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Impact of anthropogenic habitat changes on insects: A case study of mount Loleza forest reserve

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Abstract
This study assessed the impact of anthropogenic activities on the abundance, diversity and composition of insect species on Mt. Loleza forest reserve in Mbeya, Tanzania. Insects were collected in disturbed, less disturbed and undisturbed habitats using pitfall traps, sweep nets and beating sheets. Data were analysed using one way analysis of variance (ANOVA) with Tukey's post hoc test and Kruskal Wallis. Shannon and Simpson diversities were compared using diversity t-test. Bray-Curtis similarity index was used to group families and species based on the number of individuals. In total, 3058 insect specimens belonging to 21 families and 40 species were collected. Insect abundance was highest in undisturbed habitats (50.10%). The Shannon diversity differed significantly between disturbed and undisturbed habitats ($p < 0.05$); and between less disturbed and undisturbed habitats ($p < 0.05$). Results of this study are vital toward effective conservation and management of the global insect species and other animals.

Keywords: anthropogenic activities; biodiversity conservation; insect abundance; insect diversity; mount Loleza

1. Introduction

Mountain forests offer many ecosystems that support large population of animals including insect species [1, 2]. They play an important role in supporting biodiversity conservation, for instance, provision of foods, microhabitats and homes for the growth and distribution of insect population [3]. However, anthropogenic changes which occur on these mountain forests produce different types of habitats (i.e. cause habitats conversion and fragmentation) with severe consequences for species richness and diversity [4, 5]. Habitat conversion and fragmentation represent the highest threat to insect biodiversity [5]. They not only affect species abundance and composition, but also process driving their biodiversity [2]. For example, large population of insects and other animals may be isolated into sub-populations from one another due to habitat fragmentation [6]. This affect the population to reproduce, and may cause local extinction of species [2, 6].

These anthropogenic changes accelerate decreasing in abundance and community composition of insect species [4, 7–10]. In disturbed habitats, insect biota are affected directly by causing biodiversity loss or indirectly through changing of microclimate [1]. Due to their sensitivity to environmental change and habitat requirements, they are important bioindicators of disturbances in both aquatic and terrestrial ecosystems [1, 3, 7]. The high abundance, diversity and species richness of insect, especially the coleopterans represent a health ecosystem or environment [4, 11].

Like other tropical and semi-tropical forests, ecosystem health and resilience of Mt. Loleza forest reserve (MLFR) is affected by a number of anthropogenic factors. Most of these factors are due to increasing human population and consequently land-use which drives global biodiversity loss in the world [12, 13]. Increasing human population in Mbeya city, for instance, has caused conversion of forest on Mt. Loleza to agricultural land with simultaneously high biodiversity losses. Despite these threats, management and conservation efforts are not seriously being implemented. In addition, there is no study which has been conducted to assess the insect abundance, species diversity and richness, as well as ecosystem health of MLFR. This study therefore sought (i) to assess the abundance, diversity and community structure of insects of MLFR; (ii) to identify anthropogenic changes threatening the ecosystem health and insect biodiversity on the mountain; and (iii) to advice the Tanzania Forest Services Agency (TFSA) on conservation and management options for the area. The impact of anthropogenic changes on insects were assessed by comparing the abundance and diversity indices in disturbed, less disturbed and undisturbed habitats with respect to elevation. The implications of the study in terms of conservation at ecosystem and environmental level are discussed and management requirements for this mountain forest are also pointed out.

2. Materials and methods

2.1 Study area

The MLFR is located in the Mbeya range mountain, north of the city of Mbeya, Tanzania (08°51′18″S, 033°25′15″E). The peak of the mountain is 2656 metre high above sea level (Fig. 1). The climate of the region is largely tropical with marked seasonal and altitudinal temperature variations. The temperatures vary according to altitude, it ranges from 16^0C in the highlands to 30^0C in the lowland areas [14]. The mountain is managed by TFSA, an executive agency authorised for the management of national forests and nature reserves, and forest and bee resources on common lands. It is covered by bushes, grasses and trees, mainly pines and eucalyptus; however, some patches are bare ground. It has many species of animals such as dik-dik, hare, snakes, and birds' species (bulbul, Sunbirds, Red-Billed Firefinch, Pied Crow, Black and White Mannikins, Hammerkop, Widowbird, Schalow's Turaco and Olive Pigeon). In addition, it is a home of several macro in vertebrates including insects and snails. There are roads passing through the MLFR that are used by local people and vehicles. A rapid growth in population density in Mbeya city over the past decade has resulted in significant expansion of built area and a corresponding shrinkage in mountain forest area. This study examined habitat disturbances on the MLFR and their consequences on insect abundance, diversity, species richness, and composition.

2.2 Sampling of insects

Insects were collected from sixteen sites at different altitude with the lowest and highest being 1752 m and 1949 m respectively (Fig. 1). The habitats in each sites were divided into three classes based on disturbance gradient i.e. disturbed, less disturbed and undisturbed. Disturbed habitats were characterised with high level of anthropogenic activities (> 50 removal of trees, logging, burnt vegetation, fallen trees, signs of fuelwood collection and livestock grazing, greatly reduced plant cover, and large patches of bare ground); less disturbed habitats had low level of anthropogenic influence (< 50 removal of trees, intact canopy, well-established ground cover, and fewer signs of disturbances); whereas undisturbed habitats had very minimal disturbance or none, broad ground cover with woody vegetation and canopy cover, highest tree densities, no signs of off-road vehicle, and no disturbance indicators mentioned above. Representative photos of these habitats are shown in Fig. 2.

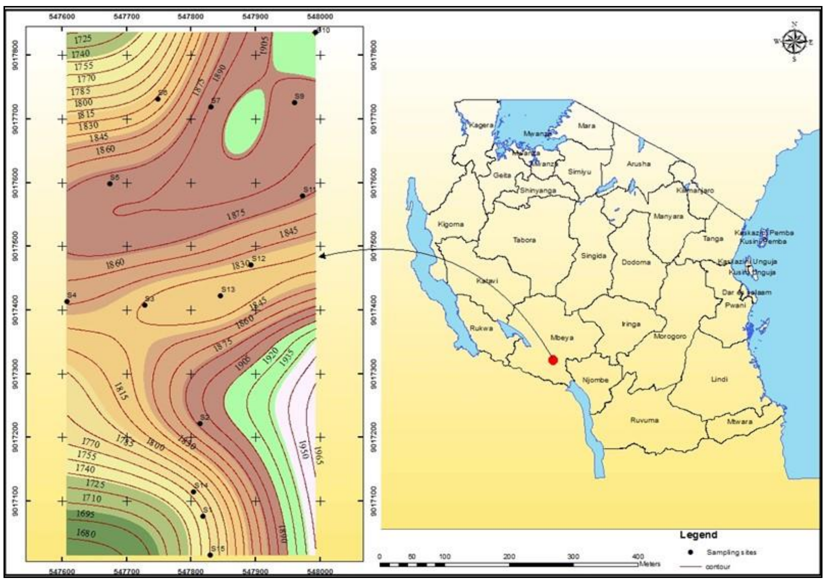

Fig 1: Location and elevation of insects sampling sites on Mt Loleza forest

Fig 2: Representative photos of disturbed habitats (A), less disturbed habitats (B), undisturbed habitats (C), and the rod passing through on Mt. Loleza forest (D)

Pitfall traps, sweep nets, beating sheets were used to collect insects, and by searching in tree trunks (Fig. 3). Ground insects were collected using *pitfall traps* **(**top diameter = 8 cm, height = 10 cm*)*. In each habitat two line transects, 10 meter apart, were established with pitfall traps being placed within the transect line. A total of 40 pitfall traps were installed at an interval of 5 m for one week in each sampling area for a period of one month. Traps were not baited; and were visited every day between 10am and 1pm to collect insects. *Sweep nets* (32 cm diameter) were used to collect insects from ground layer vegetation and flying insects. Habitats were swept two times every week from 10am to 1pm. Insects that feed and rest on trees, bushes, and other plants were sampled using *beating sheets*. Insects were identified to species level with the help of field guides and keys at Mbeya University of Science and Technology (MUST). Some specimens were killed using ethyl acetate prior to identification. Hard bodied insect specimens were stretched, dried, dry pinned while soft bodied insects were preserved in the 70% ethyl alcohol in polythene bottles.

Fig 3: Sampling and identification of insect specimens

2.3 Statistical analysis

Abundance was measured based on the total number of individuals collected, and species richness was measured based on the total number of species collected. Box-Cox transformed abundance data was used. The normality was checked using Shapiro-Wilk and Anderson-Darling statistical tests. One way analysis of variance (ANOVA) with Tukey's post hoc test was used to compare the abundance of insect between disturbed, less disturbed and undisturbed habitats. Kruskal-Wallis was used to compare the species richness of insect between disturbed, less disturbed and undisturbed habitats. Diversity indices (Margalef index, Fisher's α, Shannon-index, Berger-Parker dominance index (BPI), Simpson index and Evenness) were calculated and compared between disturbed, less disturbed and undisturbed habitats. Shannon and Simpson diversities between habitats were compared using diversity t-test. Bray-Curtis similarity index method was used to cluster species and families based on their species number and abundance respectively. All statistical test was performed using the Paleontological Statistics (PAST) software, version 3.13 [15]. Significance of the statistical tests was fixed at $\alpha = 0.05$.

3. Results

A total of 3058 insect individuals representing 21 families and 40 species were identified from MLFR over a period of three months, between July and October 2017 (Table 1). Insect abundance was lowest in disturbed habitats (17.40 %, 532 individuals) followed by less disturbed habitats (32.50%, 995 individuals), while being highest in undisturbed habitats (50.10%, 1531 individuals) (Table 2). Three species in the family Scarabaeidae (*Onthophagus hecate*, *Copris minutus, and Onthophagus aff.andersoni*), and in Acrididae (*Leptysma marginicollis*, *Sphingonotus sp*, and *Acanthacris rupicornis*), two in Nymphalidae (*Junonia hierta*, and *Acraea esebria*), and one in Carabidae (*Atractonotus mulsanti*) and Mantidae (*Archimantis latislyla*), were absent in disturbed habitats. A single species (*Acanthacris ruficornis*) in the family Acrididae was absent in less disturbed habitats. All identified species from the study site were present in undisturbed habitats. Greatest abundance of coleopterans, 48 (Carabidae) and 173 (Scarabaeidae) individuals were recorded in undisturbed habitats (Table 2).

Table 1: Overview of insect families, order and species found on Mt. Loleza in Mbeya, and abundance in disturbed (dist), less disturbed (less dist.) and undisturbed (undist) habitats

				Abundance		
Order	**Family**	**Species**	**Species code**	**Dist.**	**Less dist.**	**Undist.**
Coleoptera	Tenebrionidae	*Asida sp*	Sp1	11	13	35
		Oryctes sp	Sp2	9	4	7
		Eleodes tricostatus	Sp3	34	48	64
	Coccinellidae	*Cheilomenes lunata*	Sp4	13	11	78
	Curculionidae	*Larinus planus*	Sp5	6	4	13
	Meloidae	*Hycleus lugens*	Sp6	10	13	21
	Carabidae	*Atractonotus mulsanti*	Sp7	0	13	48
	Scarabaeidae	*Onthophagus hecate*	Sp8	0	6	34
		Kheper nigroaeneus	Sp9	9	0	34
		Gymnopleurus humanus	Sp10	11	9	22
		Copris minutus	Sp11	0	23	39
		Onthophagus aff.andersoni	Sp12	0	34	44
Mantodea	Mantidae	*Archimantis latislyla*	Sp13	0	4	11
		Sphodromantis sp	Sp14	12	23	7
Hymenoptera	Formicidae	*Dorylus sp*	Sp15	31	51	59
		Technomyrmex sp	Sp16	21	27	35
	Apidae	*Apis mellifera*	Sp17	15	69	97

	Vespidae	*Polistes dominulas*	Sp18	9	11	34
Lepidoptera	Nymphalidae	*Junonia hierta*	Sp19	0	7	11
		Acraea uvui	Sp20	6	18	12
		Acraea encedon	Sp21	12	17	29
		Acraea esebria	Sp22	0	12	19
		Pseudacraea sp	Sp23	8	3	7
		Danaus chrysippus	Sp24	9	11	17
		Precis tugela	Sp25	9	29	31
		Hamanumida daedalus	Sp26	12	13	51
	Pieridae	*Colias sp*	Sp27	11	23	23
	Noctuidae	*Achaea sp*	Sp28	23	67	81
Diptera	Muscidae	*Musca domestica*	Sp29	34	89	108
Hemiptera	Belostomatidae	*Abedus indentatus*	Sp30	24	28	39
	Coreidae	*Anoplocnemis curvipes*	Sp31	5	0	9
	Miridae	*Phytocoris trivial*	Sp32	1	19	11
Odonata	Caloplerygidae	*Phaon iridipennis*	Sp33	3	9	12
	Lestidae	*Archilestes grandis*	Sp34	51	59	83
Blattodea	Blattidae	*Periplaneta sp*	Sp35	64	87	91
	Acrididae	*Truxalis nasuta*	Sp36	2	12	17
		Abisares vitripennis	Sp37	67	91	101
		Leptysma marginicollis	Sp38	0	1	7
Orthoptera		*Sphingonotus sp*	Sp39	0	37	75
		Acanthacris ruficornis	Sp40	0	0	15
		Total number of individuals		532	995	1531

Table 2: Number of families, abundance, and species of insects collected in disturbed (Dist), less disturbed (Less dist) and undisturbed (Undist habitats)

Family	Family code	Abundance			Number of species		
		Dist.	Less dist.	Un dist.	Dist.	Less dist.	Un dist.
Tenebrionidae	F1	54	65	106	3	3	3
Coccinellidae	F2	13	11	78	1	1	1
Curculionidae	F3	6	4	13	1	1	1
Meloidae	F4	10	13	21	1	1	1
Carabidae	F5	0	13	48	0	1	1
Scarabaeidae	F6	20	72	173	2	4	5
Mantidae	F7	12	27	18	1	2	2
Formicidae	F8	52	78	94	2	2	2
Apidae	F9	15	69	97	1	1	1
Vespidae	F10	9	11	34	1	1	1
Nymphalidae	F11	56	110	177	7	8	8
Pieridae	F12	11	23	23	1	1	1
Noctuidae	F13	23	67	81	1	1	1
Muscidae	F14	34	89	108	1	1	1
Belostomatidae	F15	24	28	39	1	1	1
Coreidae	F16	5	0	9	1	1	1
Miridae	F17	1	19	11	1	1	1
Caloplerygidae	F18	3	9	12	1	1	1
Lestidae	F19	51	59	83	1	1	1
Blattidae	F20	64	87	91	1	1	1
Acrididae	F21	69	141	215	2	5	5
Total individuals/species		532	995	1531	31	39	40

The insect abundance did not differ significantly between disturbed and less disturbed ($p > 0.05$), but differed between disturbed and undisturbed ($p < 0.05$), and between less disturbed and undisturbed habitats ($p < 0.05$) (Fig. 4). The number of species identified in disturbed habitats was slightly lower than in less disturbed and undisturbed habitats. This difference was not statistically significant ($p > 0.05$) (Fig. 5). Undisturbed habitats showed high Shannon diversity (2.83), Simpson index of diversity (0.98), species richness (Margalef index of 3.93), Fisher's α (3.55) and Berger-Parker dominance index (0.18) as shown in Table 3. Diversity t-test indicated that Shannon diversity did not differ significantly between disturbed and less disturbed ($t = 0.38476$, $df = 162.56$, $p = 0.701$); but differed between disturbed and undisturbed habitats ($t = 1.2897$, $df = 162.16$, $p = 0.020$), and between less disturbed and undisturbed habitats ($t = 1.01$, $df = 226.42$, $p = 0.014$). Simpson diversity differed significantly between disturbed and undisturbed habitats ($t = 0.8787$, $df = 155.18$, $p = 0.028$); but this difference was not significant between disturbed and less disturbed habitats ($t = 0.324$, $df = 160.57$, p

= 0.747), and between less disturbed and undisturbed habitats (t = 0.60637, df = 221.63, p = 0.545). Furthermore, the abundance was greatest at higher elevations or altitudes compared to lower elevations (Fig. 6). Most disturbed habitats were located at lower elevation (Fig. 6).

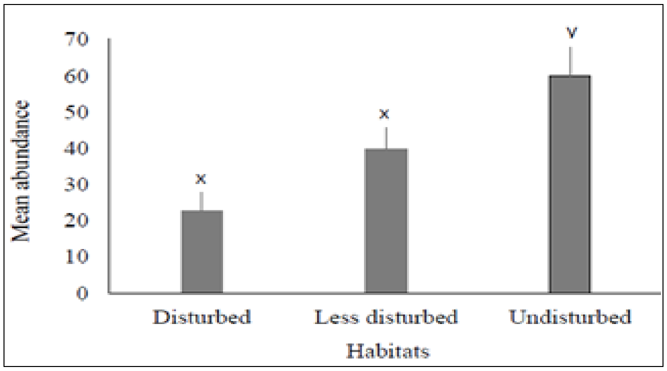

Fig. 4: Comparison of mean (± SE) abundance of insects in disturbed, less disturbed and undisturbed habitats. Means with different letters are significantly different ($F_{(2, 60)} = 5.936$, $p = 0.004$)

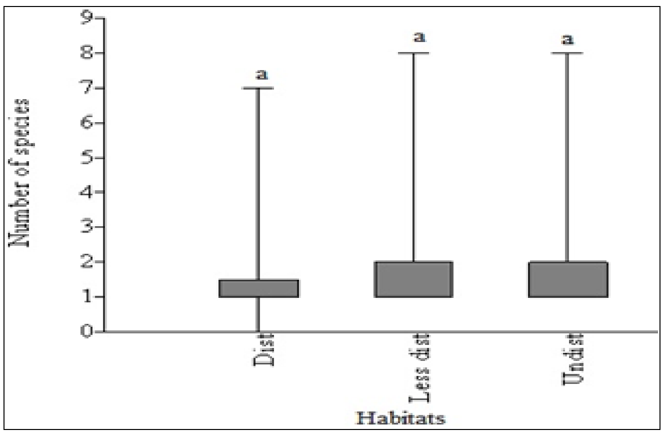

Fig 5: Comparison of species richness between disturbed, less disturbed and undisturbed habitats. Letters on the error bars indicate no significant difference in the number of species (H = 0.4308, p = 0.712)

Table 3: Diversity indices at disturbed, less disturbed and undisturbed habitats

Diversity indices	Habitats		
	Disturbed	Less disturbed	Undisturbed
Simpson	0.92	0.93	0.98
Shannon	2.65	2.69	2.83
Evenness	0.71	0.74	0.73
Margalef	3.03	3.75	3.93
Fisher's α	3.11	3.44	3.75
Berger-Parker	0.13	0.14	0.18

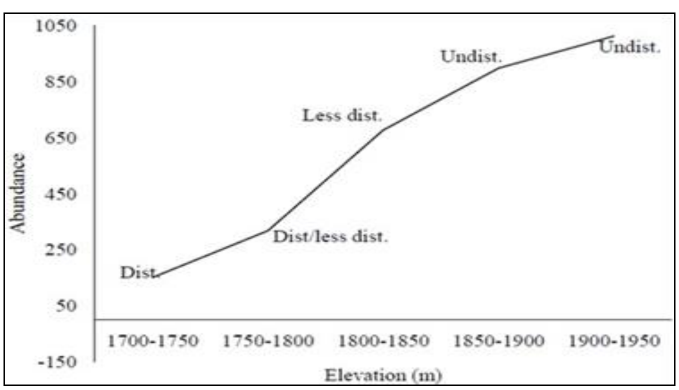

Fig 6: Abundance in disturbed, less disturbed and undisturbed habitats at different elevation on MLFR

Related insect species and families in terms of the number of species (Fig. 7) and abundance (Fig. 8) were grouped together respectively. Moreover, it was learnt that the ecosystem of MLFR is under pressure due to human activities that include encroachment, fuel wood collection, logging, grazing, habitat disintegration, forest fires, and invasion from exotic species. Others encompass human settlement and agricultural activities which were observed to be on the rise near the mountain forest ecosystem.

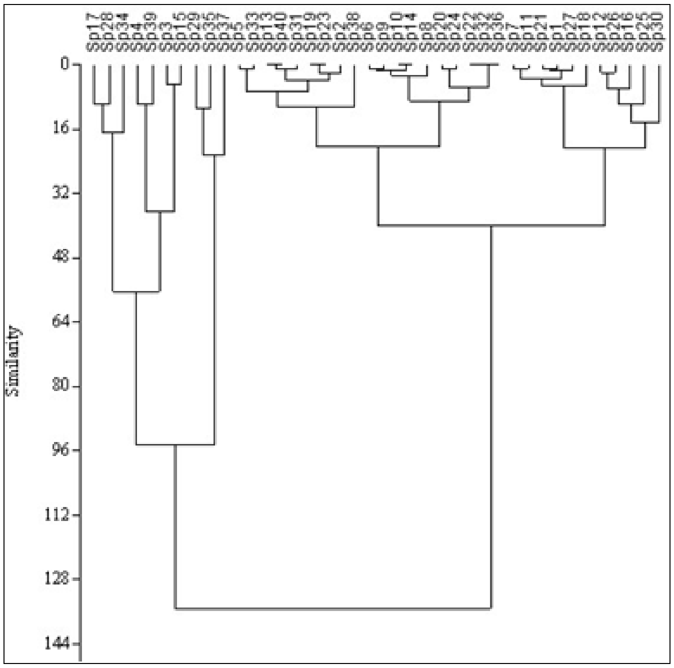

Fig 7: Dendrogram of cluster analysis. The Bray-Curtis similarity index of the species based on the number of individuals from MLFR habitats. Species are presented by their code in table 1.

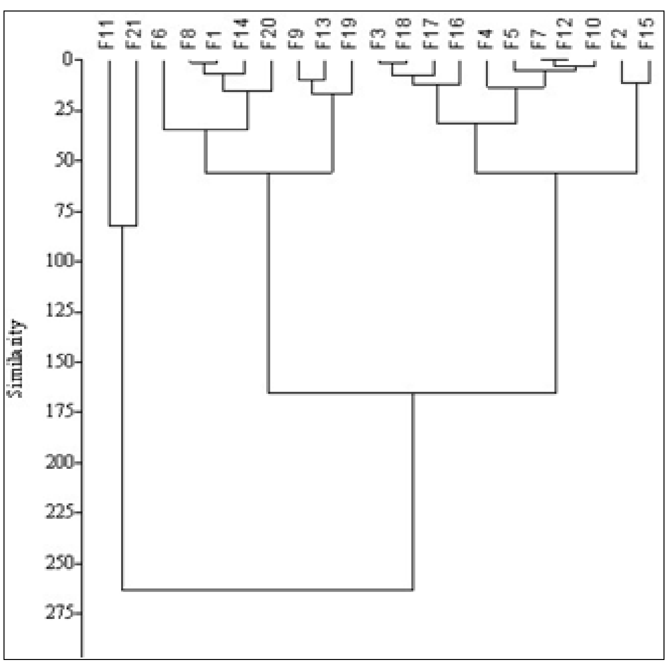

Fig 8: Classification of families using the Bray-Curtis similarity based on abundance data from the MLFR habitats. Families are presented by their code in table 2.

4. Discussion

This study observed that the integrity and resilience of MLFR as well as its ecosystem are impacted by a number of threats. These include human exploitation, fuel wood collection, logging, grazing, habitat disintegration, forest fires, and invasion from exotic species. Heat and smoke as a result of repeated forest fires in the area cause severe impacts on the ecosystem structure and ecological communities through direct individuals' mortality [2, 13]. Anthropogenic changes on the mountain forests decrease suitable habitats available for insects [12]. Loss of suitable or quality habitats affect negatively the population dynamics, distribution, and abundance of insects [4]. Based on the results and observations of this study, disturbed habitats had fewer trees with diminished ground cover and microhabitats for insects. Due to this, disturbed habitats had fewer number of insects compared to less disturbed and undisturbed habitats (Table 1 and 2). Therefore, land-use causing disturbances is a major cause of ecological change and biodiversity loss [5, 13].

Species, such as, *Onthophagus hecate, Copris minutus, Onthophagus aff.andersoni, Archimantis latislyla, Leptysma marginicollis, Sphingonotus sp, Acanthacris ruficornis, Atractonotus mulsanti*, *Acraea esebria* and *Junonia hierta*, were absent in disturbed habitats (Table 1). These species are sensitive to environmental changes, and prefer living in undisturbed habitats. For example, the coleopterans *Atractonotus mulsanti*, *Copris minutus*, *Onthophagus aff. andersoni*, and *Onthophagus hecate*. The abundance and diversity of coleopterans are known to decline where anthropogenic changes occur in the habitats [3]. The abundance and species diversity of coleopterans, especially Carabidae, the ground beetles, was found to be greatest in undisturbed habitats (Fig.4, Table 2). These ground beetles prefer living in quality environments i.e. with fewer or no disturbances [1]. Thus, they are often used as bioindicators for ecosystem health or quality.

[8, 10] reported that habitats disturbance is one of the main threats to insect biodiversity and ecological functions of tropical ecosystems [1]. on the other hand argued that habitat disturbances are one of the key factors affecting species diversity and composition. In Table 3, the impact of disturbance is revealed by the lowest values of diversity indices in disturbed habitats compared to undisturbed habitats. The greatest value of Margalef index in undisturbed habitats and lowest in disturbed habitats indicate the greater number of species at undisturbed habitats. Accordingly, the highest value of Berger-Parker Dominance Index (BPI) and Fisher's α in undisturbed habitats indicate greater dominance in single species and greatest diversity in undisturbed habitats respectively (Table 3). In addition, these results have showed that habitats without anthropogenic changes have significantly higher Shannon and Simpson index of diversities compared to disturbed habitats. Similarly, in the absence of anthropogenic disturbances, undisturbed habitats have higher species richness compared to disturbed habitats (Fig. 5).

Moreover, undisturbed habitats with greater insect abundance were found at high elevations where anthropogenic activities are minor (Fig. 6). These habitats are few of the small fragments of semi-natural habitats prevailing in the study area. Additionally, due to human exploitation and associated disturbances on the MLFR at lower elevations, habitat patches, plant species composition, and habitat connectivity reduced [2, 16]. This is due to the fact that local people are more frequently collecting fuelwood, burn and cut down trees at lower elevations; similarly, livestock are grazed and farming are practiced most often at these elevations. Therefore, insect populations, species composition, abundance, diversity, and colonisation rates are very low [12, 16]. The lowest abundance of insects in Fig. 6 recorded at lower elevations may be due to anthropogenic changes [6].

In the dendrogram (Fig. 7), insect species with similar or close number of individual species are joined together to form a single cluster. For example, *Apis mellifera* (Sp17) and *Achaea* sp (Sp28) are similar and joined to form the first cluster (with a similarity or height of > 5); other species with similar number of individual includes but not limited to *Larinus planus* (sp5), *Phaon iridipenni*s (sp33), *Archimantis latislyla* (sp13), *Acanthacris ruficornis* (sp40), *Anoplocnemis curvipes* (sp31), *Junonia hierta* (sp19), *Pseudacraea* sp (sp23), and *Oryctes* sp (sp2). In Fig.8, the dendrogram shows abundance similarity in insect families; Formicidae (F8), Tenebrionidae (F1), Muscidae (F14), and Blattidae (F20) are among the similar families in the sampled habitats. Families or species clustered together are more likely were sampled from habitats with similar disturbance gradient, and therefore, may have comparable habitat preference.

It is documented that the main driver of ecological changes and species endangerment at worldwide scale is anthropogenic change [5]. Similarly, this study has indicated that habitat disturbances as a result of anthropogenic change on MLFR are strongly influencing insect diversity levels. If these disturbances continue, insect abundance and diversity will be restricted and may even continue decreasing. Therefore, in relation to conservation measures, anthropogenic changes must be regulated to promote diversity and forest conservation in the study area. Essentially, areas at lower elevation need constant monitoring because this study has shown that anthropogenic changes most often occur at these elevations. The TFSA could achieve this through joint community conservation and management programme, for instance, community based forest management. Local people living adjacent to MLFR should be involved in management of the mountain forest via a participatory forest management (PFM) approach. The author projects that if the habitats of MLFR are properly conserved, the ecosystem is bound to attract thousands of animal species in the near future.

5. Conclusion

Although this study is a preliminary one, regarding MLFR, its results are important because they reveal that anthropogenic changes on the mountain impact the insect biodiversity. These results also form a significant step towards effective conservation of global biodiversity and management of mountain forest ecosystems. Since little is presently known about the ecosystem health of the mountain, further studies are required to assess the abundance and diversity of animals and plants. This baseline information will enable population changes of insects and anthropogenic impacts to be quantified, to reassess conservation, management and protection status of MLFR. Conversely, for now, based on observed abundance of insects in disturbed habitats, conservation measures for MLFR seem desirable in Tanzania.

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