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Records of Arthropod Species Sampled from Avocado Plant (*Persea americana* Mill) in Small-scale Agro-ecosystems at Taita Hills and Mount Kilimanjaro

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Abstract— *Avocado, Persea americana Mill, plays a central role in distribution of both beneficial and detrimental arthropods thereby influencing local species diversity in agro-ecosystems adjacent to Afromontane forests at Mount Kilimanjaro in North-eastern Tanzania and Taita Hills in South-eastern Kenya. However, little is known about arthropod species that inhabit avocado trees in the two study areas despite the fact that the crop forms the major part of agro-ecosystem in the East African highlands. A novel survey was, therefore, carried out for two years between August 2012 and July 2014 to establish arthropod species in avocado orchards along South-eastern slopes of both Mount Kilimanjaro and Taita Hills. A total of sixty one species of arthropods were recorded from the avocado crop through fruit observation and canopy sampling. The present arthropod checklist provides baseline knowledge for scientists in evaluating beneficial and pest status of each species inhabiting avocado plant in the East African agro-ecosystems.*

Keywords—Avocado, arthropods, East Africa, Mount Kilimanjaro, Taita Hills.

I. INTRODUCTION

Avocado, *Persea americana* Mill (Lauraceae), is an important crop in the world as it enhances both agro-forestry conservation concept and nutritional security (Griesbach, 2005; Bergh, 1992). The avocado trees thrives well in agro-ecosystems with relatively high altitude between 1000m a.s.l and 2600m a.s.l that receive average annual precipitation ranging from 120mm to 160mm and average temperature of 21^0C (Griesbach, 2005; Wasilwa *et al*., 2004; Whiley, 2002). Such ecosystems are located near indigenous forests with favourable agricultural conditions as exemplified by Afrotropical highlands at Mount Kilimanjaro and Taita Hills where avocado is the dominant fruit crop (Griesbach, 2005; Wasilwa *et al*., 2004). However, the potential land area available for avocado farming along slopes of Mount Kilimanjaro in North-eastern Tanzania and Taita Hills in South-eastern Kenya is shrinking as a result of ecological degradation (Conte, 2010) and human activities. The envisaged reduction of avocado orchards in these East African highlands will not only affect distribution of arthropod species but also livelihood of local farmers that depend on avocado fruits as a source of cash and nutritious food (Hemp, 2009).

Eight five percent of avocado production in Kenya and Tanzania is at small scale level with number of trees per farm varying from three to twelve where the crop is grown mainly for subsistence and local markets (Griesbach, 2005; Wasilwa *et al*., 2004). Unlike commercial plantations, the small-holder avocado cropping systems do not utilized modern-day agricultural technology leading to poor farming practices, possible increase in arthropod pests and reduction of related natural enemies (Ware *et al*., 2016; Ware *et al*., 2012; Mwatawala *et al*., 2009, Griesbach, 2005; Bale *et al*., 2002; Bergh, 1992). Moreover, there is limited information on arthropods inhabiting avocado crop in Kenya and Tanzania. This paper was, therefore, initiated to provide a checklist of arthropods sampled from different parts of avocado crop in farmlands at Mount Kilimanjaro and Taita

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Hills. Establishing checklist of arthropods inhabiting avocado plant in East Africa can furnish important baseline information on pest and beneficial status of each species

II. MATERIALS AND METHODS

2.1. Study areas

The study was carried out in avocado farmlands adjacent to East African montane forests at Mount Kilimanjaro in North-eastern Tanzania and Taita Hills in South-eastern Kenya (Fig 1a and b, respectively). Avocado crop is grown in the two study transects along altitudinal gradient from 900 to 2000m a.s.l. and form major part of agro-ecosystem in the region. Mount Kilimanjaro and Taita Hills are the first uppermost elevated montane forms inland from the Indian Ocean and these highlands are important catchment areas for surrounding lowland areas of Moshi and Voi in Tanzania and Kenya, respectively (Hemp 2006a; Hemp 2006b; Bytebier, 2001; Bennun & Njoroge, 1999). The two study areas; Taita Hills and Mount Kilimanjaro, are situated 90km apart and both are about 150km from Indian Ocean. Mount Kilimanjaro study area is located between 03^0 378`S, $37^0$ 450`E and 03^0 481`S, $37^0$ 456`E in North-eastern Tanzania (Fig 1a). Mean elevation of Mount Kilimanjaro study area is 1372.69m a.s.l, average annual rainfall was 107.83mm, an average annual temperature of 20.14ºC with a mean annual humidity of 78.97%. Taita Hills study area is located in South-eastern Kenya, 25km west of Voi town in the Taita-Taveta County between 03^0 481`S, $38^0$ 378`E and 03^0 402`S, $38^0$ 296`E (Fig 1b). Mean elevation of Taita Hills study area is 1397.02m a.s.l, average annual rainfall was 135.19mm; mean annual temperature was 19.56ºC with a mean annual humidity of 81.46%.

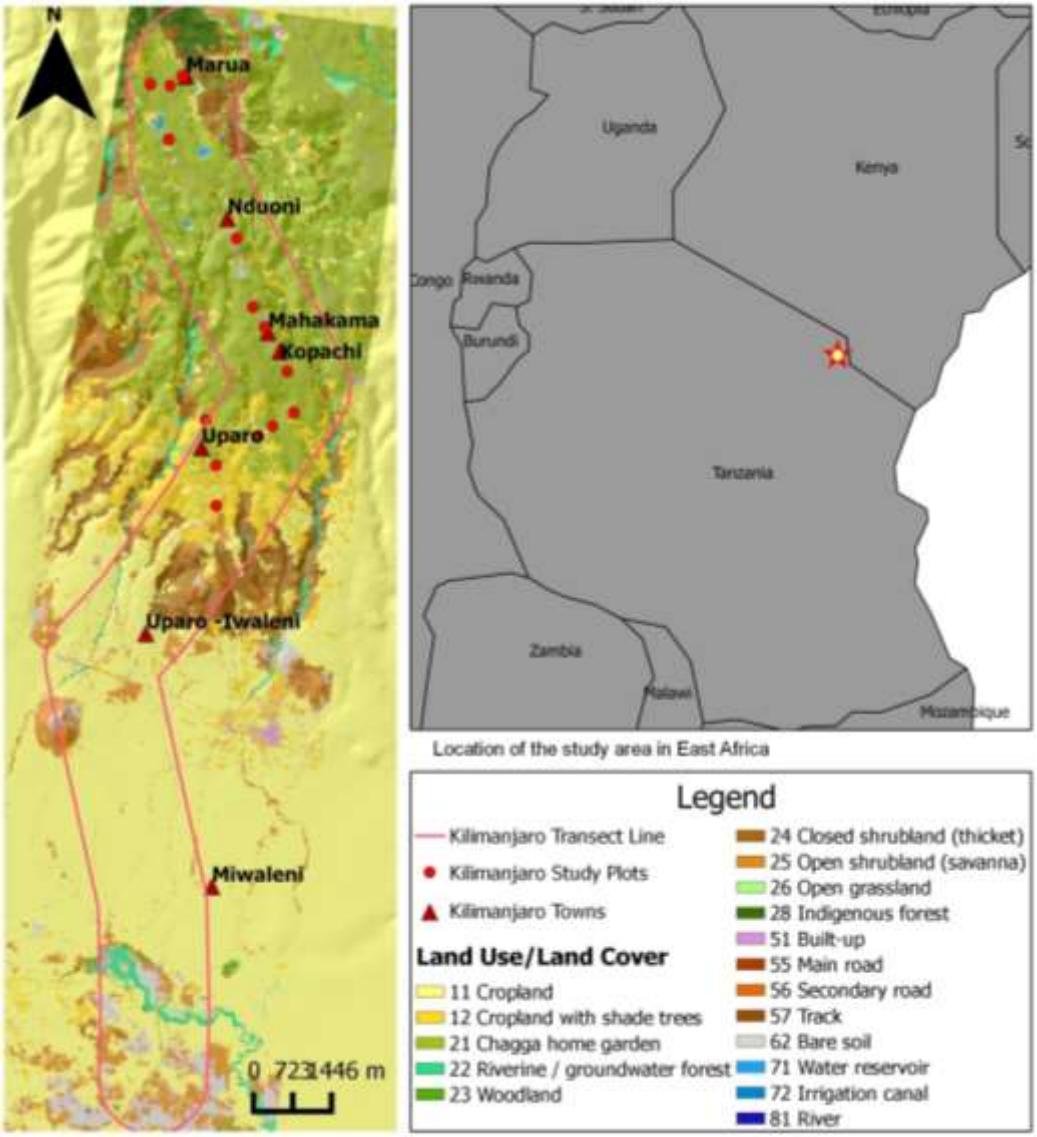

Fig.1a: Map of Mount Kilimanjaro study area in North-eastern Tanzania.

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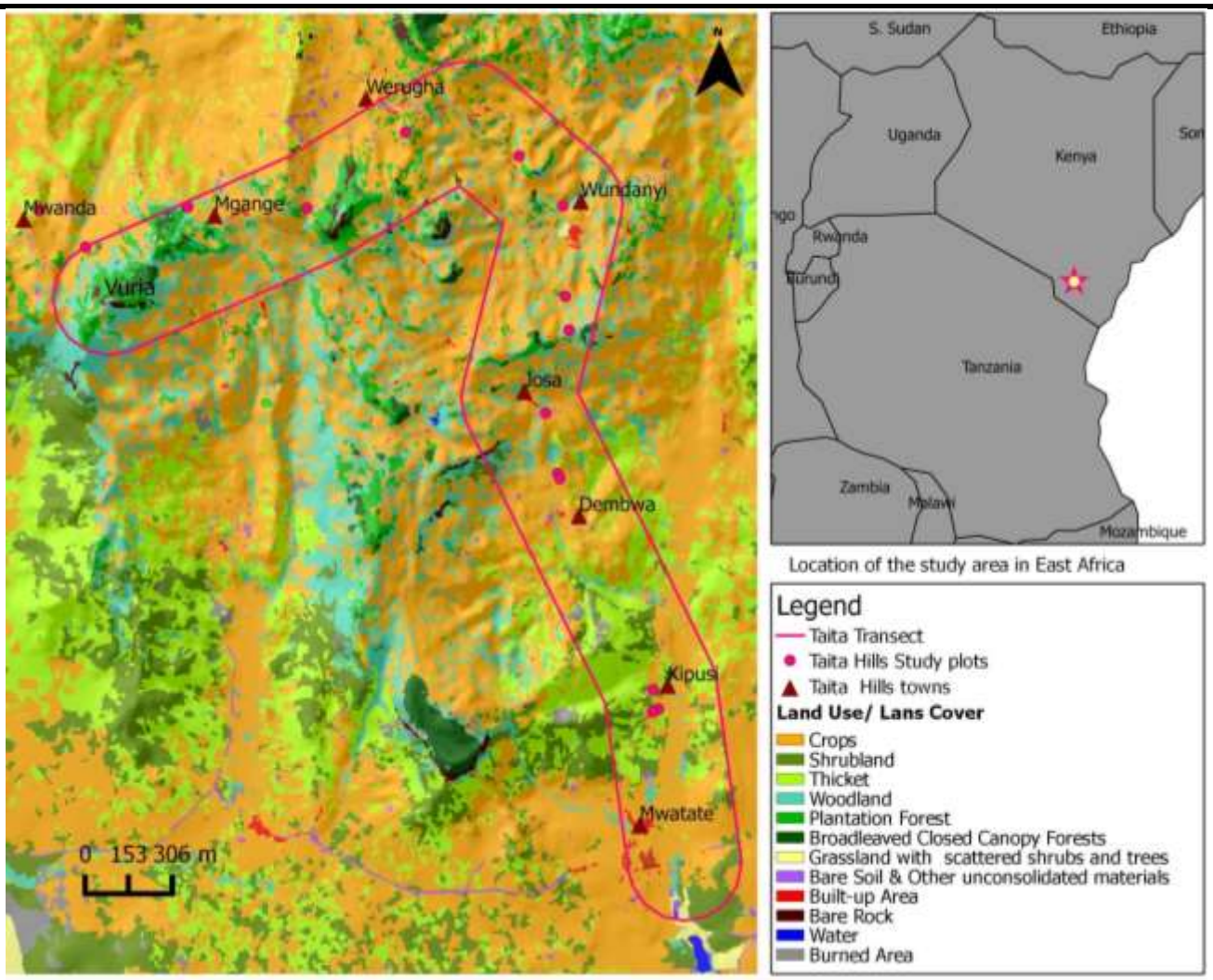

Fig.1b: Map of Taita Hills study area in South-eastern Kenya.

2.2. Sampling design

Species of arthropods were sampled randomly from avocado plants for two consecutive years between August 2012 and July 2014 along each study transect; Mount Kilimanjaro and Taita Hills. A transect comprised of fifteen blocks with each block consisting of at least a hundred avocado trees. During each survey, five avocado trees from the hundred sampling unit of the plants at each block were randomly examined for arthropods using protocol described by Ekesi *et al* (2006), Stibick (2006), Palmer (1990) and Moritz *et al* (2013). Leaves and flowers were gently shaken on a tray to sample species that inhabits plant parts as described by Palmer (1990). However, avocado fruits were observed for other arthropod species as described by Ekesi *et al* (2006). Some species were handpicked from the avocado the plant using fine forceps and aspirator following protocols described by Millar *et al* (2000). The collected specimens were preserved in vials containing 60% ethyl alcohol and later taxonomically identified at the National Museums of Kenya (NMK) entomology laboratory in Nairobi.

2.3. Statistical analysis

Rank abundance test was used to categorize arthropod species based on their population using Biodiversity-R software (R Development Core Team, 2012). Species accumulation curves were used to compare if the observed species richness at two study areas along slopes of Mount Kilimanjaro and Taita Hills reach saturation point (R Development Core Team, 2012). In order to check for the completeness of sampling, observed numbers of species were compared with projected ones (R Development Core Team, 2012). The estimated species richness was constructed for each study area using non-parametric

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estimators; Chao, Jackknife 1 and Bootstrap (R Development Core Team, 2012; Crawley, 2007; Crawley, 2005).

III. RESULTS

A total of sixty one species of arthropods were recorded inhabiting avocado plants in the farmlands adjacent to Afromontane forests within Mount Kilimanjaro in North-eastern Tanzania and Taita Hills in South-eastern Kenya. Further analysis using Rank abundance test revealed that most abundant arthropod species in avocado cropping systems at Mount Kilimanjaro and Taita Hills were; *Bactrocera* (*invadens*) *dorsalis* (Hendel) (Diptera: Tephritidae), *Thaumatotibia leucotreta* Meyrick (Lepidoptera: Tortricidae), *Frankliniella schultzei* Trybom (Thysanoptera: Thripidae) and *Heliothrips haemorrhoidalis* Bouche (Thysanoptera: Thripidae) (Table 1).

*Table.1: Arthropod species recorded on avocado crop in the two study areas of Taita Hills and Mount Kilimanjaro for two years between August 2012 and July 2014. T = Taita Hills, K = Mount Kilimanjaro study area where the species were sampled. * = equals or less than 0.1 log abundance.*

Rank	Scientific name	Common name	Plant part sampled	Log abundance	Order	Habitat sampled
1	*Bactrocera* (*invadens*) *dorsalis*	Asian invasive fruit fly	Ground collected ripened fruits	5.9	Diptera	T and K
2	*Thaumatotibia leucotreta*	False codling moth	Immature fruits	4.9	Lepidoptera	T and K
3	*Frankliniella schultzei*	common blossom thrips	Flowers	3.2	Thysanoptera	T and K
4	*Heliothrips haemorrhoidalis*	Greenhouse thrips	Leaves and young fruits	2.9	Thysanoptera	T and K
5	*Megalirothrips sjostedti*	Cowpea flower thrips	Flowers and leaves	2.8	Thysanoptera	T and K
6	*Thrips austarlis*	Western flower thrips	Flowers and leaves	2.6	Thysanoptera	T and K
7	*Thrips pusillus*	Thrips	Flowers and leaves	2.5	Thysanoptera	T and K
8	*Aleyrodicus dispersus*	Spiralling whitefly	Leaves	2.4	Hemiptera	T and K
9	*Haplothrips gowdeyi*	Thrips	Flowers and leaves	2.4	Thysanoptera	T and K
10	*Cheilomenes sulphurea*	Ladybird beetle	Flowers and leaves	2.3	Coleoptera	T and K
11	*Pheidole megacephala*	Sugar ant	Flowers and leaves	2.2	Hymenoptera	T and K
12	*Rhinocoris* sp.	Assassin bug	Flowers and leaves	2.1	Hemiptera	T and K
13	*Trialeurodes vaparariorum*	Greenhouse whitefly	Leaves	2	Hemiptera	T and K
14	*Tetranychus* sp.	Red spider mite	Flowers and leaves	1.8	Trombidiformes	T and K
15	*Bactrothrips* sp.	Thrips	Flowers and leaves	1.7	Thysanoptera	T and K
16	*Nezara viridula*	southern green stink	Flowers and leaves	1.7	Hemiptera	T and K

		bug				
17	*Helopeltis schoutedeni*	Mirid (plant bugs)	Flowers and leaves	1.7	Hemiptera	T and K
18	*Cheilomenes lunata*	Ladybird beetle	Flowers and leaves	1.7	Coleoptera	T and K
19	*Thrips abyssiniae*	Thrips	Flowers and leaves	1.7	Thysanoptera	T and K
20	*Franklinothrips* sp.	Thrips	Flowers and leaves	1.6	Thysanoptera	T and K
21	*Proboscidocoris fuliginosus*	Bugs	Flowers and leaves	1.6	Hemiptera	T and K
22	*Franklinothrips megalops*	Predatory thripsand mimics ant	Flowers and leaves	1.5	Thysanoptera	T and K
23	*Dolicholepta jeanneli*	Thrips	Flowers and leaves	1.4	Thysanoptera	T and K
24	*Gynaikothrips*sp.	Thrips	Flowers and leaves	1.3	Thysanoptera	T and K
25	*Chilothrips frontalis*	Thrips	Flowers and leaves	1.3	Thysanoptera	T and K
26	*Dendrothrips* sp.	Thrips	Flowers and leaves	1.3	Thysanoptera	T and K
27	*Scirtothrips dorsalis*	Chilli thrips or yellow tea thrips	Flowers and leaves	1.3	Thysanoptera	T and K
28	*Apterygothrips sp*	Thrips	Flowers and leaves	1.2	Thysanoptera	T and K
29	*Scirtothrips* sp1	Thrips	Flowers and leaves	1.2	Thysanoptera	T and K
30	*Frankliniella occidentalis*	Thrips	Flowers and leaves	1.2	Thysanoptera	T and K
31	*Haplothrips* sp.	Thrips	Flowers and leaves	1.0	Thysanoptera	K
32	*Gigantothrips*sp.	Thrips	Flowers and leaves	1.0	Thysanoptera	T and K
33	*Microcephalothrips abdominalis*	Thrips	Flowers and leaves	1.0	Thysanoptera	T and K
34	*Vuilletia houardi*	Thrips	Flowers and leaves	0.9	Thysanoptera	T and K
35	*Ceratothripoides brunnens*	Tomato thrips	Flowers and leaves	0.8	Thysanoptera	T and K
36	*Scirtothrips* sp.2	Thrips	Flowers and leaves	0.8	Thysanoptera	T and K
37	*Ecacanthothrips tibialis*	Thrips	Flowers and leaves	0.7	Thysanoptera	T
38	*Thrips revelatus*	Thrips	Flowers and leaves	0.7	Thysanoptera	T
39	*Sericothrips* sp.	Thrips	Flowers and leaves	0.6	Thysanoptera	T

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40	*Neosmerinthothrips sp*	Thrips	Flowers and leaves	0.5	Thysanoptera	T
41	*Diarthrothrips* sp.	Thrips	Flowers and leaves	0.3	Thysanoptera	K
42	*Frankliniella williamsi*	Thrips	Flowers and leaves	0.3	Thysanoptera	T
43	*Rhipiprothrips* sp.	Thrips	Flowers and leaves	0.3	Thysanoptera	T and K
44	*Stenchaetothrips*sp.	Thrips	Flowers and leaves	0.3	Thysanoptera	T
45	*Elaphrothrips* sp.	Thrips	Flowers and leaves	*	Thysanoptera	T
46	*Pselaphothrips pomeroyi*	Thrips	Flowers and leaves	*	Thysanoptera	T
47	*Stephanothrips* sp.	Thrips	Flowers and leaves	*	Thysanoptera	T
48	*Urothripine* sp.	Thrips	Flowers and leaves	*	Thysanoptera	T
49	*Craspedothrips* sp.	Thrips	Flowers and leaves	*	Thysanoptera	T
50	*Apis mellifera*	Honey bee	Flowers	*	Hymenoptera	T and K
51	*Camponotus maculatus*	Ant	Flowers and leaves	*	Hymenoptera	T and K
52	*Oecophylla longinoda*	Weave ant	Leaves	*	Hymenoptera	T and K
53	*Crematogaster* sp.	Ant	Flowers and leaves	*	Hymenoptera	T and K
54	*Brachypeplus* sp.	Sap-feeding beetles	Flowers and leaves	*	Coleoptera	T and K
55	*Corynas*p.	Pollen beetles	Flowers and leaves	*	Coleoptera	T and K
56	*Epitrix silvacola*	Leaf beetles	Flowers and leaves	*	Coleoptera	T and K
57	*Formicomus* sp.	Ant-like flower beetles	Flowers and leaves	*	Coleoptera	T and K
58	*Nematocerus*sp.	Weevils	Flowers and leaves	*	Coleoptera	T and K
59	*Paederus sabaceus*	Short-winged beetles	Flowers and leaves	*	Coleoptera	T and K
60	*Scymnus* sp.	Ladybugs	Flowers and leaves	*	Coleoptera	T and K
61	*Camponotus rufoglaucus*	Ant	Flowers and leaves	*	Hymenoptera	T and K

Species accumulation curve revealed that 59 species of arthropods were recorded at Taita Hills and 50 arthropod species at Mount Kilimanjaro (Fig 2; Table 2).

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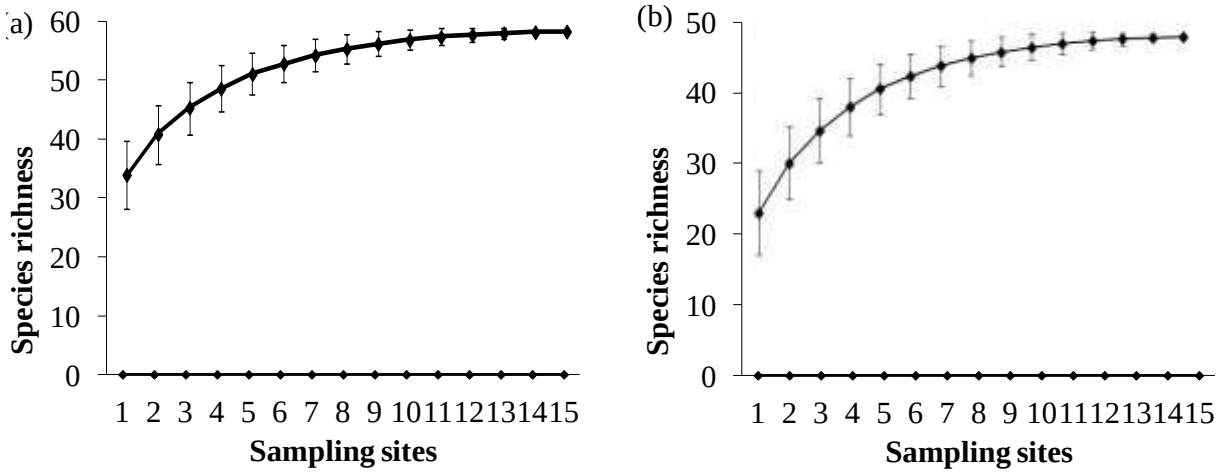

Fig.2: Species accumulation curve of arthropods recorded on avocado plants for (a) Taita Hills and (b) Mount Kilimanjaro study areas. The bars are standard errors. Sampling sites are study blocks at with each comprising of at least a hundred avocado trees.

Richness estimators (Boot, Jacknife and Chao) predicted a number of between 71 ± 3 (mean ± se) and 54 ± 2 species for Taita Hills whereas between 56 ± 2 and 43 ± 1 for Mount Kilimanjaro (Table 2).

Table.2: Observed species richness and non-parametric species richness estimators for Taita Hills and Mount Kilimanjaro transects.

Habitat	Observed species	Chao	Jacknife 1	Boot	Sampling blocks (n)
Taita Hills	59	71.51 ± 3.77	56.62 ± 2.23	54.43 ± 2.09	15
Mount Kilimanjaro	50	56.14 ± 2.81	50.20 ± 2.01	43.12 ± 1.36	15

IV. DISCUSSION

Our results revealed that the Asian invasive fruit fly (*Bactrocera dorsalis*), False codling moths (*Thaumatotibia leucotreta*), common blossom thrips (*Frankliniella schultzei*) and the Greenhouse thrips (*Heliothrips haemorrhoidalis*) are the most abundant arthropod species inhabiting avocado plant parts at Mount Kilimanjaro in Tanzania and Taita Hills in Kenya. *Bactrocera dorsalis* was recorded from ground collected ripened avocado fruits whereas *Thaumatotibia leucotreta* was sampled from immature avocado fruits confirming them as fruit a scenario that has been reported by Mwatawala *et al* (2009) and Prinsloo and Uys (2015), respectively. *Frankliniella schultzei* was recorded exclusively feeding on flower resources, however, *Heliothrips haemorrhoidalis* was recorded from leaves and young fruits proving to be pests of avocado crop as reported in Palmer (1990) and Prinsloo and Uys (2015). Beneficial or pest status of each of the species sampled was not evaluated in this novel paper since our study focused on generating the checklist of arthropods that inhabits avocado plant. However, Ware *et al* (2016), Prinsloo and Uys (2015), Ware *et al* (2012) and Mwatawala *et al* (2009) reported that *Bactrocera dorsalis* and *Thaumatotibia leucotreta* are economically important pests of avocado fruits. Moreover, beneficial insects such as honey bees (Apis melifera) was exhaustively described pollinating avocado flowers at Taita Hills in South-eastern Kenya by Luvanga (2015).

The failure of the species accumulation curves to reach saturation point indicated that more species were likely to be found if additional sampling effort continued at Taita Hills transect than at Mount Kilimanjaro study area. This hypothesizes that if surveys are conducted over multiple years, the species accumulation curves for arthropods are expected to reach saturation point probably due to a larger proportion of rare species which are often recorded in single encounters (Novotny and Basset, 2000). Most of the rare species in this study were Thysanopteran non-pest thrip species that contributed to the high projection of species richness for Taita Hills using Chao; a non-parametric estimator (R Development Core Team, 2012).

V. CONCLUSIONS

Relatively high species richness of arthropods sampled from a single crop confirmed that the avocado plant also plays vital ecosystem functioning at both Mount Kilimanjaro and

Taita Hills study areas. The present checklist provides baseline data for scientists to identify species of economic importance which can assist in designing strategies for avocado pest control and pollination services in East Africa. In order to enhance avocado farming strategies at the two study areas, spatiotemporal data is required for each species recorded. This study, therefore, recommends research on how the most abundant arthropods (*Bactrocera dorsalis*, *Thaumatotibia leucotreta*, *Frankliniella schultzei* and *Heliothrips haemorrhoidalis*) impacts on avocado farming at Mount Kilimanjaro and Taita Hills. The study, further, recommends research on possible beneficial insects such as *Apis mellifera* (Hymenoptera: Apidae), *Oecophylla longinoda* (Hymenoptera: Formicidae) and *Camponotus maculatus* (Hymenoptera: Formicidae) in the avocado orchards along slopes of Mount Kilimanjaro and Taita Hills.

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