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ARTICLE

Invertebrates Diversity in Arabuko-Sokoke Forest and Nearby Farmland at Gede, Kilifi County, Kenya

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ABSTRACT

Insectivorous bats mainly feed on various types of invertebrates. The authors studied the abundance and diversity of invertebrates in the farmland in the eastern part of Arabuko-Sokoke Forest, mainly to assess their availability to insectivorous bats occurring in the two study sites. Solar powered light traps were used to attract aerial invertebrates to a white suspended cloth sheet used as a landing surface. The sampling was conducted for four hours in one trapping station each night, and in twelve different stations both in the ASF and farmland. A total of 6,557 invertebrates individuals were trapped, which included 48% in ASF and 52% in the farmland. The two most common invertebrate orders were *Hymenoptera* (ants, bees, wasps and sawflies) represented by 38.1%, and *Coleoptera* (beetles, 28.1%). The interior of ASF had higher invertebrate species diversity (Shannon-Weiner index 1.72 ± 0.1), than the farmland (1.41 ± 0.1). Although the farmland (260.5 ± 52.9, N=12) had higher mean number of invertebrates trapped per night, than the interior of ASF (200.3 ± 36.4, N=12), there was no significant difference between the medians of invertebrates captured in the two study areas (Mann-Whitney U-Test, U=61: P>0.544). Thus, the farmland and the interior of ASF had the same invertebrate abundance. This study indicates the value of human-modified areas (agricultural and human settlements) landscapes, always ignored in biodiversity surveys, in sustaining diverse invertebrates that are preyed by different species of insectivorous bats that occur in the two study areas.

1. Introduction

Vegetation structure is one of the important factors that explain the distribution pattern of species, insectivorous bats included [1,2]. Nevertheless, vegetation features exclusively may not explain the distribution patterns of animals as well as their relationships with other features of a habitat [3]. Thus, it's needed to assess resource availability which are linked to the habitat where animals occur [3]. Insectivorous bats mainly feed on different types

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of invertebrates [4]. In a forested habitat, understanding the relationships between invertebrate prey availability and feeding insectivorous bats is crucial [5]. Moreover, insectivorous bats activity is influenced by vegetation characteristics and invertebrate prey availability [6]. Even though dense vegetation structure is associated with high density of invertebrates, and can subsequently increase the feeding activity of by insectivorous bats [7], the effects of habitat structure might mainly be independent of the invertebrate abundance [8]. This study investigated the diversity and abundance of invertebrates, which are preyed by insectivorous bats in ASF and the adjacent farmland. Insectivorous bats studies, previously conducted both in the interior of ASF and farmland (Table 1), had shown that the farmland had higher activity of insectivorous bats and individual bat captures than in the interior of ASF [9-11]. Therefore, we predicted that invertebrate would be more abundant in the farmland than in the interior of ASF.

2. Materials and Methods

Study area

The study was undertaken in the interior of Arabuko-Sokoke Forest (ASF) and nearby agricultural area dominated by crop cultivation and human settlements occurring east of ASF; in this study broadly denoted to as "farmland" (Figure 1). Arabuko-Sokoke Forest occurs in Kenya, north of Mombasa City, in Gede-Kilifi County (–3.5167S, 39.8167E, less than 80 m above sea level) [12,13]. The forest is a protected area managed by Kenya Forest Service (KFS), jointly with National Museums of Kenya (NMK), Kenya Forestry Research Institute (KEFRI) and Kenya Wildlife Service (KWS) [14]. The ASF has three main distinct broad vegetation types namely: 1) Mixed Forest (MIXFo), a variety of fairly impenetrable, tall and multiple tree species covering an estimated area of about 7000 ha; 2) *Brachystegia* woodland (BRA) covers about 7636 ha running in as a middle band through the ASF; and 3) *Cynometra* forest (CYNO), which covering an estimated area of 23,500 ha, occurring to the west on red Magarini soils, and is dominated mainly by *Cynometra webberi* [15]. The ASF is a globally renown biodiversity repository [16], particularly for the conservation of endemic, and rare globally threatened bird species in Kenya and Africa [17]. Invertebrate surveys were conducted in the interior of MIXFo, BRA and CYNO, as well as in farmland in the eastern part of ASF (Figure 1). In the forest, invertebrate sampling stations were established on the roads used to access different parts of the study area. These roads (maximum 4 m wide) are potential insectivorous bats pathways/flight paths. The farmland around ASF is the major habitat type in the study area (Figure 1), and is characterised mainly by areas of crops farming, human settlements, infrastructure development (village markets and small towns), and social amenities (access roads, villages paths, hospitals and schools). Household farms were cultivated with cashew nut (*Anacardium occidentale*), mangos (*Mangifera indica*) and coconut (*Cocos nucifera*). Some household farms were solely planted with either mangos or coconut trees, while others had a mixture of both trees in varying proportions. Other trees occasionally found in these farms were Neem (*Azadirachta indica*), Casuarinas (*Casaurina equesitifolia*), and Sugar-apple (*Annona squamos*). We selected farms dominated by mango, coconut or mixture of both trees and other trees described above. The mango farms (MAN) had 70.7% dominance by mango trees, coconut farms (COC) 89.3% coconut trees, while the mixed (MIXFa) had 52.9% coconut trees, Cashew nuts 23.2% and Mango 18.6%. The trees in the farms (especially, coconuts, mangos, casuarinas, neem trees) were more than 20 m in height. Invertebrate sampling stations were established in the open areas of selected farms. The 12 invertebrate sampling stations each, in the farmland and in the interior of ASF, were established in the general areas, that had been previously been used to sample insectivorous bat species [9-11]. In addition, a number of bat roosts actively used by bats to roost, during invertebrate survey occurred in the sampling areas in the farmland [18].

Invertebrate inventorying methods

Before the inventory of invertebrate was undertaken, six expeditions to sample insectivorous bats with mist-nets and their activity with detectors had previously been undertaken in the two study sites in between November 2014 to 2016 (Table 1). Results of these studies indicated that, insectivorous bats abundance and activity were higher in farmland than in the ASF (Table 1). Therefore, we predicted that invertebrate would be more abundant in the farmland than in the interior of ASF. Many nocturnal invertebrates, especially the different species of beetles and moths are easily attracted by artificial light at night [19]. Light traps are widely used to sample different invertebrate species which are active at night [20]. In the current study, light bulbs powered by a small inbuilt battery charged with solar panels were used to sample invertebrates [21] in the two study sites. In each sampling station in the ASF or farmland, four lights were used to attract invertebrates. In one sampling station the lights were deployed at least at a distance of 70m from each other.

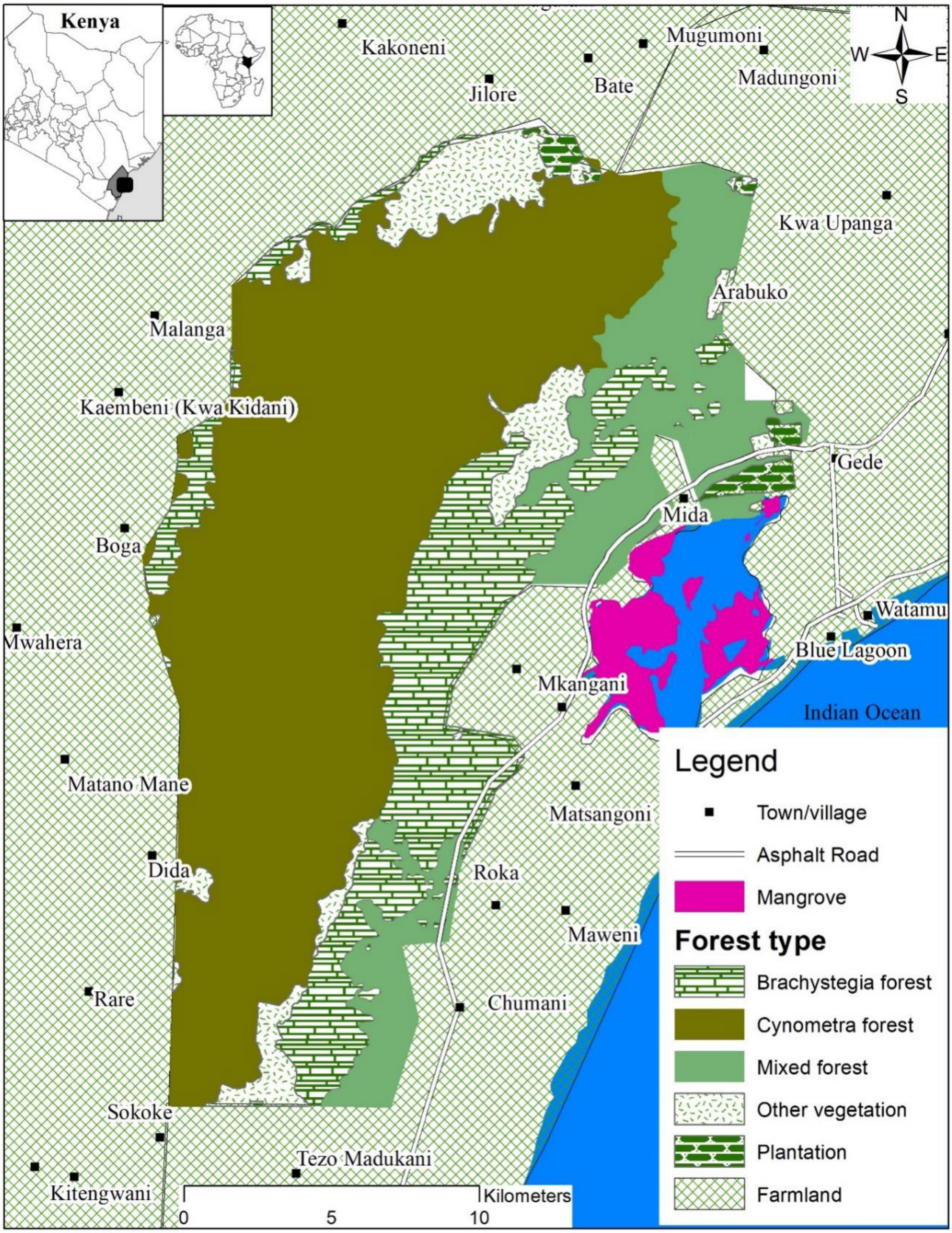

Figure 1. A map of the study areas showing the various vegetations types in the interior of Arabuko-Sokoke Forest and farmland where invertebrate sampling was conducted.

The solar powered lights (DP Light DP-6005A) http://en.dpled.com, consisted of a small battery (Figure 2), which attained a voltage of 110 V ~240 V (50/60 Hz). The battery was charged with a small solar panel (9 V/3.5 W). When the battery was charged from morning (0800 hr) to afternoon (1600 hr) during days of full sunlight, the bulb would be kept bright without dying for the night continuous sampling of four to five hours.

Figure 2. A mounted solar light and battery (DP Light DP-6005A) which was used to attract air-borne invertebrates active at night.

Invertebrate sampling stations were established in the interior of ASF at the middle of different roads used to access various vegetation types. The set up included a light trap suspended with strings, a white cloth sheet and a polythene sheeting spread on the ground (Figures 3-5). In ASF strings to suspend light traps, were tied 1.5 m above the ground on selected two trees across the road. In the farmland a sampling station was established where there were two nearby trees. A light trap was suspended at the centre of the tied string. After this a white cotton piece of cloth measuring (2 m long by 1.5 m wide), was tied at the edges with other strings and suspended facing the light trap light source with these strings at an approximate distance of a meter from the light trap (Figure 3). The white cloth which was hung about 30 cm from the ground, was used as a landing surface for nocturnal invertebrates attracted by the light trap [22]. In addition, a plastic sheet was spread under the suspended white sheet, to make it easier to collect invertebrates which dropped to the ground after colliding with the cloth barrier (Figure 3). In each sampling station the four light traps were monitored for four hours from 1900hr to 2300hr each night (Figure 4). A total of 12 light traps were used to sample invertebrates in the interior of ASF. These included four sampling stations each in *Cynometra* Forest (CYNO), Mixed Forests (MIXFo) and *Brachystegia* woodland (BRA). In the farmland 12 different stations were used to sample invertebrates, including four each in the farms dominated by mango (MAN) trees, coconut (COC) trees and other farms with multiple trees (MIXFa) species. The light traps were monitored twice each hour. Any individuals of moths captured were collected in a clear glass jar and killed with chloroform vapour soaked in cotton wool [21]. The dead moths were later removed from the glass jar, and preserved using toilet nappies and stored in plastic containers, in order to ensure that their delicate wings were not damaged. All other invertebrates excluding moths were collected in plastic jars and preserved in a fluid solution of 70% ethanol. The sample of invertebrates collected each hour was stored separately [23] in each vegetation type in the farmland and interior of ASF, so as later to assess their abundance at the end of the trapping operation.

Figure 3. The operational set up of solar light trap and battery (DP Light DP-6005A) with a transparent plastic sheeting spread on the ground (A) and suspended white cloth screen (B) for invertebrates landing

Table 1. The number of insectivorous bats echolocation calls (passes) counted with detector, and individuals captured in mist-nets in six different sampling trips in the farmland and interior of ASF in between November 2014 to June 2016.

	Survey	Sampling	Farmland	ASF Forest	Farmland	ASF Forest
	Dates/Trip	**Seasons**	**bat passes/trip**	**bat passes/trip**	**bat captures/trip**	**bat captures/trip**
1	Nov-2014	Short rain season	1775	231	161	17
2	Feb-2015	Dry season	2420	862	197	52
3	Jun-2015	Long rain season	1808	461	140	31
4	Nov-2015	Short rain season	2103	603	190	21
5	Feb-2016	Dry season	1437	871	120	15
6	Jun-2016	Long rain season	1009	1147	92	7
	TOTAL		**10,552**	**4,175**	**900**	**143**

Figure 4. The solar light and battery (DP Light DP-6005A) in operation at night attracting air-borne invertebrates to the white cloth sheet (black dots)

The individual moths from each trapping station and vegetation type were collected and stored together and not separated into hours. Any captured individuals of large moths trapped, were killed and stored in envelopes. The size of invertebrates collected measured 5 mm~40 mm in their body length. Invertebrates of small size (<5 mm) were not sampled because they are unlikely to be detected by feeding insectivorous bats [24], and those bigger (>40 mm in length) are unlikely to be consumed by them [25]. No individuals of invertebrate that were more than 30 mm by width were collected, because they were perceived to be too large a prey for Striped Leaf-nosed Bat (*Macronycteris vittata*), the largest insectivorous bat, found in the study area. Invertebrate sampling was carried interchangeably, with one night in the forest interior, followed by the next in the farmland to spread any sampling bias associated with variations in weather conditions (humidity, temperature etc.) between the ASF and the farmland. A combination of trap types and different survey methods are required for a detailed inventorying of invertebrates in an area, even for a single taxon [26]. Nevertheless, this method is problematic to implement in most field surveys, because it is expensive and time consuming [27], the reason it was not used in the current study.

Data analysis

Individuals of invertebrates were totalled and identified to taxonomic order by use of specimens collected in the past from ASF and preserved with Invertebrate Section of National Museums of Kenya. Species diversity of invertebrates was calculated using Shannon-Wiener index of diversity [28]. The total number of individuals of invertebrates in each of the 12 sampling stations in ASF and farmland was counted. To test for the differences in sample medians of invertebrates captured in each station per night in the farmland and in the ASF, a Mann-Whitney U-test non-parametric statistical test was used. To estimate the size of invertebrate (to the nearest 0.25 mm), individuals were measured using a ruler from the head (exclusive of antennae) to the tip of the abdomen (short of inclusion of cerci) [29]. Thereafter, the individuals of invertebrates were clustered into four different size groups: from the smallest of size 5 mm~10 mm, 11 mm~21 mm, 22 mm~32 mm, to the largest >33 mm. To assess the pattern of invertebrate activity during the four (1900 hr~2300 hr) sampling hours, the total number of individuals of invertebrates not including moths captured in each hour was counted. Moths were omitted from this analysis, because the individuals from each trapping station and vegetation type were collected and stored together and not separated into hours. PAST statistical program [30] was used to analyse collected data.

3. Results

Invertebrate richness and diversity

A total of 6,557 individuals of invertebrates were trapped, which included 52% in the farmland and 48% in the interior of ASF. The most abundant order was *Hymenoptera* (ants, bees, wasps and sawflies), which was represented by 38.1% of all sampled invertebrates, followed by the order *Coleoptera* (beetles (28.1%) and *Lepidoptera* (moths (15.7%) Tables 2-3). Majority of individuals of orders *Hymenopterans* and *Coleopterans* were found in the farmland than in the interior of ASF (Table 3). Many individuals of the order *Lepidopterans* and of larger sizes were found in the interior of ASF than in the farmland (Table 2). The interior of ASF had higher species diversity (Shannon-Weiner index 1.72 ± 0.1), than the farmland (1.41 ± 0.1). Although the mean number of invertebrates trapped per night in the farmland was larger (260.5 ± 52.9, N=12), than in the interior of ASF (200.3 ± 36.4, N=12), there was no significant difference between the medians of invertebrates captured in the two study areas (Mann-Whitney U-Test, U=61: P>0.544).

Invertebrate sizes and their activity pattern

Of the 6,557 invertebrate individuals captured, 68% of these were of small sizes (5 mm~10 mm), followed by those of size 11 mm~21 mm (29%) (Table 4). Most of the individuals of invertebrates in the two study sites were captured at 1900 hr. In the interior of ASF invertebrate activity (captures) underwent a steep declined from 1900 hr to 2000 hr. However, at the same in the farmland invertebrate activity maintained relatively stable decline. Finally, in both habitats invertebrate activity was lowest at 2300 hr (Figure 5).

Table 2. Abundance and diversity of orders of invertebrates sampled in three different habitat types in the interior of ASF.

	COUNT OF INVERTEBRATES IN EACH VEGETATION TYPE				
	ORDERS OF INVERTEBRATES	**MIXFo**	**BRA**	**CYNO**	**ASF**
1	Hymenoptera (Ants, bees, wasps and sawflies)	131	537	376	**1044**
2	Coleoptera (Beetles)	120	357	158	**635**
3	Hemiptera (Bugs, aphids and cicadas)	79	73	41	**193**
4	Blattodea (Cockroaches and termites)	68	108	62	**238**
5	Diptera (Flies and mosquitoes)	27	91	25	**143**
6	Orthoptera (Grasshoppers, crickets, katydids)	32	38	29	**99**
7	Mantodea (Praying mantids)	5	21	7	**33**
7	Neuroptera (Net winged invertebrate)	3	11	4	**18**
8	Odonata (Dragonflies and damselflies)	0	1	0	**1**
10	Lepidoptera (Moths)	159	280	325	**764**
Abundance		**624**	**1517**	**1027**	**3168**
Shannon_H		**1.85 ± 0.09**	**1.72 ± 0.08**	**1.57 ± 0.11**	**1.72 ±0.05**

Legend: Mixed Forest (MIXFo), *Brachystegia* Woodland (BRA), and *Cynometra* Forest (CYNO)

Table 3. Abundance and diversity of orders of invertebrates sampled in three different habitat types in the farmland.

		COUNT OF INVERTEBRATES IN EACH VEGETATION TYPE			
ORDERS OF INVERTEBRATES		**MAN**	**COC**	**MIXFa**	**FARMLAND**
1	Hymenoptera (Ants, bees, wasps and sawflies)	1157	202	93	**1452**
2	Coleoptera (Beetles)	414	247	547	**1208**
3	Hemiptera (Bugs, aphids and cicadas)	39	42	23	**104**
4	Blattodea (Cockroaches and termites)	122	10	18	**150**
5	Diptera (Flies and mosquitoes)	39	12	14	**65**
6	Orthoptera (Grasshoppers, crickets, katydids)	47	42	33	**122**
7	Mantodea (Praying mantids)	1	7	1	**9**
7	Neuroptera (Net winged invertebrate)	8	4	3	**15**
8	Odonata (Dragonflies and damselflies)	1	0	0	**1**
10	Lepidoptera (Moths)	135	46	82	**263**
Abundance		**1963**	**612**	**814**	**3389**
Shannon_H		**1.27 ±0.94**	**1.52 ± 0.15**	**1.16 ± 0.16**	**1.41 ± 0.06**

Legend: Mango farms (MAN), Coconut farms (COC), Mixed farms (MIXFa)

Table 4. The counts and percentages of invertebrates of different sizes sampled in the farmland and in the interior ASF

INVERTEBRATE BODY SIZE CLASSES					
	5-10 mm	**11-21 mm**	**22-32 mm**	**sizes >33**	**Total**
Total (Farmland and ASF) All other invertebrates minus Lepidoptera (Moths)	3,440	1,869	167	54	5530
Total (Farmland and ASF) Lepidoptera (Moths)	994	30	3	0	1027
Total (Farmland and ASF)	**4,434**	**1,899**	**170**	**54**	**6,557**
Percentage (%)	**67.6**	**29.0**	**2.6**	**0.8**	**100.0**

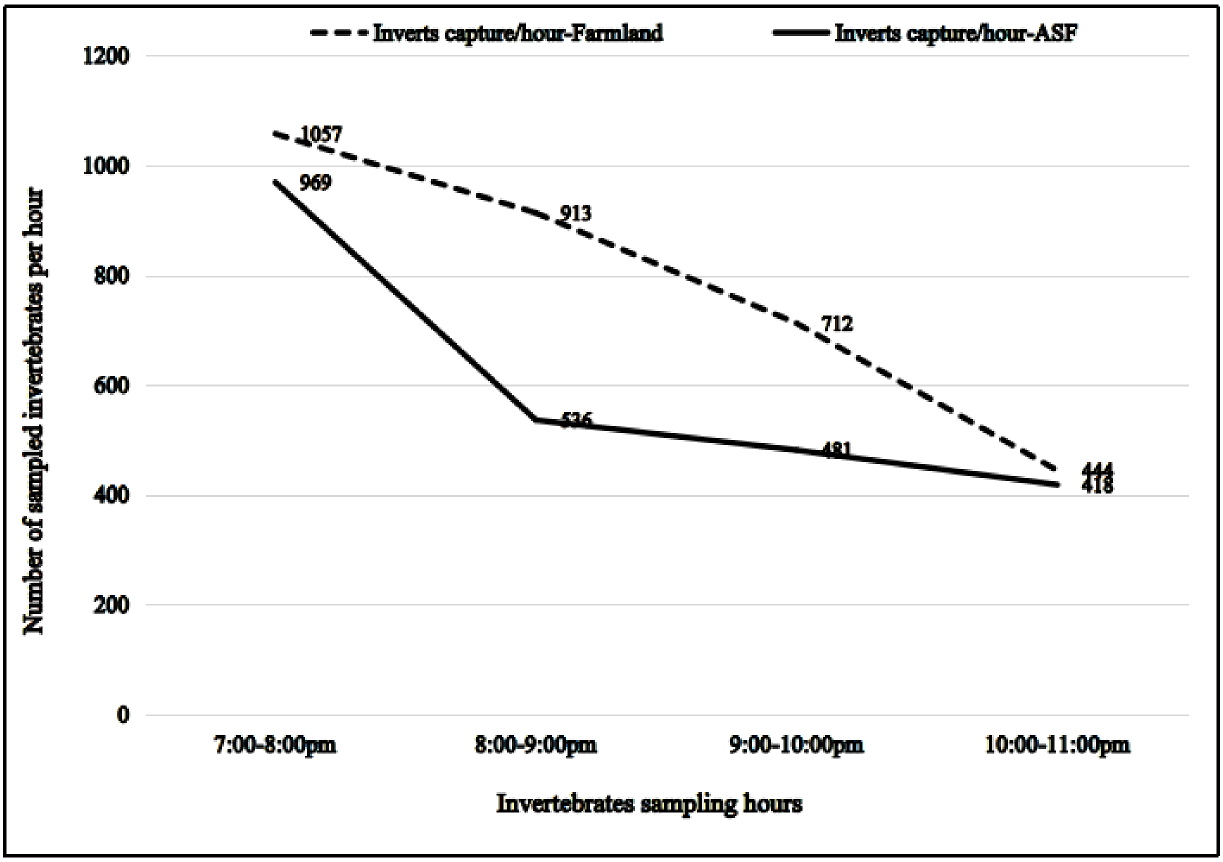

Figure 5. The hourly pattern in the activity (captures) of invertebrates (excluding moths) sampled in the farmland and the interior of ASF.

4. Discussion

The current study investigated diversity and abundance of invertebrate in the interior of ASF and surrounding farmland. The ASF is a legally protected area, characterised by indigenous vegetation typical of the east African coastal forests [10,17], while the farmland habitat is completely disturbed and modified into an agricultural landscape. Because the two contrasting habitats had been shown to host various types of insectivorous bat species [9,10], there was need to provide data on diversity and abundance of invertebrates, which are the primary food items eaten by these bats. The results of our study indicated that the farmland in the eastern part of ASF as well as the interior of ASF and had similar invertebrate abundance. However, the species diversity of invertebrate was higher in the interior of ASF than in the farmland. This was possibly because of the large number of individuals of two invertebrate orders (Coleopterans (1452), and Hymenopterans (1208) in the farmland which dominated most of the captures (Table 3), while in the forest interior the captures were fairly distributed among several orders (Table 2). The order Lepidopterans (moths) were more common and of larger sizes in the interior of ASF than in the farmland. Studies have shown that the abundance of moths decline with habitat disturbance especially fuelled by agriculatural intensification [31]. This is largely because less disturbed habitat as was the case of ASF, provides sheltered environments for moth species survival [32], as compared to the highly disturbed farmland habitat. The individuals of order *Coleoptera, Hymenoptera* and *Orthoptera* were more common in the farmland than in ASF. Comparable results were recorded in Malaysia at Kota Damansara Community Forest Reserve [33].

Among the four largest orders of invertebrates *Hymenoptera* is largest, followed by *Coleoptera*, *Lepidoptera* and *Diptera* [34]. This possibly may explain the large numbers of individuals of these orders recorded in the current study. Individuals of the order *Coleoptera, Lepidoptera, Diptera, Hymenoptera* and *Isoptera* are the most common groups of invertebrates preyed upon by insectivorous bat species [35]. In this study, representatives of these orders were captured in large numbers in both study sites. Nevertheless, many individuals of the order *Dipterans, Lepidopteran,* and *Blattodea* were more common in ASF than in the farmland. Therefore, though the interior of ASF has been shown to have low insectivorous bats abundance and activity than the farmland [9-11], most of the invertebrate orders preyed by these bats were also common in the forest interior. This probably indicates that the farmland and the interior of ASF were suitable foraging habitats for the insectivorous bat species found in the two study sites.

There are a number of vegetation characteristics related factors which may explain the abundance and composition of invertebrate diversity recorded in a specific area. For example, the understorey vegetation structure may influence the abundance of invertebrates trapped with light traps. Specifically, the undergrowth (vegetation measured <3 m by height) understorey) openness possibly increases the efficiency of light-trapping area, particularly for nightly invertebrates [36]. For instance, in the interior of ASF, the light source from the light traps, was observable in a small area, as a result of the barriers occasioned by the impenetrable understorey vegetation cover. Consequently, a small area of ASF interior may have been sampled, the area immediately around the light source. Nonetheless, in an uncluttered habitat, such as in the farmland in the current study, the light trap was noticeable from far, and perhaps attracted invertebrates from a wide trapping range. Furthermore, canopy openness has been shown to have a strong influence on beetle compositions [37], but not moths [38]. The understorey and canopy of the interior of ASF is more cluttered than that of farmland [10]. Hence, even though closed habitats which are undisturbed have high abundance of invertebrate [39], the impediment of the light trap by thick canopy vegetation, possibly reduced light detection by air-borne invertebrates, and eventually reduced overall abundance of individuals of invertebrates trapped inside ASF. This perhaps may suggest that, though results of the current study showed that, both study sites had the same invertebrate abundance, the interior of ASF may be richer in invertebrate abundance. The activity of invertebrate peaked after nightfall (1900 hrs), and gradually or sharply deteriorated to the lowest level at 2300 hr in both study sites. The activity of insectivorous bats in and around ASF has been shown to be highest immediately after dusk (1900 hrs~2000 hrs) and is lowest after midnight [9,11]). This possibly, suggests that insectiverous bats in the study area, sychronize their foraging activity with the availbility and abundance of invertebrate prey.

5. Conclusions

The farmland was highly disturbed, and in continous habitat modification, and was expected to have a low abundance of invertebartes [40]. Nevertheless, the farmland had the similar invertebarte abundance with the comparatively less disturbed ASF. This may suggest that the two study sites provided suitable feeding areas for the insectivorous bat species found in the area. This study, highlight the value of human-modified areas, always ignored in biodiversity surveys, in sustaining diverse invertebrates that are preyed upon by different species of insectivorous bats that occur in the two study areas. In order to have a detailed documentation of invertebrate composition in the two study sites in future studies, it is recommended to employ a combination of different invertebrate sampling methods [26]. This is because the efficacy of light traps in invertebrates sampling varies between taxa [41]. Furthermore, light traps sample exclusively individuals of invertebrate taxa attracted to light [42].

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Conflict of Interest

There is no conflict of interest.

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