original Research Article

Abundance and diversity of insects associated with citrus orchards in two different agroecological zones of Ghana

ABSTRACT

The abundance and diversity of entomofauna in two citrus orchards in the Semi-Deciduous Rain Forest and the Coastal Savannah agro-ecological zones of Ghana were investigated. To manage natural resources and restore disturbed habitats or conserve valuable species of concern, the biodiversity of insect species of specific areas or target habitats needs to be assessed, however, in Ghana, research of this nature serving as a baseline data for future studies is generally lacking in citrus plantations. The objectives of the study were to identify and generate a list of entomofauna in citrus orchards and to compare the relative abundance and diversity of insect species in the two different agroecological zones. Malaise traps, flight interception traps, pitfall traps, chemical "knock down" and visual observations were used for data collection. A total of 20,285 individual insects belonging to 387 species from 107 families and 13 orders were recorded. Several species of insects were common to both agro-ecological zones but some were specific to citrus orchards of a particular agroecological zone. Diversity indices such as Shannon-Wiener index, Pielou's evenness, Simpson's dominance index, Margalef index and Equitability index were higher in the Coastal Savannah zone than the Semi-Deciduous Rainforest zone. *Oecophylla longinoda* Latreille was the most dominant insect species in each agro-ecological zone, however, they were more abundant in the Semi-Deciduous Rainforest than the Coastal Savannah zone. To conserve insect biodiversity in citrus orchards, this study recommends that management tactics which have less or no negative effects on natural enemies, pollinators among others but can effectively suppress insect pest populations (such as the use of biological control agents, restriction of herbicides and pesticides) should be adopted. This study has also provided a first comprehensive inventory of insect species associated with citrus agroecosystems for future studies and may also serve as a useful foundation for exploring integrated pest management for citrus production in Ghana.

Keywords: *Insect diversity, abundance, integrated pest management, Oecophylla longinoda, citrus*

1. INTRODUCTION

Insects constitute the most dominant component of terrestrial and freshwater biodiversity in terms of species richness, animal biomass and critical ecological functions [1]. They have invaded every niche, except the oceanic benthic zone [2]. Estimates of species richness of insects have been reported to vary from 2 millions to as many as 50 millions [3]. Insects are very sensitive to human-mediated disturbances, habitat loss, pollution and climate change, and because of their sensitivity several insect taxa are used as indicators of global change [4]. The majority of insects on earth are important to humans: a few are harmful such as agriculture pests and disease vectors whereas others are beneficial such as decomposers, seed dispersers, pollinators and natural enemies of pests [5].

Pesticides are used in conventional farming to suppress pest populations below economic threshold levels and research has shown that more arthropod taxa were found in non-sprayed fields together with greater numbers of predators such as Coccinellids than in fields treated with broad-spectrum insecticides and herbicides [6]. Reduction in bumblebee and butterflies has been observed in farms with higher pesticides application than those with no or lower pesticide application [7]. In Ghana, control of major pests of citrus relies on pesticides application [8] and herbicides

application is one of the weed management practices adopted by farmers in Ghana [9]. These herbicides do not only deprive insects of their source of food but also directly kill them.

After citrus establishment, insect species colonize and over time progressively increase in diversity and abundance. Insects which were previously considered as minor pests are emerging as key pests in many agroecosystems. There is also evidence that honeybees and other pollinators, such as flies, butterflies and major bioindicators such as ants and beetles are in decline across the globe [10]. Anthropogenic climate change threats to insect biodiversity are global. The quickened rate of environmental deterioration could lead to a loss of whole taxonomic groups. In Ghana, [12] reported on annotated list of insects associated with citrus plantation at Kade in the Semi-deciduous rainforest zone, however, knowledge of diversity and abundance of insects associated with citrus agroecosystem in two different agroecological zones is poorly understood.

To manage natural resources, restore disturbed habitats or conserve valuable species of concern, the biodiversity of insects of specific areas or target habitats needs to be assessed and this requires a comprehensive but efficient inventory of the organisms and perhaps their role in the ecosystem [13]. This underscores the critical necessity of this biodiversity studies to gain an in-depth knowledge of insects associated with citrus agroecosystem to help implement measures that ensure the conservation of biodiversity and the maintenance of agriculture lands to enhance agriculture productivity and sustainability in Ghana.

2. MATERIALS AND METHODS

2.1 Sampling zone

The research was conducted in citrus orchards (monoculture) in the Semi-Deciduous Rain Forest and Coastal Savannah agro-ecological zones. In both orchards, weed management was by the use of machetes, both farms were wholly organic and the citrus variety was Late Valencia. In the Semi-Deciduous Rain Forest zone, the research was carried out in citrus plantation (CI. 25) of the Forest and Horticultural Crops Research Centre (FOHCREC) at Okumaning, Kade in the Kwaebibirem District of the Eastern Region of Ghana. This area experiences an annual bimodal rainfall pattern ranging between 1200-1300mm, temperature range of 25-38°C [14]. The Global Positioning System coordinates of the site were N 06° 09.473', W 000 54.550' and E: 552ft. The orchard was established 20 years ago with a triangular planting distance of 6m x 6m. The vegetation in the study site consisted mainly of *Panicum maximum* and *Pueraria phaseoloides*. In the Coastal Savannah zone, the research was carried out in a farmer's plot at Asuansi Agriculture Research Station in the Abura/Aseibu/Kwamankesse District of the Central Region of Ghana. The area experiences a mean annual rainfall of 980mm and the rainfall pattern follows the bimodal distribution. Mean monthly temperature is about 26.90°C (Ministry of Food and Agriculture 2013) and the Global Positioning System coordinates of the study site were N 05° 18.654', W 001° 15.667' and E: 363ft. The citrus orchard was established 15 years ago with a triangular planting distance of 7m x 7m. The predominant vegetation of the study area consisted mainly of *Chromolaena odorata* and *Panicum maximum*.

2.2 Insect collection

The study was carried out from September 2013 to March 2014. There were eleven main sampling methods used for the insect collection. Sweep nets were used to sweep the topmost part of the vegetation of the understory to collect vegetation-dwelling insects; Aerial nets were used for flying insects such as dragonflies, butterflies and members belonging to the family Cetoniidae; at each agro-ecological zone, 10 pitfall traps were randomly set to collect ground crawling insects at; 10 coloured pan traps (yellow, blue and orange) were randomly set to collect insects which are attracted to a particular colour; and 5 yellow sticky traps were to collect flying insects. One malaise trap was set at each zone to collect mainly

flying nocturnal insects; one flight interception trap was used for both ground crawling insects and flying insects by intercepting their flights. Hand picking was used for collecting specifically slow moving insects and those which play dead when the vegetation is disturbed. Chemical knockdown was used to collect insects in the canopy of the citrus tree: 10 trees were randomly selected during each sampling and sprayed with CYDIM super (an emulsifiable concentrate containing 36g cypermethrin and 400g dimethoate active ingredient/L) at a rate of 120ml insecticide/ha using a motorized mist blower early in the morning between 6:00-10:00 am. Pieces of vinyl sheets measuring 2.8m × 8m were placed beneath the selected trees to collect any insects that fell from the trees during and after spraying.

2.3 Identification of insects

Insects collected were preserved in 70% ethanol, sorted, identified to the lowest taxonomic rank possible and counted. Identification of insects was done with reference to collection in the museum of the Department of Animal Biology and Conservation Science (DBCS), University of Ghana, as well as with reference to Gullan and Cranston [15],[16];[17];[18]; [19]; [20]; [21]. Dr. Maxwell K. Billah of DABCS helped in the identification of the fruit flies. The voucher specimens were deposited at the African Regional Postgraduate Programme in Insect Science (ARPPIS), West African Sub-Regional Centre.

2.4 Data analysis

Shannon-Weiner diversity index (H'), Margalef, Brillouin index, the Simpson dominance index (C) Evenness, and Equitability index were computed using Past 3.01. To check the completeness of inventory in the orchards, EstimateS (version 9.1.0) was used. The insects were put into four different functional groups; pollinators, predators, pests and others (insects whose status are unknown).

3. RESULTS

A total of 20,285 individual insects belonging to 387 species from 107 families and 13 orders were identified (Table 1). The total number of entomofauna in the Semi-Deciduous Rain Forest zone was higher than that in the Coastal Savannah zone. 11646 individual insects belonging to 265 species were recorded in the Semi-Deciduous Rain Forest zone compared to 8639 insects from 246 species in the Coastal Savannah zone. Figure 1 show some insects sampled during the study period.

103 **Table 1. List of the insect morphospecies and the higher taxonomic ranks of the voucher specimens collected in Semi-deciduous Rain**
 104 **Forest zone (SD) and Coastal Savannah zone (CS) of Ghana**

Order	Family	Morphospecies	SD	CS	Economic Status
Coleoptera	Scarabaeidae	<i>Madateuchus viettei</i>	0	0	others
		<i>Scarabaeus viettei</i> Paulian	1	19	others
		<i>Scarabaeus</i> sp.	2	3	others
		<i>Caccobius schreberi</i> L.	0	1	others
		<i>Onthophagus loalien</i>	0	6	others
		<i>Onthophagus</i> sp.	2	1	others
		<i>Pseudohammus nyrmelonum</i>	0	5	others
		<i>Copris</i> sp.	2	9	others
		<i>Caccobius kelleri</i>	0	3	others
		<i>Alleucosma viridula</i> Kirby	0	5	others
	Cetoniidae	<i>Pachnoda abyssinica</i>	0	2	pest
		<i>Marmylida marginella</i> Fab.	5	2	pest
		<i>Thermophilum fornasini</i>	0	3	pest
		<i>Torynorrhina flammea</i>	0	3	pest
		<i>Caelorrhina barthi</i>	0	1	pest
		<i>Protaetia fusca</i>	0	3	pest
		<i>Pachnoda cordata</i> Dury	0	1	pest
		<i>Amara ovata</i>	1	6	predator
	Carabidae	<i>Scaphinotus angusticollis</i>	0	1	predator
		<i>Amara</i> sp.	2	0	predator
		<i>Amara</i> sp. 1	1	0	others
		<i>Anomala</i> sp.	0	5	predator
		<i>Tefflus mmegerui</i>	0	2	predator
		<i>Tefflus</i> sp.	0	4	predator
		<i>Harpalus caliginosus</i> Fab.	1	3	predator
		<i>Bembidion patrulele</i> Dejean	3	0	predator
		<i>Tetragonoderus deuvei</i>	4	0	predator
		<i>Tenebrio</i> sp.1	0	2	others
	Tenebrionidae	<i>Alphitobius</i> sp.	1	0	others
		<i>Tenebrio</i> sp. 2	12	0	others
		<i>Coelocnemis</i> sp.	0	1	others
		<i>Coelocnemis lucia</i> Doyen	1	15	others
		<i>Gonocephalum simplex</i> Fab.	0	10	others
		<i>Eleodes</i> sp.	21	12	others
		<i>Alobates pennsylvanicus</i> DeGeer	0	1	others

Chrysomelidae	<i>Chrysochus</i> sp.	0	4	others
	<i>Lilioceris</i> sp.	13	0	others
	<i>Lilioceris lili</i>	1	0	others
	<i>Ootheca mutabilis</i>	2	6	others
	<i>Cryptocephalus</i> sp.	0	2	others
	<i>Podagrica uniformis</i> Jac.	0	7	others
	<i>Sagara femorata</i> Drury	5	1	others
	<i>Sagra</i> sp.	4	0	others
	<i>Cassida</i> sp.	4	1	others
	<i>Cassida viridus</i>	4	2	others
	<i>Cassida rubiginosa</i>	1	0	others
	<i>Nsotra uniformis</i> Jac.	11	0	others
Cerambycidae	<i>Monochamus</i> sp.	0	7	pest
	<i>Adynata exilis</i> Borch	0	1	pest
	<i>Elaphidion</i> sp.	8	0	pest
Coccinellidae	<i>Henosepilachna</i>	0	36	predator
	<i>vigintioctopunctata</i>			
	<i>Exochomus</i> sp.	2	20	predator
	<i>Scymnus</i> sp.	0	5	predator
	<i>Chilocorus</i> sp.	0	5	predator
	<i>Cryptocephalus signaticeps</i>	2	0	predator
	<i>Cheilicomus</i> sp.	2	0	predator
	<i>Harmonia axyridis</i>	1	0	predator
	<i>Epilachna bifaciata</i>	1	0	predator
	<i>Epilachna</i> sp.	9	0	predator
Curculionidae	<i>Lixus</i> sp.	0	6	others
	<i>Bryochcta pusilla</i> Pasc.	3	0	others
	<i>Eloeidobius kamerunicus</i>	0	5	others
	<i>Sphenophorus maidis</i> Chittenden	0	1	others
Lagriidae	<i>Lagria hirta</i>	0	1	others
	<i>Lagria villosa</i> Fab.	14	6	others
	<i>Cereyonia citri</i>	2	2	others
	<i>Lagria</i> sp.	9	6	others
Lycidae	<i>Lycus</i> sp.	8	5	others
	<i>Calopteron terminale</i>	0	2	others
	<i>Lycus trabeatus</i>	11	3	others
Anobiidae	<i>Stegobium paniceum</i>	0	1	others
Lampyridae	<i>Aspisoma</i> sp.	0	2	others
Cucujidae	<i>Silvanus oblitus</i> Grouv	8	5	others
Byrrhidae	<i>Byrrhus fasciatus</i> Forster	0	2	others

Diptera	Trogostidae	<i>Phloeobius cordiger</i> Fahrs	0	2	others
	Cicindelidae	<i>Cicindela leng</i>	2	0	others
		<i>Cicindella</i> sp.	6	0	others
	Cleridae	<i>Necrobia</i> sp.	1	1	others
		<i>Necrobia rufibes</i> DeGeer	0	2	others
	Histeridae	<i>Saprinus felipae</i> Lewis	10	0	others
		<i>Saprinus</i> sp.	6	0	others
		<i>Spilodiscus biplagiatus</i> Le Conte	12	0	others
		<i>Platylomalus aequalis</i> Say	3	0	others
	Melolonthidae	<i>Maladera insanabilis</i> Brenske	10	1	others
		<i>Serica</i> sp.	8	0	others
		<i>Acanthosternum</i> sp.	0	1	others
		<i>Agrilus anxius</i> Gory	7	0	others
	Buprestidae	<i>Araecerus fasciculatus</i> Deg.	3	0	others
	Anthribidae	<i>Omosita colon</i> Linn.	7	0	others
	Nitidulidae	<i>Stenodontes</i> sp.	10	0	others
	Prionidae	<i>Cardiophorus</i> sp.	4	0	others
	Elateridae	<i>Ceratitis ditissima</i> Munro	10	210	pest
	Tephritidae	<i>Bactrocera invadens</i>	6	11	pest
		<i>Dacus</i> sp.	0	1	pest
		<i>Ceratitis cosyra</i> .	2	1	pest
		<i>Pterandus</i> sp.	1	0	pest
		<i>Evansomyia</i> sp.	1	5	others
		<i>Stenopogon</i> sp.	0	9	predator
	Asilidae	<i>Stichopogon</i> sp.	8	0	predator
		<i>Ommatius</i> sp.	0	8	predator
		<i>Laphria</i> sp.	2	0	predator
		<i>Machimus</i> sp.	2	0	predator
		<i>Promachus</i> sp.	25	0	predator
		<i>Eumerus</i> sp.	0	2	others
	Syrphidae	<i>Pseudodorus clavatus</i> Fab.	0	16	others
		<i>Melannostoma scalare</i> Fab.	2	0	others
		<i>Biblio albipennis</i> Say	2	1	others
	Bibionidae	<i>Drosophila melanogaster</i>	13	175	pest
	Drosophilidae	<i>Diopsis longicornis</i> Macquart	2	4	others
	Diospidae	<i>Diopsis</i> sp.	3	0	others
		<i>Sarcophaga</i> sp.	8	5	others
	Sarcophagidae	<i>Musca domestica</i> Linn.	3	18	others
	Muscidae	<i>Musca vicina</i> Macq.	3	0	others
		<i>Caliphora</i> sp.	2	6	others

Hymenoptera	Agromyzidae	<i>Lucilia sericata</i> Meigen	3	0	others
		<i>Lucilia</i> sp.	5	0	others
		<i>Melanagromyza similis</i> Lamb	3	10	others
		<i>Ramonda spathulata</i>	4	0	others
		<i>Bombylius</i> sp.	3	0	others
		<i>Mayetiola destructor</i> Say	8	0	others
		<i>Isodontia mexicana</i> Saussure	10	0	others
		<i>Ephutomorpha</i> sp.	2	2	others
		<i>Eumenes smithii</i>	4	4	parasitoid
		<i>Eumenes</i> sp.	4	0	parasitoid
	Vespidae	<i>Synagris anali</i>	2	11	parasitoid
		<i>Ropalidia cincta</i> Lepeletier	7	0	parasitoid
		<i>Synagris cornuta</i>	0	3	parasitoid
		<i>Polistes</i> sp.	11	0	parasitoid
		<i>Cremnops desertor</i> L.	3	16	parasitoid
		<i>Synagris</i> sp.	0	1	parasitoid
	Formicidae	<i>Oecophylla longinoda</i> Latri.	7598	4996	predator
		<i>Odontomachus haematoda</i> Linn.	54	109	predator
		<i>Messor babarus</i>	1	2	predator
		<i>Monomorium Pharaonis</i> Linn.	45	135	predator
		<i>Atopomyrmex cryptoceroides</i> Emery	0	85	predator
		<i>Camponotus pennsylvanicus</i>	0	15	predator
		<i>Odontomachus</i> sp.	46	55	predator
		<i>Messor</i> sp.	4	65	predator
		<i>Crematogaster peringueyi</i> Emery	1131	0	predator
		<i>Pachycondyla</i> sp.	9	11	predator
	Sphecidae	<i>Crematogaster</i> sp.	839	826	predator
		<i>Tetramorium</i> sp.	176	232	predator
		<i>Camponotus</i> sp.	23	94	predator
		<i>Phasmomyrmex aberrans</i> Bolton	5	0	predator
		<i>Polyrhachis sulcata</i> Bolton	2	5	predator
		<i>Ammophila</i> sp.	2	5	predator
		<i>Amophila insignis</i> Beauv	8	1	others
		<i>Echilanthus</i> sp.	1	0	others
		<i>Sphex pensylvanicus</i> Linn.	2	2	others
	Ichneumonidae	<i>Enisoscophilus</i> sp.	0	5	parasitoid
		<i>Lissonota</i> sp.	2	5	parasitoid
		<i>Echthrus</i> sp.	0	2	parasitoid
		<i>Ophia</i> sp.	10	8	parasitoid

Hemiptera	Apidae	<i>Anacis</i> sp.	0	2	parasitoid
		<i>Priocnemis conformis</i> Smith	0	1	parasitoid
		<i>Xylocopa</i> sp.	22	6	pollinator
		<i>Bombus hortorum</i> L.	0	11	pollinator
		<i>Xylocopa violacea</i> Linn.	22	6	pollinator
		<i>Xylocopa virginica</i> Linn.	3	0	pollinator
	Gasterulidae	<i>Gasteruption assectator</i>	4	0	others
	Braconidae	<i>Euphorius</i> sp.	1	0	parasitoid
		<i>Phanerotoma</i> sp.	0	12	parasitoid
		<i>Atanycolus</i> sp.	0	6	parasitoid
		<i>Capitorius</i> sp.	20	0	parasitoid
	Chalcididae	<i>Mesocomys pulchriceps</i> Cam	0	4	others
	Evanidae	<i>Evania appendigaster</i> L.	0	4	others
	Melipulidae	<i>Melipona</i> sp.	1	0	others
	Pompilidae	<i>Arachnosphill anceps</i> Gesson	2	0	others
	Coreidae	<i>Trachypompilus</i> sp.	3	0	others
		<i>Leptoglossus oppositus</i>	0	6	pest
		<i>Leptoglossus</i> sp.	76	7	pest
		<i>Acanthocephala</i> sp.	0	5	others
		<i>Hypselonotus</i> sp.	3	0	others
		<i>Homoeocerus pallens</i> F.	6	0	others
		<i>Homoeocerus</i> sp.	7	0	others
		<i>Pyrops</i> sp.	2	0	others
		<i>Leptocorisa acuta</i> Thumb	2	0	others
		<i>Spilostethus pandurus</i>	0	2	others
		<i>Oncopelta fasciatu</i>	0	2	others
		<i>Oncopelta</i> sp.	6	0	others
		<i>Mucanum</i> sp.	4	0	others
		<i>Rhyperochromus</i> sp.	0	2	others
	Lygaeidae	<i>Neacoryphus</i> sp.	3	0	others
		<i>Neacoryphus bicrucis</i> Say	3	0	others
		<i>Tropidothorax leucopterus</i>	0	6	others

	Goeze			
Pentatomidae	<i>Oebalus</i> sp.	0	2	others
	<i>Loxa flavicolis</i>	0	2	others
	<i>Halyomorpha halys</i>	6	8	others
	<i>Pentatoma rufipes</i> Linn	4	0	others
	<i>Euschistus heros</i>	1	4	others
	<i>Aspavia armigera</i> F.	1	5	others
	<i>Pentatoma</i> sp.	4	0	others
	<i>Aspavia albidomaculatus</i> Stall	5	1	others
	<i>Nezera viridula</i> Linn.	11	0	others
Saldidae	<i>Pentacora ligata</i> Say	0	15	others
Reduviidae	<i>Glymmatophora</i> sp.	21	10	others
	<i>Arilus</i> sp.	7	2	others
	<i>Saica</i> sp.	1	0	others
	<i>Zelus</i> sp.	1	0	others
	<i>Rhodius picipes</i>	2	0	others
	<i>Archilestidium</i> sp.	0	2	others
	<i>Rapida</i> sp.	0	1	others
	<i>Tropidothorax leucopterus</i>	0	5	others
	<i>Reduvius</i> sp.	0	2	others
	<i>Cydnocoris</i> sp.	0	5	others
	<i>Nagusta goedeli</i>	0	1	others
	<i>Stenopoda spinulosa</i>	4	0	others
	<i>Rhynocoris</i> sp.	4	0	others
	<i>Triatoma</i> sp.	6	0	others
Alydidae	<i>Ormenaria rufifascia</i>	0	6	others
Pyrrhocoridae	<i>Dysdercus superstitionis</i>	9	3	others
	<i>Cenaesus distinguendus</i> Blote	0	12	others
	<i>Dysdercus</i> sp.	6	0	others
Alydidae	<i>Leptocoris acuta</i>	0	1	others
	<i>Alydus eurinus</i> Say	0	1	others
Cercopidae	<i>Neophlaenus</i> sp.	6	0	others
	<i>Poophilus costalis</i> Walker	1	31	others
	<i>Poophilus</i> sp.	2	4	others
	<i>Neophilaerius</i> sp.	6	0	others
	<i>Pylus grossus</i> L.	0	40	others
Membracidae	<i>Oxyrachis lamborni</i> Dist.	0	3	others
	<i>Oxirachis</i> sp.	1	0	others
	<i>Gargara</i> sp.	2	1	others
Corixidae	<i>Hesperocoris</i> sp.	1	0	others

Lepidoptera	Aphididae	<i>Aphis gossypii</i> Glover	32	8	pest
		<i>Toxoptera citricidus</i> Fitch	19	105	pest
		<i>Aphis maidens</i> Fitch	6	0	pest
		<i>Toxoptera aurantii</i> Boyer	12	88	pest
	Aradidae	<i>Aradius acutus</i> Say	0	10	others
		<i>Protenor</i> sp.	0	7	others
	Gerridae	<i>Gerris remigis</i> Say	2	0	others
	Issidae	<i>Dieuches armipes</i> Fab.	19	105	others
	Cydnidae	<i>Sehirus cinctus</i> Palisot de Beauvois	6	0	others
		<i>Pangaeus bilimeatus</i> Say	4	0	others
	Miridae	<i>Brycoropsis laticollis</i> Schum	0	10	others
		<i>Miridae</i> sp	1	0	others
		<i>Chamus boxi</i> China	5	0	others
	Psyllidae	<i>Mesohomotoma tessmani</i> (Allum)	6	0	others
		<i>Ricanidae</i> sp.	0	2	others
	Naucoridae	<i>Ambrysus</i> sp.	0	6	others
	Scuteridae	<i>Diolcus</i> sp	12	0	others
	Berytidae	<i>Jalysus spinosus</i> Say	8	0	others
	Cicadidae	<i>Cicada orni</i> Boulard	0	6	others
	Dictyopharidae	<i>Taosa</i> sp.	0	3	others
	Coccidae	<i>Lepidosaphes beckii</i> Newn	45	51	pest
		<i>Planococcus citri</i> Risso	2	6	pest
	Danaidae	<i>Amauris</i> sp.	0	2	others
		<i>Danaus chrysippus</i> Linn.	11	5	others
		<i>Hypolimnas misippus</i>	2	0	others
		<i>Amauris niavius</i>	7	2	others
		<i>Amauris albimaculata</i>	0	1	others
		<i>Acraea</i> sp. 1	4	4	others
	Acraeidae	<i>Acraea</i> sp. 2	0	2	others
		<i>Acraea pentopolis</i> Ward	0	16	others
		<i>Acraea ancedon</i>	5	0	others
		<i>Acraea perenna</i>	2	0	others
		<i>Acraea alciope</i>	7	0	others
		<i>Calaenorrhinus galenus</i>	3	2	others
	Hesperiidae	<i>Pyrrhochelcia iphis</i>	2	0	others
		<i>Pyrrhochalcia iphis</i> Drury	0	3	others
	Zygaenidae	<i>Zygaena</i> sp.	0	3	others

	<i>Zygaena ephieltes</i>	2	3	others
	<i>Zygaena</i> sp 1	1	0	others
	<i>Zygaena</i> sp 2	2	0	others
Noctuidae	<i>Achaea</i> sp.	98	28	pest
	<i>Achaea obvia</i> Hmps	0	1	pest
	<i>Anomis leona</i> Schaus	10	3	others
	<i>Ammalo insulata</i>	0	2	others
Papilionidae	<i>Papilio demodocus</i> Linn.	21	9	others
	<i>Papilio cynorta</i>	2	1	others
	<i>Papilio nireus</i>	1	1	others
	<i>Papilio dardanus</i>	0	3	others
	<i>Papilio conorta</i>	2	1	others
	<i>Papilio menestheus</i>	0	1	others
	<i>Pentila pauli</i> Staudinger	1	0	others
Nymphalidae	<i>Acraea johnstoni</i>	0	1	others
	<i>Eurytela dryopa</i> Edwards	3	0	others
	<i>Hypolimnas debius</i> Linn.	3	0	others
	<i>Hypolimnas misippus</i> Linn.	7	0	others
	<i>Byblia anvatarata</i> R&J	2	13	others
	<i>Byblia anvatarata</i> Boisd	4	0	others
	<i>Precis pelarga</i> F.	6	2	others
	<i>Salamis temora</i>	0	1	others
	<i>Junonia oenone</i>	14	2	others
	<i>Psuedoacraea</i> sp.	0	3	others
	<i>Mylanitis leda</i>	0	1	others
	<i>Bermastistes epaea</i>	2	2	others
	<i>Achroia</i> sp.	0	1	others
	<i>Neptis laefa</i> Moore	3	0	others
	<i>Neptis laeta</i> Oliv.	0	1	others
	<i>Bicyclus xeneas</i>	2	3	others
	<i>Erytela</i> sp.	1	0	others
Arctidae	<i>Arctidae</i> sp.	0	5	others
	<i>Zale minera</i>	5	0	others
	<i>Spilosoma mundata</i> Walker	0	5	others
Pieridae	<i>Dixela doxo</i>	0	1	others
	<i>Colotis ovagore</i> Klug	1	7	others
	<i>Eurema briggita</i> Stoll	9	1	others
	<i>Mylothris poppea</i> Cr.	1	0	others

Orthoptera	Satyridae	<i>Achiroia</i> sp.	0	1	others
		<i>Mylothris chloris</i> Fab.	1	3	others
		<i>Eurema hecabe</i> Linn.	4	3	others
		<i>Colotis evippe</i> Butler	2	5	others
		<i>Bicyclus safitza</i> Hew	5	2	others
		<i>Melanis leda</i> Linn.	1	0	others
		<i>Bicyclus hewitson</i>	1	0	others
		<i>Pyralia</i> sp.	2	0	others
	Pyralidae	<i>Homophylotis catori</i> Jord.	7	0	others
	Tinieidae	<i>Ptilobola inornatella</i> Wals	2	0	others
	Gracillariidae	<i>Phyllocnistis citrella</i> Stainto	0	1	pest
	Saturniidae	<i>Eacles imperialis</i> Dury	0	3	others
	Gryllidae	<i>Gryllus lucens</i> Walker	28	24	others
	Tettigonidae	<i>Gryllus pensylvanicus</i>	0	2	others
		<i>Oecanthus nigricornis</i>	1	5	others
		<i>Oecanthus</i> sp.	10	1	others
		<i>Gryllus</i> sp.	5	1	others
		<i>Gymnogryllus lucens</i> Walker	6	0	others
		<i>Atlanticus gibbosus</i>	0	1	others
		<i>Orophus</i> sp.	5	1	others
		<i>Hyperhomala woodfordi</i> Kirby	0	5	others
		<i>Pterophylla camelifora</i> Fab.	32	8	others
		<i>Conocephalus brevipennis</i>	9	2	others
		Scudder			
		<i>Tetrix undulata</i> (Sow)	6	3	others
		<i>Tetrix</i> sp.	10	0	others
		<i>Tettigonia viridissima</i> Linn	4	0	others
		<i>Arantia rectifolia</i>	0	8	others
		<i>Metrioptera roeselii</i> Hagen	2	0	others
		<i>Conocephalus brevipennis</i>	0	1	others
		<i>Neoconocephalus ensiger</i>	0	1	others
		<i>Zabalus lineolatus</i> Stall	6	0	others
		<i>Scudderia furcata</i> Bruner	1	3	others
	Acrididae	<i>Mustius seralatus</i> Bolivar	1	0	others
		<i>Neduba carinata</i>	0	1	others
		<i>Froggaltina</i> sp	0	1	others
		<i>Schistocerca</i> sp.	6	1	others
		<i>Schistocerca cancellata</i>	0	1	others
		<i>Acrida</i> sp.	12	17	others
		<i>Acrida conica</i>	0	2	others

Odonata	Pyrgomorphidae	<i>Melanoplus</i> sp.	5	0	others
		<i>Acanthacris ruficornis</i> Fab.	10	2	others
		<i>Locusta migratoria</i>	0	3	pest
		<i>Abisare viridipennis</i>	3	6	others
		<i>Schistocera albolineata</i>	11	3	others
		<i>Melanoplus femurrubrum</i>	2	0	others
		<i>Heteracris littoralis</i> Rambur	26	2	others
		<i>Gymmobothrus subparallelus</i>	4	0	others
		<i>Zonocerus variegatus</i> Linn.	119	104	pest
		<i>Taphronota</i> sp.	0	9	others
	Tetrigidae	<i>Attractomorpha similis</i> Bolivar	7	0	others
		<i>Aractomorpha</i> sp.	1	0	others
		<i>Tetrix areuosa</i> Burmeister	5	0	others
		<i>Pantelia horrenda</i> Walker	0	4	others
	Catantopidae	<i>Tetrix undulate</i> (Sow)	0	4	others
		<i>Heteracris littoralis</i> Rambur	3	0	others
		<i>Anacidium</i> sp.	2	0	others
	Raphidophoridae	<i>Catantops</i> sp.	13	0	others
		<i>Acheta domesticus</i>	3	0	others
		<i>Ceuthophilus maculatus</i> Harris	0	7	others
	Libellulidae	<i>Centhophilus</i> sp.	2	11	others
		<i>Neurothermis</i> sp.	3	2	predator
		<i>Sympetrum corruptum</i>	2	3	predator
		<i>Diplecodes lifebvri</i> Rambur	2	3	predator
		<i>Sympathrum obstrusum</i> (Hagen)	5	0	predator
		<i>Gomphus militaris</i>	3	0	predator
		<i>Plathemis lydia</i>	1	0	predator
		<i>Platheris</i> sp.	3	0	predator
		<i>Libellula quadrimaculata</i> Linn.	3	0	predator
		<i>Erythrodiplax umbrata</i>	2	0	predator
		<i>Brechmorhoga</i> sp.	4	0	predator
		Aeshnidae <i>Anax</i> sp.	1	1	others
		<i>Anax junius</i>	3	0	others
	Coenogronidae	<i>Argia apicalis</i> Hagen	3	0	others
		<i>Agriocnemis fomina fermina</i>	6	5	others
		Brauer			
Dictyoptera	Blattidae	<i>Blatta orientalis</i> (Linn.)	8	14	others
		<i>Blattella germanica</i> Linn.	16	23	others
		<i>Blatteria germinica</i> Linn.	2	4	others
	Mantidae	<i>Mantis religiosa</i> Linn	13	12	predator

Isoptera	Termitidae	<i>Sphodromantis</i> sp.	17	1	predator
		<i>Macrotermes</i> sp.	50	22	pest
		<i>Microtermis</i> sp.	12	23	pest
Psocoptera	Psyllipsocidae	<i>Psyllipsococcus ramburi</i>	0	48	others
Neuroptera	Myrmeleontidae	<i>Brachynemerus abdominalis</i>	3	1	pest
		<i>Brachynemusus sackeni</i> Hagen	2	3	others
Dermaptera	Forficulidae	<i>Forficula auricularia</i> Linn.	2	15	others
		<i>Doru aculeatum</i> (Scudder)	2	3	others
Thysanura	Lapismatidae	<i>Lapisma saccharina</i>	5	93	others

Figure 1. shows some insects collected during the sampling period.



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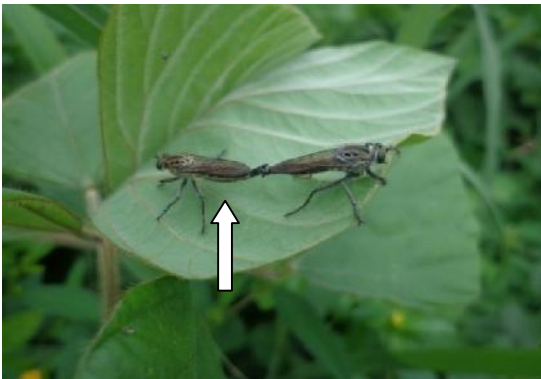


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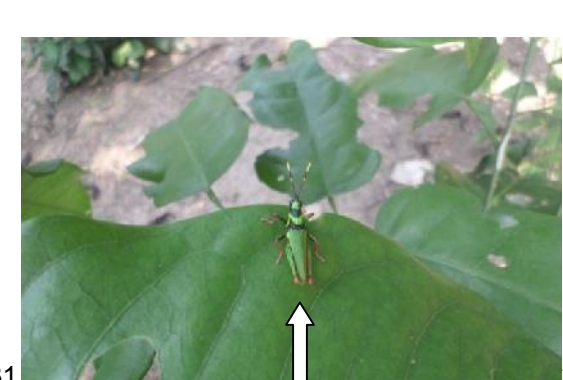


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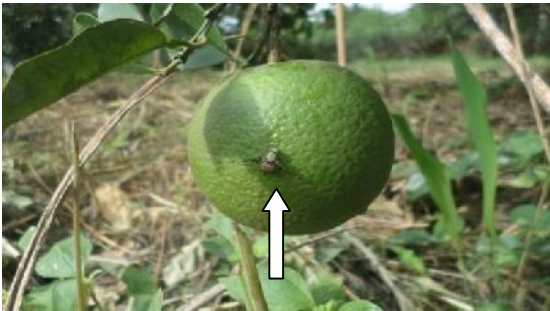


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143 Figure 4 (1-45) *Ophion leteus* (1), *Brachon* sp. (2) *Mantis religiosa* (3) *Sphodromantis* sp. (4),
 144 *Z. variegatus* (5), *Celaenorrhinus galenus* (6), *Homocerus pallens* (7), *Alydus eurinus* (8),
 145 *Promachus* sp. (9), *Halyomorpha halys* (10), Dragonfly (11), *Acraea* sp. (12), Green lacewing
 146 (13), *Zygaena* sp. (14), *Dysdercus* sp. (15) *Mylothris* sp. (16) *Tropidothorax leucopterus* (17),
 147 *Lagria villosa* (18), *Rhagonycha fulva* (19), *Lixus* sp. (20), *Lilioceris lillii* (21), *Diopsis*
 148 *longicornis* (22), *Promachus* sp. (23), *Epilachna bifasciata* (24) *Marmylida marginella* (25),
 149 *Acrida conica* (26), *Orophus* sp. (27), *Lycus trabeatus* (28), *Sagra femorata* (29), *Oecophylla*
 150 *longinoda* (30) *Drosophilla melanogaster* (31), *Taphronota* sp. (32) *Laphria* sp. (33),
 151 *Sarcophaga* sp. (34), *Ceratitis ditissima* (35), *Cicada* sp. (36), *Polyrhachis sulcata* (37),
 152 *Coelocnemis lucia* (38), *Tefflus* sp. (39), *Leptoglossus* sp. (40) *Blatella germinica* (41),
 153 *Glymmatophora* sp.(42), *Cerambycidae* sp.(43), *Pterophylla camellifolia* (44), *Madateuchus*
 154 *viettei* (45).

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156 The percentage relative abundance of the entomofauna families collected from citrus orchards in both zones is given in Figure 2. In the Semi-
 157 Deciduous Rain Forest zone, the four most dominant orders were Hymenoptera (86.34%), Hemiptera (3.48%), Orthoptera (3.12%) and Coleoptera
 158 (2.34%) whereas Hymenoptera (77.12%), Hemiptera (5.96%), Diptera (5.56%) and Coleoptera (3.15%) were the four most dominant orders in the
 159 Coastal Savannah zone (Figure 1). *O. longinoda* was the most abundant species recorded in both agro-ecological zones, recording 7598 (65%)
 160 and 4996 (58%) individuals for the Semi-Deciduous Rain Forest and Coastal Savannah zones respectively.

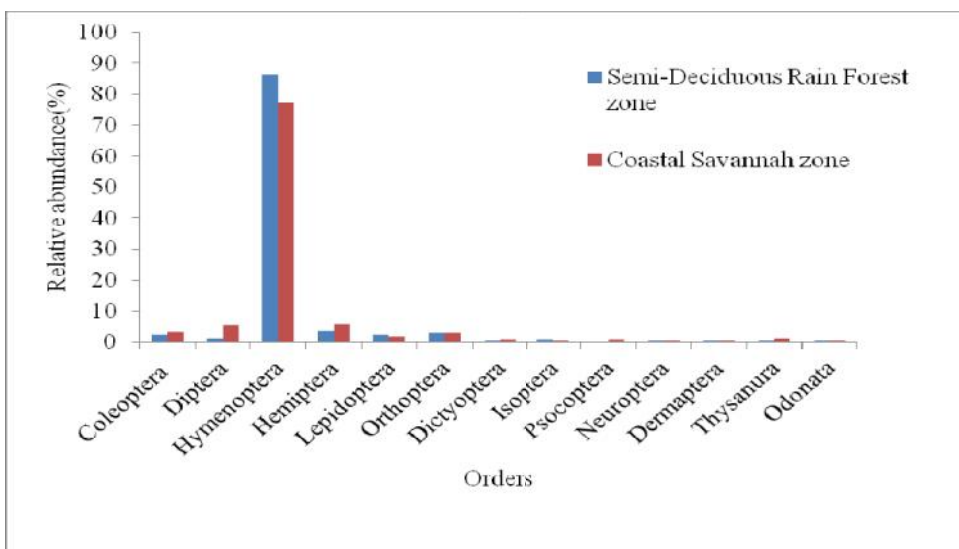


Figure 2. Relative abundance of insect orders recorded in the study

The community indices, specifically Shannon-Wiener (H'), Margalef (d), Brillouin index, Species richness (C), Dominance, Pielou's evenness, Simpson's dominance, Equitability were calculated for the wet season (September-November) and the dry season (January-March) in each agro-ecological zone (Table 2) as well as the two agro-ecological zones (Table 2). In the wet season, the results show that Species richness ($S=12$), Margalef ($d=1.341$) and Shannon-Wiener diversity ($H'=1.011$) were higher in the Coastal Savannah zone than in the Semi-Deciduous Rain Forest zone. Species richness ($S=13$), Margalef ($d=1.429$) and Shannon-Wiener diversity ($H'=0.8613$) were also higher in the Coastal Savannah zone in the dry season than the Semi-Deciduous-Rain Forest zone. Evenness of species was relatively low for both agro-ecological zones in both seasons (Table 2). The results show that all the diversity indices were higher in the Coastal Savannah zone than those in the Semi-Deciduous Rain Forest zone (Table 3).

198 Table 2: Diversity indices of the entomofauna for the wet (September-November) and dry (January-March) seasons in the Semi-Deciduous Rain
199 Forest and the Coastal Savannah agro-ecological zones of Ghana.

Diversity indices	Semi-Deciduous Rain Forest/Wet	Coastal Savannah/Wet	Semi- Deciduous Rain Forest/ Dry	Coastal Savannah/Dry
Simpson, 1-D	0.236	0.4128	0.2442	0.3517
Shannon, H'	0.6086	1.011	0.6309	0.8613
Evenness	0.1671	0.229	0.1566	0.182
Brillouin	0.6031	1.003	0.6259	0.8541
Margalef, d	1.184	1.341	1.28	1.429
Equitability, J	0.2538	0.4068	0.2539	0.3358

200
201 Table 3: Diversity indices of the entomofauna in the Semi-Deciduous Rain Forest
202 and Coastal Savannah agro-ecological zones of Ghana.

Diversity indices	Semi-Deciduous Rain Forest	Coastal Savannah
Simpson, 1-D	0.251	0.396
Shannon, H'	0.651	0.987
Evenness	0.160	0.204
Brillouin	0.648	0.983
Margalef, d	1.175	1.327
Equitability_J	0.262	0.385

203
204 Estimated species richness of insects captured using Incidence-based estimator (Chao 1), Abundance-based estimator (Chao 2), First-order
205 jackknife estimator (Jack 1), Second-order jackknife estimator (Jack 2), Abundance-based coverage Estimator (ACE) and Incidence-based
206 coverage Estimator (ICE) per zone were shown in the species accumulation curves for the Semi-Deciduous Rain Forest zone and Coastal
207 Savannah zone respectively. In both Semi-Deciduous Rain Forest and Coastal Savannah zones, the species accumulation curves were clearly
208 approaching an asymptote showing that species saturation had been reached and sampling effort was adequate (Figure 3 and 4).
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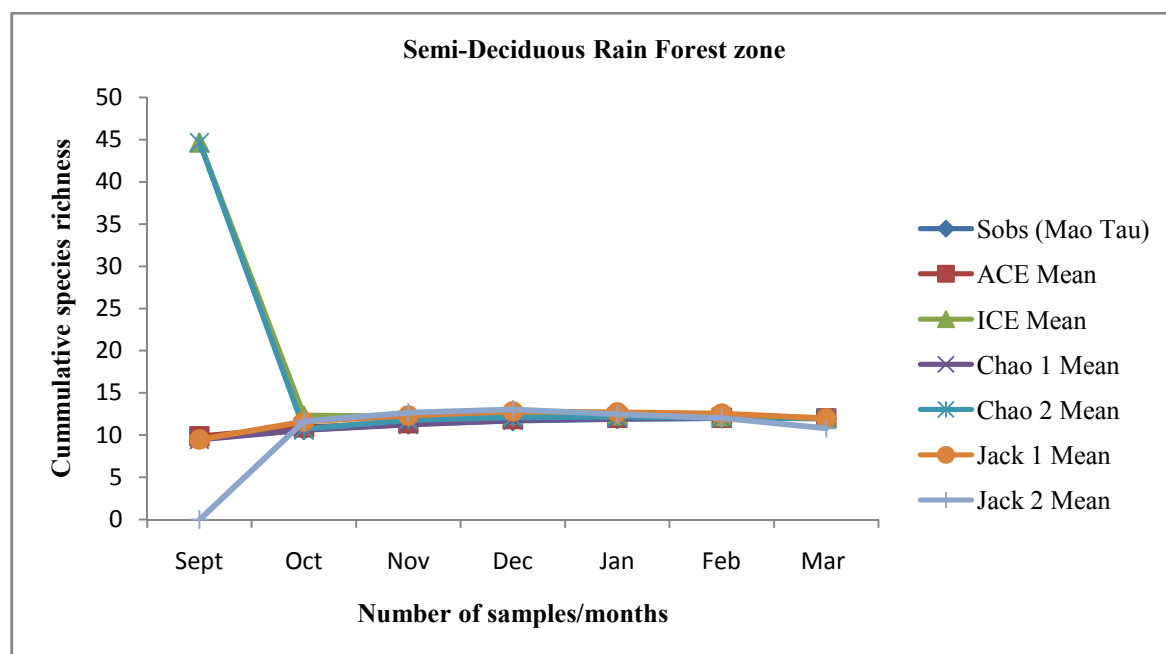


Figure 3. Species accumulation curve for entomofauna associated with citrus orchard in the Semi-Deciduous Rain Forest zone and its species richness estimators. Average species richness is based on 50 randomizations [22].

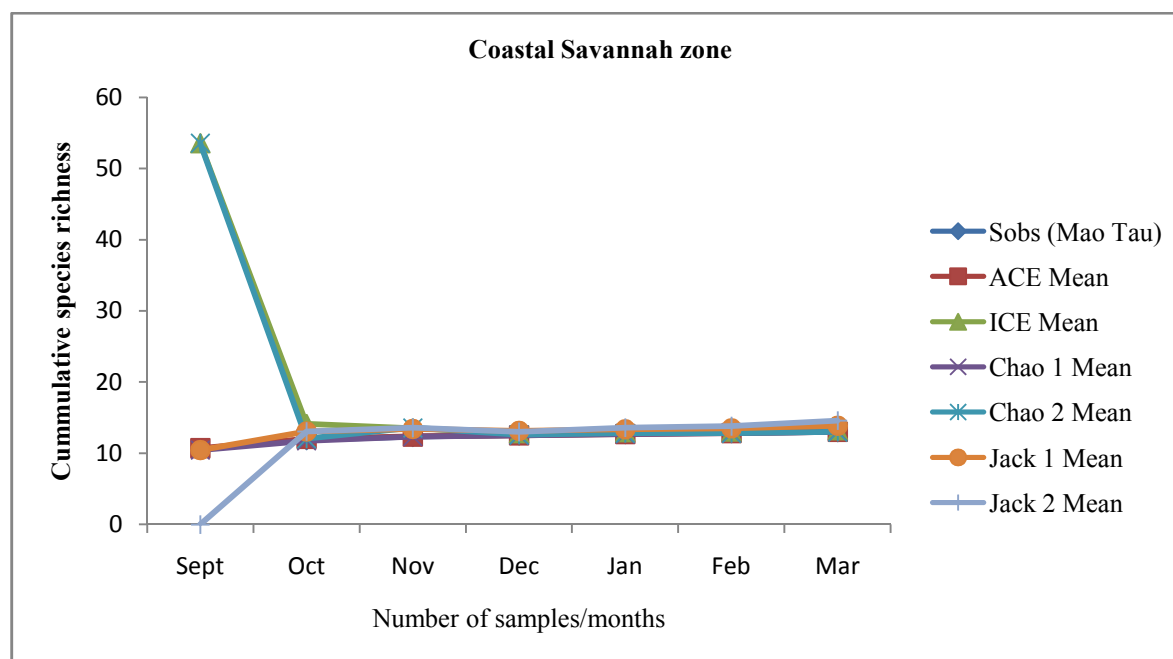


Figure 4. Species accumulation curve for entomofauna associated with citrus orchard in the Coastal Savannah zone and its species richness estimators. Average species richness is based on 50 randomizations [22].

4. DISCUSSION

A total of 387 species of insects was collected in the present study. The number of insect species found in this present study shows that citrus agroecosystem provides refugium for a plethora of many insect species in Ghana. The current study reports 387 insects compared to 123 insect species that was earlier reported [12]. This could be probably attributed to the number of locations, management regimes, sampling techniques and sampling effort in the different studies. This, however, provides the first comprehensive inventory of insects associated with citrus plantations with increasing sampling effort in Ghana.

O. longinoda was found to be the most abundant insect species in each agro-ecological zone. This confirms earlier findings of [23] who reported that Weaver ants (*O. longinoda*) tend to be common over most of their ranges. He further noted that in many localities they are among the most abundant and ecologically dominant elements of the arboreal ant fauna. They were, however, more abundant in the Semi-Deciduous Rain Forest zone than in the Coastal Savannah zone, probably due to the age differences in the two orchards, citrus trees in the Semi-Deciduous Rain Forest zone being older than those in the Coastal Savannah zone. *O. longinoda* prefers older trees and trees with close canopies [24], [25]. Results in the present study are consistent with this earlier observation. The dominance of *O. longinoda* over other insect species could also be attributed to the abundance of honeydew-producing insect species such as citrus aphids (*Toxoptera aurantii*, *Toxoptera citricidus*, and *Aphis gossypii*), citrus scale insects *Lepidosaphes beckii* and citrus mealy bugs *Planococcus citri* [26], [27]. The higher number of *O. longinoda* in the

Semi-Deciduous Rain Forest zone indicates that citrus trees in this agro-ecological zone would be better protected from insect pests of citrus than those in the Coastal Savannah zone. It has been earlier noted by [28] that *O. longinoda* protects crops against insect pests, however, the abundance of *O. longinoda* could trigger an outbreak of honeydew-producing hemipterans [29] which are not only pests but also transmit plant pathogens [30]. It was also earlier reported that the association between ants and pests such as aphids and scale insects protect *O. longinoda* thereby increasing their abundance, damage and deterring predation by natural enemies [31].

The study shows that the diversity indices in the Semi-Deciduous Rain Forest zone were lower than those in the Coastal Savannah zone. Even though each citrus orchard had several common weeds, some weeds were specific to a particular citrus orchard. The differences could be responsible for variations in abundance and diversity of insect species in each orchard. Variation in the vegetation structure and richness of undergrowth indirectly influence the entomofaunal abundance and diversity [32]. This also confirms the findings of [33] who earlier reported that the structure of vegetation in different zones may influence the diversity of insects in a particular habitat. Similarly, all the diversity indices were higher in the dry season compared to the wet season. During the wet season from September-November there were no matured citrus fruits, therefore there were few insects in the orchards but during the dry season from January to March, the fruits were matured and ripened, hence there were more insects in the orchards. This could account for the higher diversity in the dry season than the wet season.

In the Semi-deciduous Rain Forest zone, it was observed that the abundance of predatory insects belonging to Formicidae (*Crematogaster* sp., *O. longinoda*, *Tetramorium* sp.) and Asilidae (*Promachus* sp., *Laphria* sp., *Stichnopogon* sp, *Machimus* sp.,) was more than those in the Coastal Savannah zone. This could also account for the low diversity of insects in the Semi-Deciduous Rain Forest zone. This had earlier been reported in several studies where the abundance of predators, parasitoids, and the prevalence of diseases are all involved in insect population control [34], [35].

5. CONCLUSION

The study has provided a species list of insects in citrus plantations in Ghana. The presence of 20,285 individual insects belonging to 387 species, 107 families and 13 orders indicates the importance of citrus plantations as a favourable habitat for insect species. This may provide a useful foundation for exploring the integrated production and pest management for citrus production. To conserve insect species in citrus orchards management tactics which have less or no negative effects on natural enemies, pollinators and other insects but can effectively suppress insect pest populations (use of biological control agents, restriction of herbicides and pesticides use) should be adopted.

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