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DIVERSITY OF RIPARIAN GROUND BEETLES (COLEOPTERA, CARABIDAE) AT THREE ALTITUDES IN ULUGURU MOUNTAINS, TANZANIA

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ABSTRACT: The diversity of riparian ground beetles at three altitudes (Low: 400-1100m a.s.l., Mid: 1100-1800 m a.s.l., High: 1800-2500 m a.s.l.) in Uluguru Mountains was investigated. The samples of ground beetles were collected by active searching method from nine sites between May and June 2012. A total of 3261 specimens of ground beetles representing 13 subfamilies and 29 species were recorded. Ground beetle abundance, species richness and diversity were analyzed statistically using Diversity and Richness–2.65, PRIMER 6 and SYSTAT Version 10 software. The abundance of ground beetles was low at mid altitude (n = 499) and high at low and high altitudes (n = 1988; n = 774 respectively). There was significant variation in ground beetle abundance among the three altitudes (Kruskal-Wallis H=84.533, p<0.05). The most abundant species, *Trechodes babaulti*, was abundant at low and high altitudes (n=1534; 47.04% and n=501; 15.36% of the collected beetles respectively). Both species richness and Shannon-Wiener index of diversity (H') of ground beetles varied between low, mid and high altitudes with the highest species richness and diversity found at mid altitude. Pairwise comparison showed a significant difference in diversity of ground beetle species for all three pairs (high/mid, high/low & mid/low) of altitudes (p<0.05).

Key words: diversity, altitude, riparian, ground beetles, Uluguru Mountains

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INTRODUCTION

The Uluguru Mountains (UMs) block is one of the most outstanding of the Eastern Arc Mountain (EAM) blocks. They are situated in eastern Tanzania to the south east of the main EAM chain, around 180 Km from the Indian Ocean [1]. The UMs range between 7°2' - 7°16' S and 38°0' - 38°12' E and rise from around 150 m a.s.l on their south-eastern margin and they extend to 2630 m a.s.l at their highest point, Kimhandu Peak [2, 3]. These mountains are considered to be one of the most important forest blocks in Africa in terms of biodiversity conservation [4]. In addition, they are also home to over one hundred thousand people, mostly from the Luguru community. The mountains further provide an important source of water supply for Morogoro, Coast and Dar es Salaam regions in Tanzania [5]. Despite their ecological and economic significance, the forests of the UMs face an increasing pressure from human activities, which threaten the biodiversity of the area.

Living organisms, including ground beetles, have been widely used as indicators of environmental change and the health of ecosystems or habitats [6, 7, 8]. The way in which biodiversity responds to direct and indirect impacts is a useful indicator of change when compared against a baseline [9].

Baseline inventories are therefore important as they can serve as indicators of the impacts of climate change [6, 9] and other forest transformations. The Ground beetle fauna of the UMs has been documented in two surveys carried out in 1957-59 [10] and another survey in 1971 [11]. These are Museum collections which do not address many ecological questions, including distribution patterns. There has been no recent survey in the UMs, despite the fact that forest clearing for food crop production and other threats continues to escalate.

In the present study, the riparian ground beetles were collected from sites located along stream banks (riparian habitat) at three altitudes in the UMs in order to investigate their diversity in relation to altitude variation. Rarely occurring species within the sample set were also evaluated.

MATERIALS AND METHODS

Study areas

This study was conducted in the UMs' riparian areas. In this study, a riparian area was defined as the interface between land and a stream. The riparian ground beetles were sampled at nine sampling sites (located at different streams) ranging from 400m a.s.l to 2200m a.s.l covering three altitude (high, mid and low) (Figure 1). The samples of the ground beetles were collected along the banks of Bigwa, Vituli and Lukuyu streams (Bigwa area in the low altitude: 400m-1100m a.s.l), Mungula, Nola and Malongole streams (Bunduki Village in the mid altitude: 1100m–1800m a.s.l) and Zagila, Nyamigadu and Lung'angale streams (Tchenzema Village in the high altitude: 1800m–2500m a.s.l) (Table 1). Both high and mid altitude study sites were forested areas located in the Uluguru Nature Reserve (UNR) just 100 m from the forest edge and low altitude study sites were forested areas (remnant forest) located outside the UNR under the management of the Morogoro Urban Water Supply and Sanitation Authority (MORUWASA). Two sites (Lung'angale and Zagila streams) at high altitude had signs of illegal logging activities. The vegetation cover for both high and mid altitude study sites was more or less similar characterized by the presence of large trees, ferns and various types of herbs while low altitude sites had few large trees and herbs. In addition, the areas close to low altitude sites were heavily inhabited and dominated by farming and quarry mining activities. Although all the study sites were forested, high and mid altitude sites were much more shaded compared to low altitude sites and in addition high altitude sites had signs of illegal logging activities and some few open spaces. Each stream or sampling site measured 110m long and 3m on each side from the stream-water boundary (that is 6m width in total). At each sampling site, three sampling points (10 m long each) were established at a distance of 40m from each other (only a few sampling points differed slightly with a range of 38-42m apart depending on the nature of the terrain and accessibility of the stream).

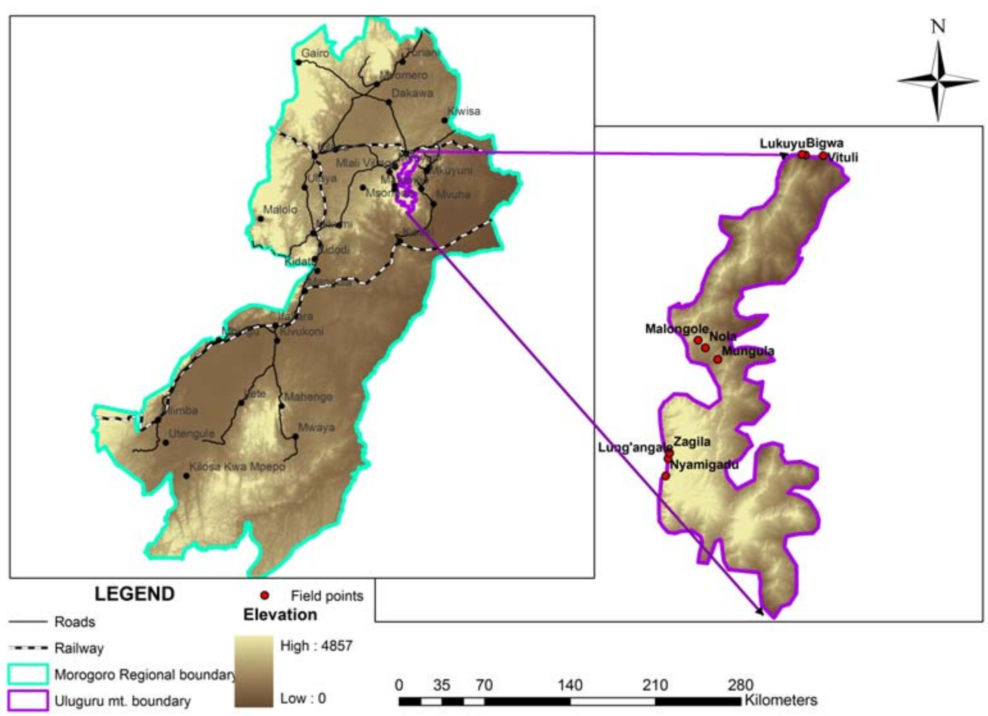

Figure 1: Map of Morogoro Region showing the location of the study sites in the UMs

Beetle sampling

Sample collection was conducted between May and June 2012. It involved active searching for the ground beetles on the ground, in leaf litter and in other hiding places such as under logs, stones and large debris found along stream banks during the day. Moist leaf litter was scooped onto a piece of white cloth (1.0 m^2) and ground beetles were caught using an aspirator or by hand. The ground beetles collected by each of the four collectors that were involved for a period of one hour within a sampling point constituted one 'sample' and were placed in a plastic vial or plastic bag. At each sampling point, 10 samples were collected making a total of 30 samples per site. All the collected ground beetles were preserved in 75% ethanol. The geographical position and altitude of each site were recorded using a GPS (Garmin GPS 60, accuracy ± 7 - 21 m).

In the laboratory, the collected ground beetles in each of the 270 samples collected from the nine sites were identified to species level wherever possible. Identification of ground beetles was done according to Basilewsky and White [12, 13] in which nine species were identified to species level and other specimens were assigned to morph species with classification based on external morphology, not including genitalia. Voucher specimens were lodged with the Zoology Laboratory of the University of Dar es Salaam for future reference purposes.

Table 1: Locality data for the nine sites at three altitude belts (GPS readings: UTM zone 37S).

SITE (STREAM)	GPS READING FOR SAMPLING POINTS	ALTITUDE	ALTITUDE BAND	DESCRIPTION
Lung'angale	0345513 0345022 0345011 9213931 9213855 9213846	2107, 1889, 1881	1800-2500	<u>High altitudinal level</u> Large trees & few open areas with few trees, ferns, herbs, illegal logging & farming activities around
Zagila	0345671 0345574 0345114 9214503 9214509 9214681	2068, 2054, 1874	1800-2500	
Nyamigadu	0345304 0345232 0344601 9212239 9212223 9212383	1989, 1985, 1930	1800-2500	
Malongole	0348434 0348256 0348403 9225595 9225046 9225631	1774, 1565, 1752	1100–1800	<u>Mid altitudinal level</u> Large trees & ferns, herbs with little disturbance
Nola	0349139 0349205 0349284 9224855 9224834 9224745	1578, 1547, 1528	1100–1800	
Mungula	0350371 0350345 0350255 9223716 9223703 9223667	1473, 1467, 1449	1100–1800	
Vituli	0360664 0360592 0360564 9244606 9244626 9244618	665, 656 642	400–1100	<u>Low altitudinal level</u> Few large trees, surrounding area heavily inhabited with farming and quarry mining activities
Lukuyu	0358947 0358994 0359181 9245483 9245348 9246520	593, 623 608,	400–1100	
Bigwa	0358494 0358482 0358497 9245515 9245685 9245623	597, 589, 584	400–1100	

GPS reading format: UTM system (Universal Transverse Mercator coordinate system)

Data analysis

The Shannon-Wiener diversity index was calculated using Diversity and Richness–2.65 software [14] and PRIMER 6 software [15]. Riparian ground beetle species diversity between pairs of altitudes was compared using student's t-test. Kruskal-Wallis test was performed using SYSTAT Version 10 [16] to compare the abundance of ground beetles among altitudes. The number of beetle species with rare occurrence within the sample set was estimated using taxonomic index. The taxonomic index is often used in biodiversity studies from a taxonomic perspective and accounts for rarely occurring species as singletons and doubletons (when a species is represented by one and two specimens respectively) and it also includes species represented by three, four and five specimens [9, 17]. In this study therefore all collected ground beetle species with individuals ranging from one to five were defined as rarely occurring species.

RESULTS

A total of 3261 individuals belonging to twenty nine species from thirteen subfamilies of the Carabidae were collected. The most speciose subfamilies were Bembidiinae (represented by 8 morphospecies), Anchomeninae (4 morphospecies) and Pterostichinae (4 morphospecies).

In addition to having high species richness, the three subfamilies and a fourth (the Trechinae) showed high abundance: Trechinae (n = 2304), Bembidiinae (n = 572), Pterostichinae (n = 214) and Anchomeninae (n = 98). Among the nine sites the greatest number of individuals (n = 969) were collected at Bigwa stream, a low altitude site, while the least number of individuals (n = 85) were collected at Nola stream, one of the mid altitude sites (Figure 2).

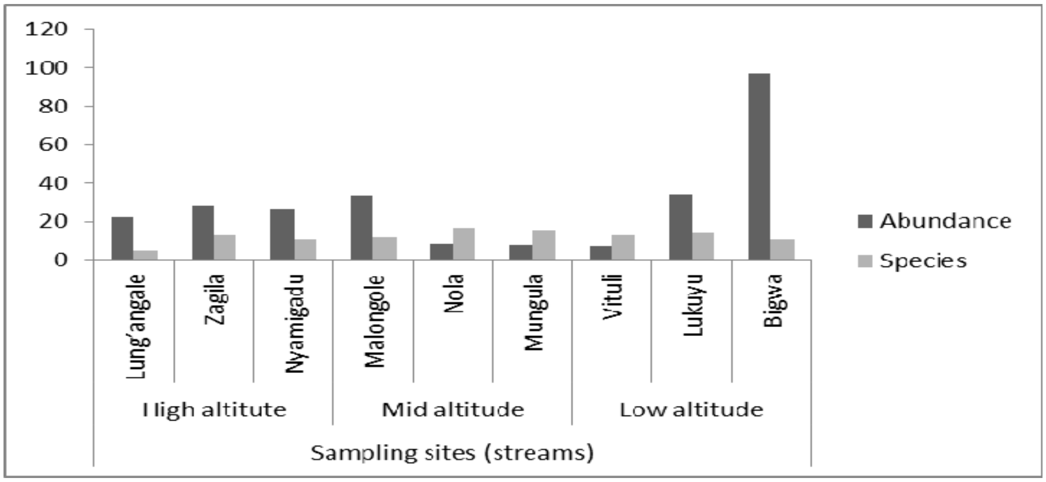

Figure 2: Abundance (x 10) and number of riparian ground beetles species at each sampling site (stream) along three altitude belts.

The number of individual ground beetles collected varied greatly with altitudes, with the highest abundance found at low altitude, followed by high altitude and the least abundance found at mid altitude (Table 2). Kruskal-Wallis one-way analysis of variance showed a significant difference in abundance of riparian carabid beetles between the three altitudes (Kruskal-Wallis H = 84.533, $p < 0.05$). *Trechodes babaulti* (Trechinae) was the most abundant species and attained high numbers of ground beetles at both low and high altitudes (n = 1534; 47.04% and n = 501; 15.36% of the total catch respectively) except at mid altitude (n = 7; 0.002%). When the most abundant species, *Trechodes babaulti* was considered as an outlier (because it had extremely more individuals than the rest of the species) and removed from the sample, mid altitude bulge pattern of abundance was obtained. In this case high altitude had the lowest abundance of carabid beetles (n = 273; 22.40%), followed by low altitude (n = 454; 37.24%) while mid altitude had the highest abundance (n = 492; 40.36%). After removing *Trechodes babaulti* from the sample, there was a significant statistical difference (Kruskal-Wallis H = 9.149, $p < 0.05$).

Species richness (s) of the ground beetles also varied with altitude. It was high at mid altitude (23 species) and low at both high and low altitudes (18 species each) (Table 3). The highest diversity was also observed at mid altitude (H′ = 2.1676) followed by high altitude (H′ = 1.3422) and the lowest diversity was found at low altitude (H′ = 1.0370). The presence or absence of *Trechodes babaulti* in the sample did not affect the pattern of ground beetle species richness and diversity as it was for abundance.

Pair wise comparison showed a significant difference in diversity of riparian ground beetle species for all three pairs of altitudes (Table 3). Also the number of species differed among sites at different levels of altitude ranging from 5 to 13, 12 to 17 and 11 to 14 at high, mid and low altitude respectively (Figure 2). The analysis indicated that species richness was generally inversely proportional to the ground beetle species abundance. This was clearly indicated by high species richness and low species abundance at the mid altitude in general as well as at Nola stream in particular (Figure 2).

The results from this study showed a low level of site specificity for ground beetle species and subfamilies. 72% of species occurred at two or all three altitudes. The majority of species (41.38%: 12 out of 29 species) were collected at two altitudes. Species collected at only one altitude accounted for 27.57% (8 out of 29 species) whereas 31.03% (9 out of 29 species) of species were found at all the three altitudes (Figure 3). *Trechodes babaulti* occurred at all the three altitudes and was the most abundant species, represented by 2042 individuals accounting for 62.62% of the total individuals collected. At subfamily level, similar trends occurred, with 23.08% (3 out of 13 subfamilies) limited to one altitude, whereas 38.46% (5 out of 13 subfamilies) were found at all the three altitudes (Table 3).

Table 2: List of subfamilies, genera, morphospecies, total and average (± se) abundance of ground beetles collected at High, Mid and Low altitude belts.

S.No	Subfamily	Genus	Species	Altitude belt		
				High	Mid	Low
1	Anchomeninae	*Metagonum*	*Metagonum* sp.1	1	8	0
2	Anchomeninae	*Metagonum*	*Metagonum mboko*	44	34	6
3	Anchomeninae	*Metagonum*	*Metagonum* sp.2	1	0	0
4	Anchomeninae	*Metagonum*	*Metagonum* sp.3	4	0	0
5	Bembidiinae	*Peryphus*	*Peryphus meruanus*	0	74	6
6	Bembidiinae	*Tachys*	*Tachys* sp.1	0	4	28
7	Bembidiinae	*Peryphus*	*Peryphus* sp.1	91	47	15
8	Bembidiinae	*Peryphus*	*Peryphus* sp.2	1	56	24
9	Bembidiinae	*Peryphus*	*Peryphus* sp.3	59	9	67
10	Bembidiinae	*Tachys*	*Tachys* sp.2	26	0	9
11	Bembidiinae	*Tachys*	*Tachys* sp.3	3	2	0
12	Bembidiinae	*Tachys*	*Tachys* sp.4	0	4	47
13	Brachininae	*Crepidogaster*	*Crepidogaster pauliani*	0	13	2
14	Harpalinae	*Diatypus*	*Diatypus uluguruanus*	0	3	0
15	Helluoninae	*Triaenogenius*	*Triaenogenius* sp.1	4	2	0
16	Lebiinae	*Afrotarus*	*Afrotarus kilimanus*	0	9	0
17	Odacanthinae	*Odacantha*	*Odacantha sp.1*	0	0	1
18	Odacanthinae	*Odacantha*	*Odacantha sp.2*	0	1	0
19	Omophroninae	*Omophron*	*Omophron africanus*	0	0	1
20	Panagaeinae	*Craspedophorus*	*Craspedophorus* sp.1	2	2	0
21	Pterostichinae	*Abacetus*	*Abacetus* sp.1	3	29	10
22	Pterostichinae	*Abacetus*	*Abacetus* sp.2	6	10	126
23	Pterostichinae	*Abacetus*	*Abacetus* sp.3	5	2	4
24	Pterostichinae	*Abacetus*	*Abacetus* sp.4	17	2	0
25	Scaritinae	*Clivina*	*Clivina fossor*	0	1	23
26	Scaritinae	*Scarites*	*Scarites linearis*	3	0	0
27	Thyreopterinae	*Thyreopterus*	*Thyreopterus* sp.1	0	1	5
28	Trechinae	*Trechodes*	*Trechodes* sp.1	3	179	80
29	Trechinae	*Trechodes*	*Trechodes babaulti*	501	7	1534
			Total abundance	**774**	**499**	**1988**
			Average abundance (±se)	**26.7±17**	**17.2±7**	**68.6±52**

Key: (±se) – Standard error

Table 3: Species richness, number of subfamilies and specificity by taxa and pair-wise comparison of ground beetle species diversity at the three altitude belts.

	Altitude Belts			Diversity Comparison Pairs	Delta	Probability (p)
	High	**Mid**	**Low**	High & Mid altitude	0.82535	Less than 0.05
Species	18 (3)	23 (3)	18 (2)	High & Low altitude	0.30524	Less than 0.05
Subfamilies	7 (0)	12 (2)	9 (1)	Mid & Low altitude	0.13059	Less than 0.05

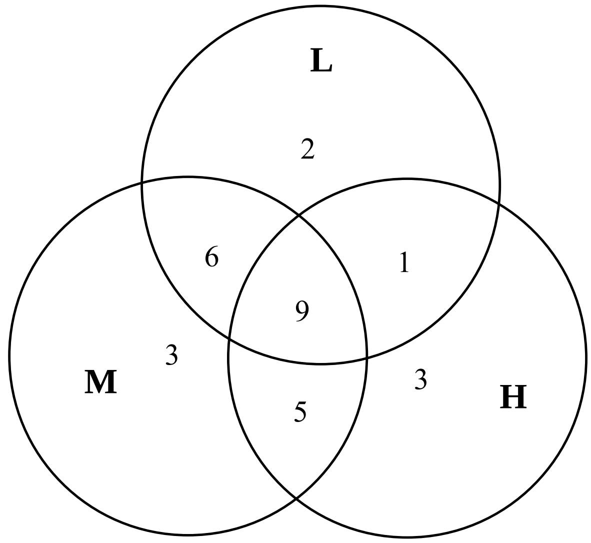

Figure 3: VENN Diagram showing species restricted to each Altitude belt and species shared among altitude belts (Key: H - High altitude belt, M - Mid altitude belt and L - Low altitude belt)

The taxonomic index (an index of rarity) showed that nine ground beetle species (31.03%) or approximately one third of the twenty nine species recorded in the sample set were represented by five or fewer individuals. These occurred at all the three altitudes with some species being restricted to particular altitudes (Table 2). The taxonomic index showed an increase in the proportion of rare species with increasing altitude level.

DISCUSSION

This study represented first biodiversity inventory of riparian ground beetles at three altitudes in the Uluguru Mountains. Most of the ground beetles collected belonged to groups containing riparian species such as subfamily Bembidiinae and Trechinae [18, 19]. The ground beetle groups such as Pterostichinae considered to contain some forest floor specialist species and species preferring damp habitats were also recorded [20, 21].

The abundance of ground beetles species collected in the present study indicated lowest abundance at the mid altitude and highest abundance at low and high altitudes. Similar results have also been obtained by Nyundo & Yarro [22] in the study carried out in the Udzungwa Mountains National Park, one of the EAM blocks, involving forest floor ground beetles. The high abundance of ground beetles at mid altitude can be explained by the species composition at the three altitudes. According to Blackburn & Gaston [23] species are not equally abundant based on the amount of energy available to species of different body sizes. At the low altitude the dominant species, *Trechodes babaulti*, attained high abundance (n=1534). This species was also the most abundant species at high altitude giving a total of 501 individuals collected, however only 7 individuals were recorded at mid altitude. A virtual absence of *Trechodes babaulti* at mid altitude may be one of the reasons for the observed low abundance of ground beetles. At the mid altitude sites the dominant species (*Trechodes* sp.1) had relatively lower abundance (n = 179) as compare to *Trechodes babaulti* at both high and low altitudes. *Trechodes* sp.1 (Trechinae) occurred also at low altitude with its individual abundance reduced to almost half and also occurred at high altitude with only 3 individuals. The assemblages of ground beetles are known to fluctuate usually with vegetation cover and local edaphic conditions [24, 25]. Two high altitude sites (Lung'angale and Zagila streams) and low altitude sites (Bigwa, Vituli and Lukuyu) were greatly dominated by human activities than it was for mid altitude sites.

The low altitudes sites were sources of stones and gravels for building activities and the areas surrounding such riparian habitat were residential and cultivated farmland. Lung'angale and Zagila streams were dominated by illegal logging. Despite such disturbance, *Trechodes babaulti* attained high abundance; this may be indicating tolerance to disturbance and preference to areas that are not heavily shaded. Similar trend of abundance shown by *Trechodes babaulti* has been shown by *Peryphus* sp.3 (subfamily Bembidiinae). These species had very few individual ground beetle records at mid altitude. There is a possibility that disturbance created habitat heterogeneity which supported high abundance of ground beetles at low altitude. Habitat disturbance may have favoured high abundance of *Trechodes babaulti* and *Peryphus* sp.3 by creating varieties of disturbed and undisturbed micro-habitats. This may also be an indication of disturbance tolerance of the two species, *Trechodes babaulti* and *Peryphus* sp.3.

The results of the present study support the view which suggests an increase in species richness and diversity to mid altitudes before falling off towards higher elevations [26, 27]. Mid elevation peaks in species richness has been frequently documented for dung [28], ants [29, 30], invertebrates in general [31], vertebrates groups such as birds [26, 32, 33], small mammals [34], herpetofauna [35, 36], and plants [37, 38, 39]. In the present study, the mid altitude peak in species may be a result of contact and mixing of ground beetle communities characterized by different environmental adaptations from high and low altitudes. The decline in both species richness and diversity of ground beetles towards higher altitudes may suggest also a change in some environmental factors that may limit beetles assemblages. Alternative explanation for high species richness and diversity of ground beetles at mid altitude may be a result of human mediated disturbances occurring at low altitude. Mid altitude was less influenced by anthropogenic activities than both low and high altitudes. Relatively undisturbed sites may be suitable for a greater variety of species and with this view disturbed habitats should support communities with reduced diversity that include mixtures tolerant native and non-native species [29].

In addition to the variation in species richness among the three altitudes, the results from this study showed a low level of site (altitude) specificity for ground beetle species and subfamilies. This is because more than 70% of all the species and subfamilies were recorded at more than one altitude indicating a wide distribution range. *Scarites linearis*, *Metagonum* sp.2 and *Metagonum* sp.3 were specific to high altitude; *Afrotarus kilimanus, Diatypus uluguruanus* and *Odacantha* sp.2 were specific to mid altitude while *Odacantha* sp.1 occurred only at low altitude. Wide range distribution of ground beetles may be a result of a range of habitat associations based on local micro-habitat conditions [24]. Rare species also appeared to be wide ranging species occurring at all altitudes with some few species occurring at specific altitudes.

CONCLUSIONS AND RECOMMENDATIONS

This study revealed that in the Uluguru Mountains species richness and diversity of riparian carabid beetles increase to the mid altitudes, followed by a decrease in species richness towards higher altitudes. A total of 3261 individuals represented by 29 species were collected from the three altitudes in the Uluguru Mountains. From the evaluation of abundance and species, it appears that Uluguru Mountains are rich in ground beetle fauna. Spatially, different parts of the Uluguru Mountains have different abundance and diversity of riparian carabid beetles. Moreover attempts to sample more habitat types not covered by the present study should be made in order to obtain a better picture of the diversity of carabid beetles. Inventories should also be carried out during other times of the year in order to cover seasonal variations. As it has been done in this study, most diversity studies are restricted to either low, mid or high altitudes. Therefore studies that cover the entire gradient are likely to present a more comprehensive pattern of species assemblage.

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