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Diversity and Abundance of a Pollinator Group: Hawkmoths (Lepidoptera: Sphingidae) in Forests and Surrounding Farmlands, East Usambara Mountains, Tanzania

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Abstract

Pollinators are now facing a drastic biodiversity fall in various parts of our world. In Africa data to measure and monitor their biodiversity trend is still inadequate and concentrated more on some insect pollinator groups, especially bees and butterflies. In this study, hawkmoth diversity and abundance in East Usambara Mountains were assessed. Data collection was conducted from three different habitat types that included thick vegetation assemblage with canopy cover, edges of the forest, and farmlands between 2017 and 2019. Hawkmoths were captured using a UV-light trap 250W mercury bulb in 12 sampling sites. A total of 35 hawkmoth species and 991 individuals belonging to the family Sphingidae were identified. The highest hawkmoth abundance was recorded from forest edges ($p < 0.05$). Canopy cover and farmlands showed lower hawkmoth abundance. Accordingly, higher Shannon Weiner diversity indices were recorded from canopy cover and forest edges ($p < 0.05$). Farmlands had the lowest Shannon Weiner diversity index. Differences in diversity and abundance of hawkmoths among three habitat types suggest that accelerating anthropogenic factors has led to the destruction of natural habitats. Meanwhile, natural habitat destruction has often been found to exert adverse effects on biodiversity. Moreover, the decline in biodiversity of pollinator insects like hawkmoths hinders the vital pollination service to both crops and wild flora. East Usambara Mountains are still an important refuge for many species that become restricted to different environments due to climate change and anthropogenic pressure, hence calling for regular pollinator conservation and monitoring. This study will provide the baseline data on hawkmoth species richness, abundances and diversity for potential conservation and monitoring programs.

Keywords: Hawkmoths; Abundance; Diversity; East Usambara mountains; Habitat types; Pollinator group; Pollinator conservation

Introduction

Insect pollinators contribute greatly to plant pollination compared to other pollinator groups but sadly they are now facing drastic declines in various parts of our world [1-3]. In Africa, data to measure and monitor their trend is still inadequate and concentrated more on some insect pollinator groups especially bees neglecting other groups such as hawkmoths. Hawkmoths provide vital ecosystem services as pollinators of both crops and wild flora [4]. They are insects from order Lepidoptera family Sphingidae. They pollinate many plants like pawpaw (*Carica papaya* and *Asimina triloba*), coffee (Coffee spp.), kapok (*Ceiba pentandra*) and Sphingophilous flowers which include Lantana spp., Lonicera spp., and Silene spp. [4-6]. There are about 4% of all the plants in Kenya, including pawpaw, and many different African orchids such as aerangoid orchids which are pollinated by hawkmoths [7,8]. A study conducted in South Africa by Johnson & Raguso [9], together with the findings of Martins & Johnson [10] in East Africa, demonstrates the existence of a guild of African plants that appears to rely almost exclusively on the long-tongued convolvulus hawkmoth *Agrius convolvuli* for pollination.

Hawkmoths comprise about 1,602 species and 205 genera worldwide [11]. About 70% of these species occur in the Africa and the New World [12,13]. Most species are crepuscular and nocturnal, except for some strictly diurnal hawkmoths, such as species of Aellopos, Hemaris and Macroglossum [14]. Hawkmoths are generally composed of nectarivorous species with little exclusion which makes them a very important pollinator group

[15]. Apart from hawkmoths, insect pollinator groups include bees, flies, butterflies, moths, wasps, beetles, and thrips, among others [5,16]. It has been estimated that animal pollinators are considered necessary for the reproduction of 90% of flowering plants and one-third of human food crops [17]. Abundant and healthy populations of pollinators can enhance fruit set, quality, and size, then ultimately in farming increase production per acre, and in the wild, biodiversity and wildlife food sources increase [18]. In the United States year 2005 the value of honey bee and non-honey bee pollination services was worth an estimated US $ 15 billion and $ 5-6 billion respectively per year [19].

Currently, there is a persistent decline in the abundance and diversity of Lepidopterans in some countries such as Tanzania and the United States [20,21]. Furthermore, pollinating hawkmoth declines of eight species had been reported in the Northeastern United States which may have ecological effects on both the plants pollinated by these species and vertebrate predators of the moths [22]. In Tanzania, quantification of Lepidopterans to check their diversity trend is at an insufficient level even in the areas where the biodiversity hotspots of the world such as the East Usambara Mountains. Unfortunately, East Usambara Mountains have been under considerable pressure as a result of expanding human population and demands for arable land [23-25]. These activities have led to the clearance of a large part of the forests as well as fragmentation and hence a decrease in biodiversity [26,27]. Moreover, the fragmentation of forests leads to the decline of pollinator diversity of endangered plant species found in the East Usambara Mountains such as Mesogyne insignis [28]. The study by Notø [29] showed anthropogenic disturbance in the East Usambara Mountains affecting the abundance and diversity of fruit-feeding butterflies (Lepidoptera; Nymphalidae). It is recently reported that the abundance of some Lepidoptera pollinating families at farmlands in East Usambara Mountain is significantly dwindling compared to woodland [30].

Data is required to understand how these threats affect the pollinator groups and how to manage agricultural and wild landscapes to secure pollination in such circumstances. Data is needed to provide information for the management and decision-making agencies about various pollinator groups. These key knowledge gaps are targeted focusing on hawkmoths. Sampling took place in a key ecosystem area, the East Usambara Mountains. Forests and the agroecosystems surrounding the forests were sampled for the hawkmoth species as little information exists on the diversity, abundance, and status of this pollinator group in forests and the surrounding farmlands.

Materials and Methods

Study site

A sampling of hawkmoths was conducted in the East Usambara Mountains situated in northeastern Tanzania about 40km from the town of Tanga region between 4º45′-5º20′S and 38º26′-38º48′E (Figure 1), with an altitudinal range of 130m to 1506m [24,31]. The rainfall distribution of East Usambara Mountains is bi-modal, peaking between March and May and between September and December [32]. The dry seasons are from June to August and January to March, however, precipitation occurs in all months [33]. Rainfall is greatest at higher altitudes and in the southeast of the mountains, increasing from 1,200 mm annually in the foothills to over 2,200mm at higher altitudes [34].

A total of 12 sampling sites located in 3 different habitat types including thick vegetation assemblage with canopy cover, forest edges, and farmlands were sampled between 2017 and 2019 (Figure 1). The study sites were georeferenced using Garmin eTrex 30x GPS and validated with google Maps (Table 1). The dominant crops found in the farmlands were *Camellia sinensis,* Elettaria spp., Amomum spp., Cinnamomum spp., Saccharum spp., Musa spp., *Piper nigrum*, *Artocarpus heterophyllus*, *Syzygium aromaticum*, and Dioscorea spp. The dominant vegetation compositions in canopy cover were tree species such as *Cephalosphaera usambarensis, Leptonychia Usambarensis, Allanblackia stuhlmannii*, and *Annickia kummeriae*. Meanwhile, at the edges of the forest, the dominant vegetations were grassy verges such as *Cynodon* spp., *Pennisetum purpureum*, *Lantana camara, Clidemia hirta,* and tree species such as Eucalyptus spp., and *Maesopsis eminii*.

Hawkmoth sampling

Sampling took place for the period of 60 days during long rain (April-June) and short rain (November-December). Hawkmoths were sampled with the help of a UV-light trap consisting of 250W mercury bulbs. Lamps were connected to a 250V generator to ensure stable voltage output. Lamps were placed 1.5m above ground in front of a 3 x 2m white sheet which was attached vertically to two wooden poles. This installation was placed at each site with a white sheet facing only the particular sampling site. The techniques used to sample hawkmoths almost resemble those described in Kingstone & Nummelin [35], Ferro & Romanowski [36], and Lourido et al. [37]. All three habitat types were surveyed between 18:00 and 24:00 hours, 5 days each. Hawkmoths attracted to the light trap were captured by direct handling or with an insect net. Sampled specimens were killed and then placed in envelopes for later preparation and species identification in the Biology laboratory at the National Museum of Tanzania. Identifications were made to species level from keys, illustrations, and guides [4,38,39].

Statistical analysis

Species diversity was calculated using Shannon-Wiener diversity index (H') [40,41]. The Shannon-Wiener diversity index is given by the formula:

$$H' = -\sum_{i=1}^{R}\left[(Pi)\times(InPi)\right]$$

While $Pi = \frac{n}{N}$, Where *Pi* is proportional to species i^{th} relative to the total number of species *R*. *n* is the number of individuals in a species, and *N* is the total number of individuals in a sample.

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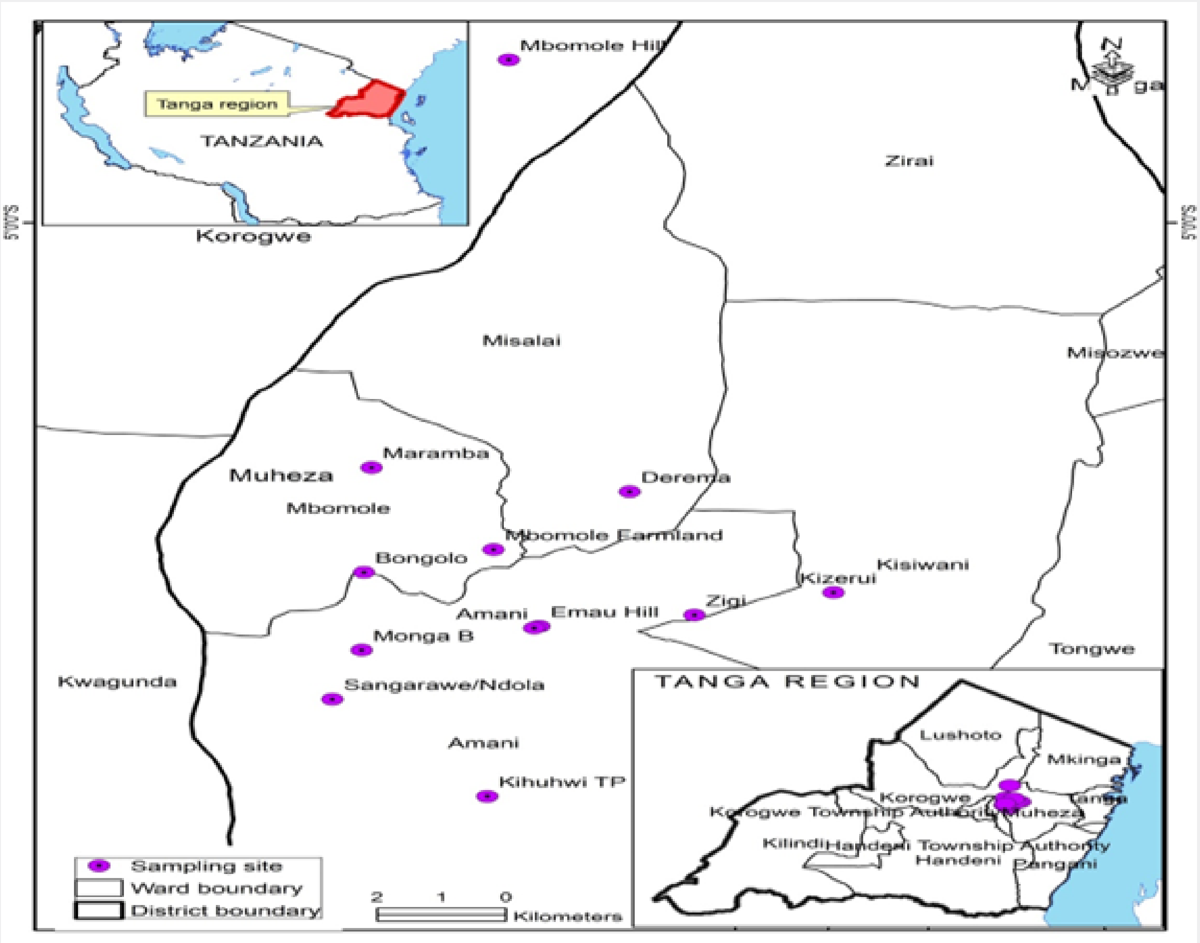

Figure 1: Map showing sampling sites in East Usambara Mountains, Tanzania.

Table 1: Habitat types sampled in the East Usambara Mountains with their respective coordinates and altitudes.

Habitat Type	Sampling Site	Coordinates		Altitude (m)
		Decimal Latitude	Decimal Longitude	
Forest Edges	Kihuhwi TP	-5.1437	38.6222	949
	Sangarawe/Ndola	-5.1194	38.6006	1002
	Bongolo	-5.0876	38.605	982
	Kizerui	-5.09267	38.6705	789
Canopy Cover	Mbomole Hill	-4.95919	38.62519	1100
	Emau Hill	-5.10111	38.62944	1023
	Amani	-5.10156	38.62875	929
	Zigi	-5.0983	38.6511	463
Farmlands	Mbomole Farmland	-5.08192	38.6231	904
	Maramba	-5.06139	38.60608	1003
	Derema	-5.06742	38.64208	966
	Monga B	-5.1071	38.6047	967

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Pielou's evenness index was used to measure species evenness of the hawkmoth species in a habitats type [42] Pielou's evenness was computed using the following formula:

$$J' = \frac{H'}{InS}$$

Where J' is Pielou's evenness index, H' is a Shannon-Wiener index and S is species richness.

Sørensen index of similarity was used to measure the similarity of species communities among pairs of habitats [43]. Sørensen index of similarity was calculated using the following equation:

$$Cs = \frac{2ab}{a+b}$$

Where CS explains the coefficient of similarity, a is the number of species found in habitat A; b is the number of species present in habitat B and ab is the number of species shared by the two habitats.

Shapiro-Wilk normality test was used to test the normality of the data by which the normal distribution of the data was verified ($p > 0.05$). The abundance of hawkmoths among habitats was analyzed by One-way ANOVA test. Comparisons of abundance between pairs of habitats were conducted by Dunn's post hoc test. A special t-test (diversity t-test) was used to compare the species diversity between pairs of habitats. Paleontological Statistics (PAST) version 3.20 was used for all mentioned above analyses [44]. The statistical significance level for accepting all null hypotheses was 5% ($\alpha = 0.05$). Results were summarized using tables and graphic presentations.

Results

In total, 991 hawkmoth individuals were collected belonging to 35 species from all sites in three habitat types (Appendix 1). The abundance and species richness of Sphingids was highest in forest edges, followed by closed canopy cover, and lowest in farmlands (Figure 2). The differences in abundance among habitats were statistically significant (One-way ANOVA test, $F = 5.531$, $p = 0.0052$). Abundance comparisons between pairs of habitats to check where statistically significant differences exist by using Dunn's post hoc test shown in Table 2 below:

Table 2: Summary of Dunn's post hoc test on comparison of hawkmoth abundance between habitats.

Comparison	p	Remarks
Forest Edges vs Canopy Cover	0.00082	Significant
Forest Edges vs Farmlands	0.00002	Significant
Farmlands vs Canopy Cover	0.344	Not Significant

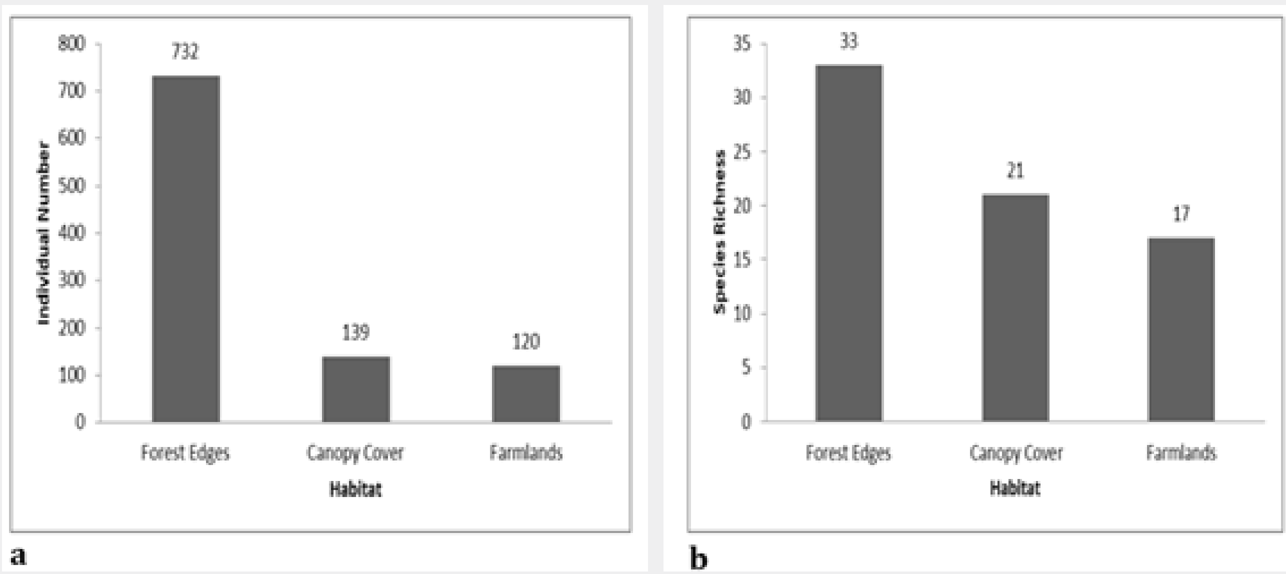

Figure 2: Abundance (a) and species richness (b) of hawkmoths in three habitat types of East Usambara Mountains.

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Appendix 1: Hawkmoth Species abundance and their distribution in 12 sampling sites of three habitat types, East Usambara Mountains (KZ=Kizerui; BL=Bongolo; KH=Kihuhwi; SN = Sangarawe/Ndola; ZG= Zigi; MH=Mbomole Hill; AN= Amani; EH=Emau Hill; ML=Mbomole; DR=Derema; MR= Maramba; MB=Monga B).

S/N	Species	Forest Edges				Canopy Cover				Farmlands			
		KZ	BL	KH	SN	ZG	MH	AN	EH	ML	DR	MR	MB
1	*Acherontia atropos*	0	0	0	9	0	5	0	0	0	0	0	0
2	*Agrius convolvulis*	0	0	7	0	0	1	0	0	0	0	0	0
3	*Andriasa contraria*	0	0	0	3	0	0	0	0	0	0	0	0
4	*Basiothia medea*	1	0	0	0	0	4	0	0	0	0	0	0
5	*Centroctena imitans*	0	0	0	5	0	1	0	0	0	0	0	0
6	*cephonodes hylas*	0	0	0	1	0	0	0	0	0	0	0	0
7	*Chloroclanis virescens*	0	1	0	0	1	0	0	0	0	0	0	0
8	*Coelonia fulvinotata*	11	7	12	33	1	9	2	1	1	4	5	2
9	*Daphnis nerii*	0	0	1	0	0	0	0	0	1	0	0	0
10	*Euchloron megaera*	8	33	84	105	2	12	2	1	11	3	3	2
11	*Falcatula falcatus*	0	2	0	0	1	0	0	0	0	0	0	0
12	*Hippotion eson*	2	0	8	2	0	0	0	0	0	1	0	0
13	*Hippotion osiris*	2	0	0	2	1	10	0	0	0	0	0	0
14	*Macroglossum trochilus*	0	0	0	0	0	0	7	0	0	0	0	0
15	*Macropoliana natalensis*	0	0	0	5	0	2	0	0	0	0	0	0
16	*Neoclanis basalis*	0	0	0	0	0	0	1	0	0	0	0	0
17	*Nephele aequivalens*	0	0	12	3	0	0	0	0	1	0	0	0
18	*Nephele argentifera*	12	10	22	43	4	25	2	2	10	1	1	4
19	*Nephele bipartita*	0	2	2	2	0	0	0	0	1	0	0	1
20	*Nephele comma*	9	2	4	4	1	2	1	1	1	1	1	1
21	*Nephele funebris*	6	5	25	11	3	2	1	1	9	1	1	1
22	*Nephele oenopion*	0	0	3	1	2	0	0	0	1	0	0	0
23	*Nephele vau*	0	0	0	1	0	0	0	0	1	0	0	0
24	*Pantophaea favillacea*	0	0	1	1	0	0	0	0	0	0	0	0
25	*Polyptychus andosa*	0	18	0	13	3	1	0	0	1	0	0	2
26	*Polyptychus coryndoni*	3	23	2	6	0	0	1	0	0	0	2	6
27	*Pseudoclanis kenyae*	0	1	0	2	1	0	0	0	2	0	0	0
28	*Temnora atrofasciata*	0	1	0	0	0	0	0	0	0	0	0	0
29	*Temnora crenulata*	0	17	0	5	0	4	0	0	0	2	1	0
30	*Temnora elegans*	1	23	14	31	2	8	1	5	15	12	4	1
31	*Temnora fumosa*	0	0	6	21	0	0	0	0	0	0	0	0
32	*Temnora iapygoides*	0	0	0	1	0	0	0	0	2	0	0	0
33	*Temnora pylades*	2	0	0	3	0	2	0	0	0	0	0	0
34	*Theretra capensis*	2	0	0	2	0	0	0	0	0	0	0	0
35	*Xanthopan morganni*	0	3	0	7	0	0	0	0	0	0	0	0
	TOTAL	**59**	**148**	**203**	**322**	**22**	**88**	**18**	**11**	**57**	**25**	**18**	**20**

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Table 3: Summary of habitat species evenness and diversity t-test comparison between habitat types.

Habitat Type	Evenness (*J'*)	Comparison	t	p	Remarks
Forest Edges	0.714	Forest Edges vs Canopy Cover	-0.534	0.59406	Not Significant
Canopy cover	0.837	Forest Edges vs Farmlands	2.426	0.01619	Significant
Farmland	0.796	Farmlands vs Canopy Cover	2.402	0.017	Significant

Diversity by Shannon-Wiener index was highest in canopy cover followed by forest edges and lowest in farmlands (Figure 3). The diversity t-test using the Shannon-Wiener index showed statistical differences in diversity between two habitat pairs (Forest Edges against farmlands, and Farmlands against Canopy Cover) as shown in Table 3.

The coefficient of similarity of hawkmoth community from three selected habitat types in the East Usambara Mountains was observed to be high ranging from 58% to 74% (Table 4).

Table 4: Hawkmoth Sorensen index of similarity in three habitat types, East Usambara Mountains.

Habitat Type	Forest Edges	Farmlands	Canopy Cover
Forest Edges	1	0.68	0.74
Farmland	0.68	1	0.58
Canopy Cover	0.74	0.58	1

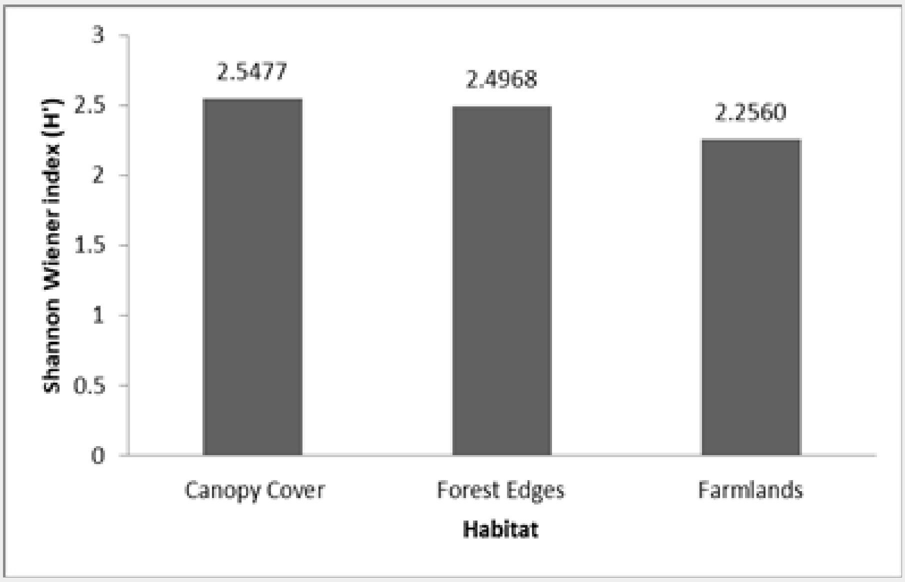

Figure 3: Diversity (Shannon-Wiener index H') of hawkmoth species in three habitat types of East Usambara Mountains.

Discussion

Hawkmoth species sampled in the East Usambara Mountains by this study represent about 63% of all Sphingid species sampled on the lower slopes of the Uluguru Mountains located in the eastern part of Tanzania [35]. Moreover, this study includes about 21% of all Sphingid species known from Tanzania [38]. The most common species were *Euchloron Megaera, Coelonia fulvinotata, Nephele argentifera, Nephele comma,* and *Temnora elegans*. 4 species were the least abundant and very uncommon among sphingid species detected in all sites. These species were *Centroctena imitans, Cephonodes hylas, Neoclanis basalis,* and *Temnora atrofasciata* (Appendix 1). On the other hand, *Euchloron Megaera* and *Nephele comma* were recorded as among the most common and abundant species by Kingstone & Nummelin [35] and Kioko et al. [45] concordant with this present study. None of the Sphingid species caught were endemic to Tanzania in this study, although species such as *Chaerocina livingstonensis* and *Macropoliana scheveni* are known to be endemic to Tanzania [35,46].

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The abundance and species richness of hawkmoths showed a declining trend as one moves from the forest edges through canopy cover to farmlands (Figure 2). Additionally, farmlands had the lowest Shannon Wiener index of diversity compared to those indices of the canopy cover and the forest edges (Figure 3). A study by Selemani [30] showed that farmlands in the East Usambara Mountains had lower hawkmoth abundance compared to woodland. These findings of the lowest species abundance, species richness, and species diversity regarding farmlands, indicate this habitat type experienced severe disturbance and probably from anthropogenic pressure. Furthermore, farmland disturbances have adverse impacts on both pollinators and crop pollination, and this negatively affects crop production and commodity markets [47]. On the other hand, Forest edges had a significantly higher abundance than canopy cover (Table 2). It might be due to a nectar source plant; *Lantana camara,* an invasive plant species which was predominant at the forest edges. This implies either declines of native nectar plants in the forest canopies or higher competition shown by invasive nectar plants against native nectar plants in pollination ecology. Hawkmoths had been observed extending their forages on *Lantana camara* and other introduced invasive species such as *Tithonia diversifolia* in various African countries such as Madagascar and Kenya [10,48]. Higher Sorensen indices of similarity between habitat types propose a wide and almost even distribution of the majority of hawkmoth species in the East Usambara Mountains recorded by this study.

Conclusion and Recommendations

The findings of this present study showed that forest edges and canopy cover were providing potential support to the diversity and abundance of hawkmoths in the East Usambara Mountains. Hence, attention should not only be given to these two forest habitat types but also to the farmlands and other habitat types to boost the diversity of various pollinator groups. Due to the higher species similarities of the hawkmoths on farmlands and forest habitat types, agroforestry should be encouraged. This is because, if the farmlands are managed well, they could be a valuable conservation asset in the difficult trade-off situation between the conservation of biodiversity and the sustainability of rural livelihood. The diversity of hawkmoths and all Lepidoptera species, in general, is directly connected to the availability of specific host plants and not every plant in a particular habitat type. Therefore, for effective and efficient conservation of this pollinator group, a study of the knowledge of hawkmoth host plants should be conducted in the East Usambara Mountains.

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