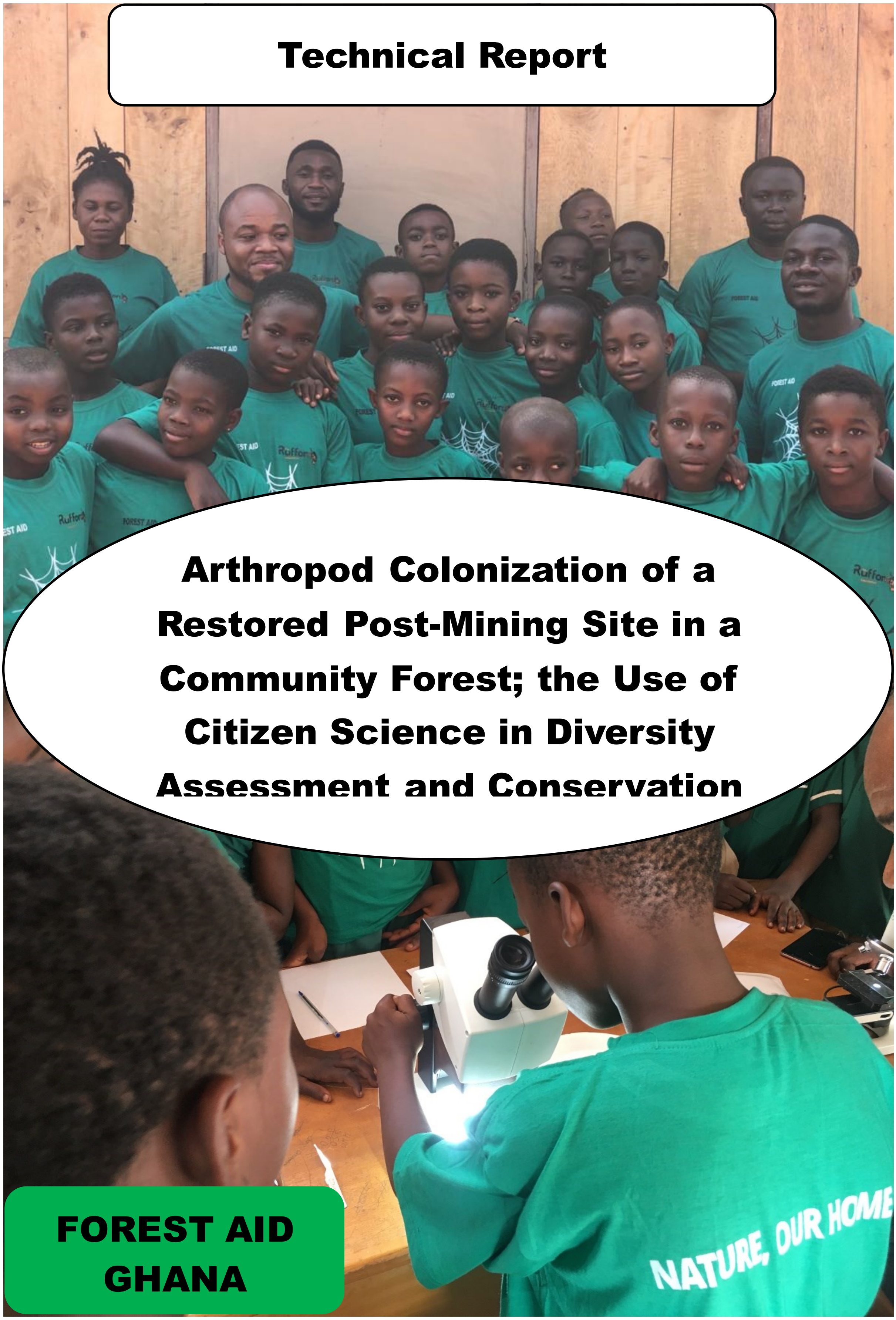
Technical Report



Arthropod Colonization of a Restored Post-Mining Site in a Community Forest; the Use of Citizen Science in Diversity Assessment and Conservation

FOREST AID GHANA

Arthropod Colonization of a Restored Post-Mining Site in a Community Forest; the Use of Citizen Science in Diversity Assessment and Conservation

TECHNICAL REPORT

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Acknowledgements

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Summary

Considerable funds and efforts have been invested in restoring an abandoned post-gravel-mine landscape into a community forest supposedly capable of providing ecological and cultural benefits to local communities. Decades after restoration, the need for a systematic assessment using citizen scientists and bio-indicator approaches is needed to evaluate how successful management has been in restoring the disturbed landscape into an ecosystem that is capable of providing services and benefits. Numerous studies have identified citizen scientists (school children and community members) as essential partners of many conservation projects. This then required such citizen scientists to be trained to be able to address fundamental conservation challenges. This project has hence trained and uses citizen scientists to quantify the levels and dynamics of arthropod community structure in a restored post-mine area. The ecological attributes of the restored forest were examined with reference to a natural forest reserve using arthropods as bioindicators. For this assessment, eight spatially separated quadrats with sizes 20 m x 20 m were systematically sampled with a stratified design to produce 16 sampling units. Sampling was done for ten weeks, with five pitfall traps per unit. The study revealed the restored forest to be on a trajectory resembling the attributes of the natural forest. Restoration interventions have hence facilitated the recovery of indicator taxa of ecosystem health such as Hymenoptera, Orthoptera, and Coleoptera. Strategic and continuous management of the restored forest is highly recommended to ensure full recovery of the ecosystem and its arthropod diversity.

Keywords: Arthropods, Assessment, Degradation, Ecosystem, Forest, Restoration

Introduction

The global reduction in forest cover (FAO 2016; Chakravarty et al. 2012), threatens biodiversity (Vieira et al. 2008) and increases greenhouse effects (Angelsen et al. 2009). A significant approach to counteracting this global forest depletion is to employ forest restoration activities in areas where the forest ecosystem is no longer sustainable in the long term (Mansourian et al. 2005). Through the ecological restoration, the biodiversity of degraded forest ecosystems could be enhanced, thereby increasing system resilience, and essentially enhancing levels of ecosystem service provision (Wortley et al. 2013).

Forest restoration, a process of boosting the recovery of an ecosystem that has previously been degraded, damaged or destroyed (Sala 2000; SER 2002; Stanturf and Madsen 2002) aim to regain the ecological integrity of those systems, rebuild the ecosystem to some historical or more desirable stage (Dudley et al. 2005*)*, improve conservation efforts (Laarmann et al. 2013), restore a range of forest functions (Stanturf and Madsen 2002) and enhance the provision of ecosystem services as well as overturning biodiversity losses (Bullock et al. 2011). Degraded forests that are restored need to be assessed for their level of naturalness, diversity of species (both plants and animals), and ecological integrity in order to advise decision-makers and management about future restoration activities (Dudley 2005).

The management practices at a restored post-mining area in Ghana (Newmont Ghana Gold Limited reclamation test plot) located at Terchire in the Ahafo Region of Ghana have created ideal conditions to observe and assess the ecological effects of restoration on ecosystem attributes. Using citizen scientists (school children and local community members) and researchers, we aimed to determine and compare arthropod order abundance and richness in a restored forest with reference to a natural forest and, more so, to determine the most dominant arthropod orders characterizing the restored forest.

2.0 Methodology

2.1 Study area

The effect of restoration on arthropod community structure was investigated by citizen scientists (school children, community members) with the assistance of some experts (foresters, researchers) using a restored post-gravel mine area located at Terchire (on latitude 7°14.075’N and longitude 2°10.842’W) in the Ahafo Region of Ghana (Figure 1). The area is a 15-hectare borrow pit created as a result of the construction of the Kumasi – Sunyani highway in the early 1980s. The topsoil was stripped, and the subsoil was taken for road construction, leaving the area bare and open (Damptey et al. 2020).

In 1999, the area was first subjected to earthworks, and grasses or cover crops were planted. As part of restoration interventions, the place was subjected to the planting of potted seedlings. Fast growth exotic species were inter-planted with native species to stabilise the soil at the initial stage of the project to prevent erosion. Other leguminous exotic tree species were also planted to fix quick atmospheric nitrogen for better soil development (Damptey et al., 2020). Asukese Forest Reserve, located few kilometres away, served as a reference system for comparison of arthropod diversity.

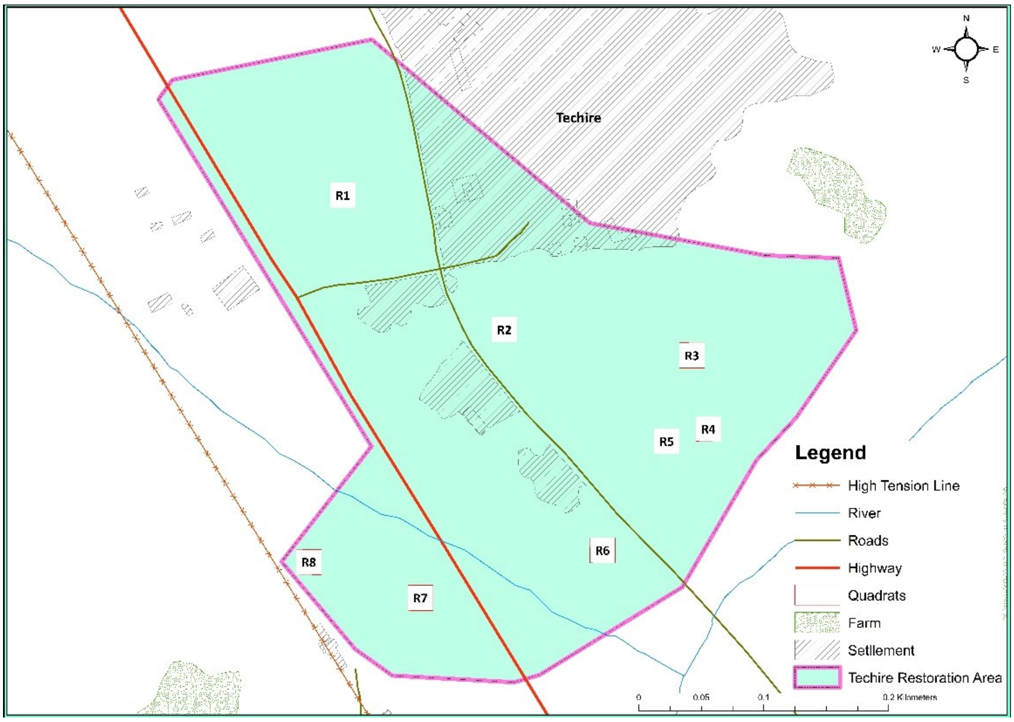

Figure 1: Map of the Terchire Restoration Area. The square boxes are the eight demarcated quadrats (R1 - R8)

2.2 Soil, climate and vegetation characteristics of the restored forest

The soil of the restored area is predominantly sandy loam, with a pH value of 5.69. It is a tropical region with an average precipitation of 1189 mm and an average temperature of 26 ^{o}C. The vegetation of the restored site is characterized as Fabaceae > Meliaceae > Malvaceae > Combretaceae family association with dominant tree species including *Cassia siamea, leucaena leucocephala, Albizia zygia, Entandrophragma utile, Entandrophragma angolense, Khaya anthotheca, Cedrela odorata, Cola gigantea, Ceiba pentandra, Triplochiton scleroxylon, Mansonia altissima*, and *Terminalia superba* (Awoke 2019).

Figure 2: The vegetation characteristics of the restored forest

2.3 Experimental design

To evaluate the success of restoration using arthropods as bio-indicators of ecosystem health, eight quadrats were demarcated in both the restored area and the reference forest. These quadrats were further sampled in stratified design with 20 m × 20 m plots leading to sixteen sampling units.

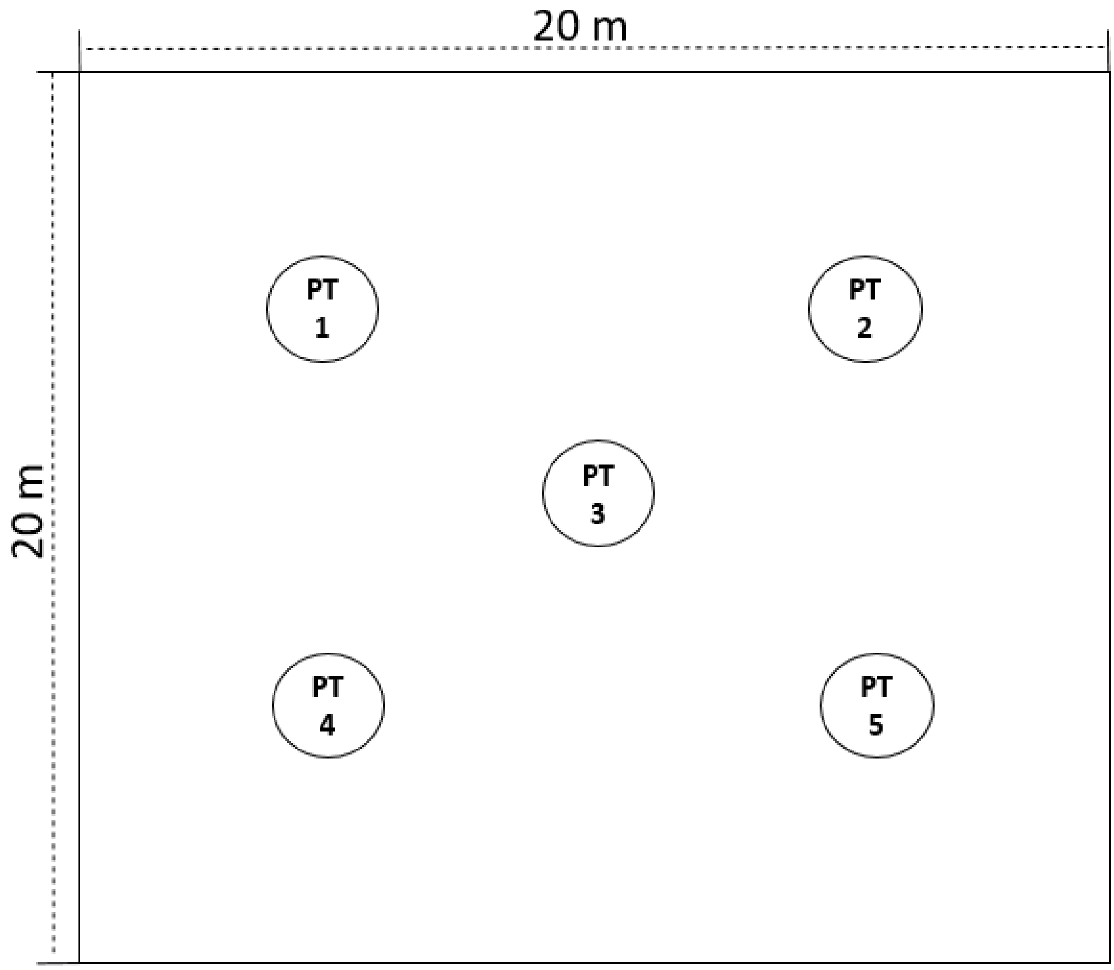

Figure 3: Sampling plot layout. Five pitfall traps in each quadrat with a size of 20 m x 20 m

2.4 Tree enumeration

All tree species with a diameter ≥ 10 cm at breast height (dbh @ 1.3 m) were counted and measured using a girth tape and a calliper (Appiah 2013). Trees were identified to species level with the aid of a field manual (Hawthorne and Gyakari 2006) and with the assistance of a botanist. Stands were characterised according to density, height, size-classes, and dominance by following dendrometric indicators: diameter at breast height (dbh), vertical layering (H), basal area (BA), and density of trees (D). These indicators helped to characterise the structure of and sites.

Figure 4: Field team measuring the structure and deadwood attributes of the study sites.

2.5 Arthropod sampling

A stratified sampling method involving the use of five pitfall traps in each plot were used to sample activity densities of ground-dwelling arthropods. These traps were filled with 50 % ethylene glycol/water mixtures (as recommended by (Schmidt et al. 2006) with added odor-free detergent to reduce surface tension (Pais and Varanda 2010). Traps were sheltered by small rain cover to minimize dilution by rain (Underwood and Quinn 2010). To minimize the digging-in effect (attraction by cutting of roots while digging holes for pitfall traps), holes were left unused for one week prior to trapping (Greenslade 1973). Traps were emptied every 7 days for four conservative weeks.

After sampling, samples were cleaned and preserved in ethanol for further sorting into taxonomic units. Figure 5 shows the various stages of pitfall trap settings and harvesting whiles Figure 6 also shows the sorting of harvested samples by citizen scientists.

Figure 5: Participants setting up pitfall traps in the study sites

Figure 6: Citizen scientists sorting and identifying trapped samples.

2. 5 Data analysis

Arthropod order diversity was sorted and placed in various taxa for further analysis. Plot abundance was average and log-transformed (Log(X+1)) to generate arthropod order activity density. Significant differences in terms of arthropod composition between the restored and the reference forest were evaluated with a one-factorial PERMANOVA design using Bray-Curtis similarity measure and 9999 permutations with the site as a fixed factor (Site).

Patterns between sites were presented graphically using an nMDS ordination. Characteristic taxa for each site were further overlaid on the nMDS cluster, and the goodness of fit evaluated using a stress value. A similarity percentage (SIMPER) analysis – species contributions using a One-Way Analysis on Bray-Curtis similarity and a Cut-off percentage of 70 % was used to select orders contributing to the average dissimilarity among the study sites (Somerfield and Clarke 2013). PRIMER 7 was used for all statistical analysis and graphical presentation of results (Clarke and Gorley 2015).

3.0 Results

3.1 Order composition of the study sites

A total of 17,491 individual arthropods (9,982 from the reference forest and 7,509 from the restored forest) were collected from both study sites. 12 different taxa were sampled in the reference forest while 11 taxa were also sampled in the restored forest. 450 individuals of Glomerida were found in the reference forest with 0 records in the restored forest (Table 1).

Figure 7: Some taxa sampled in the study sites

Table 1: Individual number of arthropods recorded in the study

Sites	Araneae	Acari	Blattodea	Coleoptera	Hemiptera	Hymenoptera	Julia	Opiliones	Orthoptera	Polydesmida	Scolopendra	Glomerida
Reference forest	553	109	739	1909	68	5045	215	21	839	33	1	450
Restored forest	667	45	191	834	56	4151	149	11	1335	67	3	0

A simper analysis revealed the restored forest to be dominated by Hymenoptera, Orthoptera and Coleoptera, all contributing 71 % to the average similarity within the restored forest. The most abundant contributing taxa was Hymenoptera (1.38), followed by Orthoptera (1.13) and Coleoptera (0.88). The reference forest was, however, characterised by Hymenoptera (1.72), Coleoptera (1.35), Orthoptera (0.86), and Araneae (0.72). These four dominant orders contributed about 75 % of the average similarity within the reference forest.

Figure 8 displays nMDS ordination results for the two forests based on their arthropod order composition. Two main clusters could be observed with the restored forest clustered separately from the reference forest. The restored forest shows a strong affinity for Orthoptera, Polydesmida, and Scolopendra while the reference forest is showing a higher affinity for Hemiptera, Coleoptera, Julida, Glomerida, Hymenoptera, Blattodea, and Opiliones.

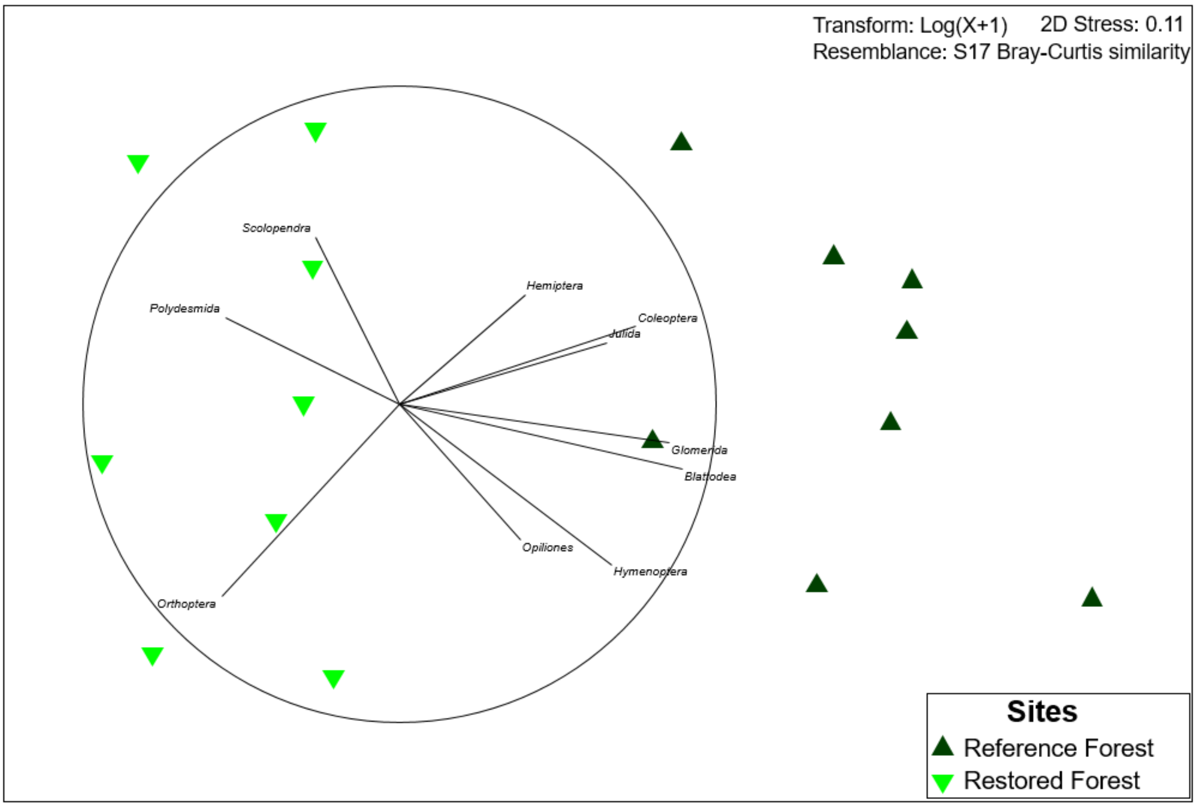

Figure 8: Non-metric multidimensional scaling (n-MDS) ordination of arthropod order composition among the two sites (16 sample plots). The length and direction of vectors represent the strength and direction of the association between arthropod order composition and sites. The circle indicates a maximum vector length corresponding to a Pearson correlation coefficient of 1.0.

The distinction in arthropod order composition for both sites was further confirmed by a PERMANOVA test, revealing statistically significant differences between the two forests (Sites - $F_{1,14} = 13.511$, $P < 0.001$). A SIMPER analysis at 70 % cut off low contribution revealed 23.86 % average dissimilarity between the two sites with five main orders contributing about 78 % to the above dissimilarity. Specifically, the Coleoptera had 1.35 average abundance for the reference forest and 0.88 for the restored forest, and the Glomerida had 0.47 for the reference forest and 0 for the restored forest, Blattodea recorded 1.72 for the reference forest and 0.29 for the restored forest, Hymenoptera recorded 1.72 for the reference forest and 1.38 for the restored forest whiles the Orthoptera recorded 0.86 for the reference forest and 1.13 for the restored forest (Table 2). Overall, Coleoptera contributed 18 %, Glomerida contributed 17 %, Blattodea contributed 16 %, Hymenoptera contributed 16 %, and Orthoptera contributed 12 % to the dissimilarity between the two sites.

Table 2: Similarity Percentage analysis (SIMPER) on arthropod order composition between two forests (Av. Abund = Average abundance, Av. Diss = Average dissimilarity, SD S.D. = Standard deviation, Contrib = contribution percentage, Cum = Cumulative percentage)

	Reference	Restored				
Orders	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Coleoptera	1.35	0.88	4.21	1.80	17.63	17.63
Glomerida	0.47	0.00	4.09	2.21	17.14	34.77
Blattodea	0.73	0.29	3.78	2.12	15.82	50.59
Hymenoptera	1.72	1.38	3.71	1.53	15.53	66.13
Orthoptera	0.86	1.13	2.82	1.33	11.80	77.92

3.2 Factor influencing arthropod abundance in the restored forest

Multiple linear regression was used to predict arthropod abundance based on tree species abundance, height, basal area, and canopy openness of trees cover in the restored forest. Arthropod abundance correlated positively with the abundance of individual plants and the height of trees, while a negative correlation was observed for basal area and canopy cover (Figure 9).

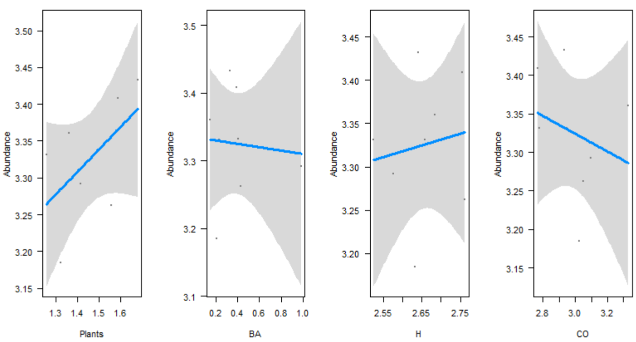

Figure 9: The relationship between Arthropod abundance and plants abundance, basal area (BA), the height of trees (H) and canopy openness (CO)

3.3 Beetles (Order: Coleoptera) diversity of the restored forest

A total of 782 individual beetles belonging to 15 families were recorded in the restored forest. Scarabaeidae (269) was the highest, followed by Carabidae (204), Erotylidae (89), Histeridae (78), Hydrophilidae (41), Staphylinidae (39), Cetoniidae (31), Curculionidae (8), Nitidulidae (7), Dytiscidae (4), Endomychidae (4), Tenebrionidae (3), Elateridae (2), Pselaphidae (2) and Scydmaenidae (1).

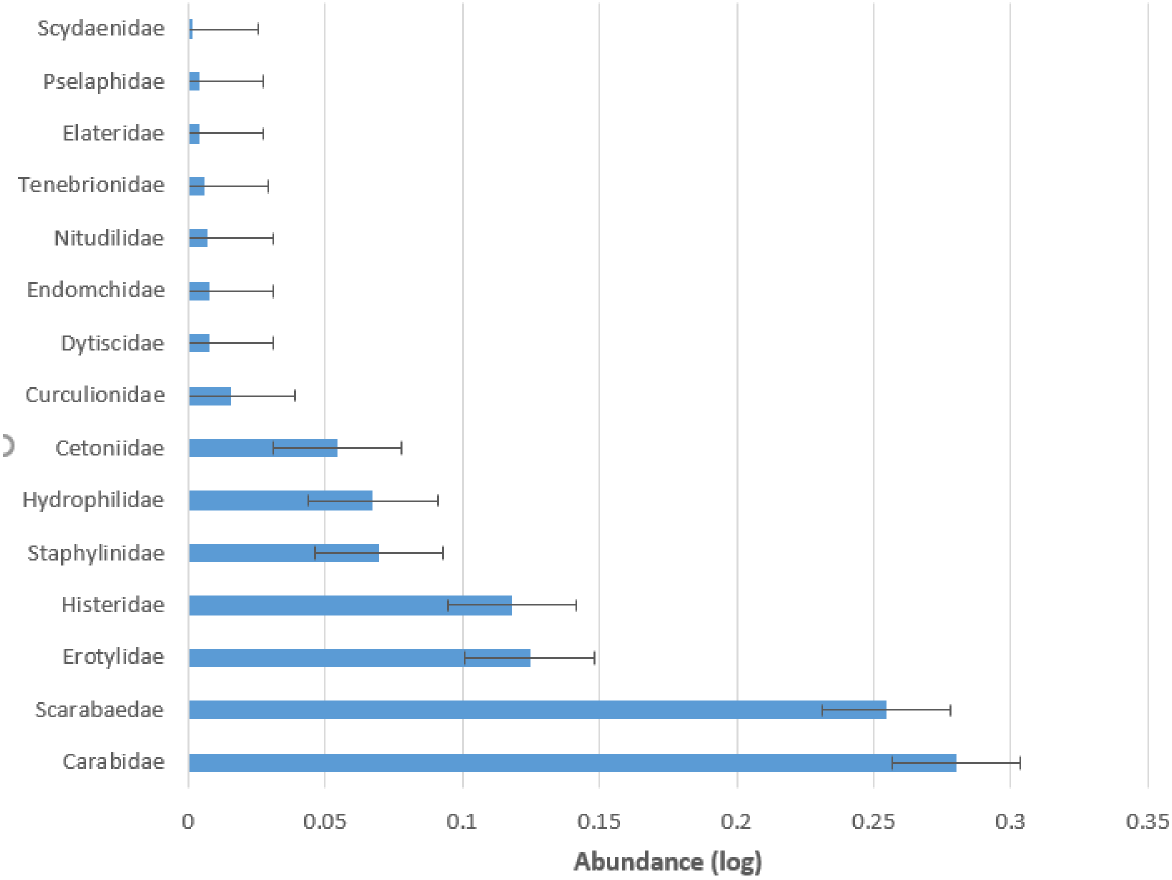

Figure 10: Beetle family abundance of the restored forest. Error bars are presented

3.4 Spiders (Order: Araneae) diversity of the restored forest

525 individual spiders belonging to 14 families were recorded in the restored forest. The highest number of individuals came from the family of Zodariidae (200), followed by Salticidae (148), Ctenidae (72), Lycosidae (38), Cyrtaucheniidae (27), Corinnidae (15), Palpimanidae (11), Liocranidae (3), Oxypidae (2), Araneidae (1), Barychelidae (1), Idiopidae (1) and Nephilidae (1).

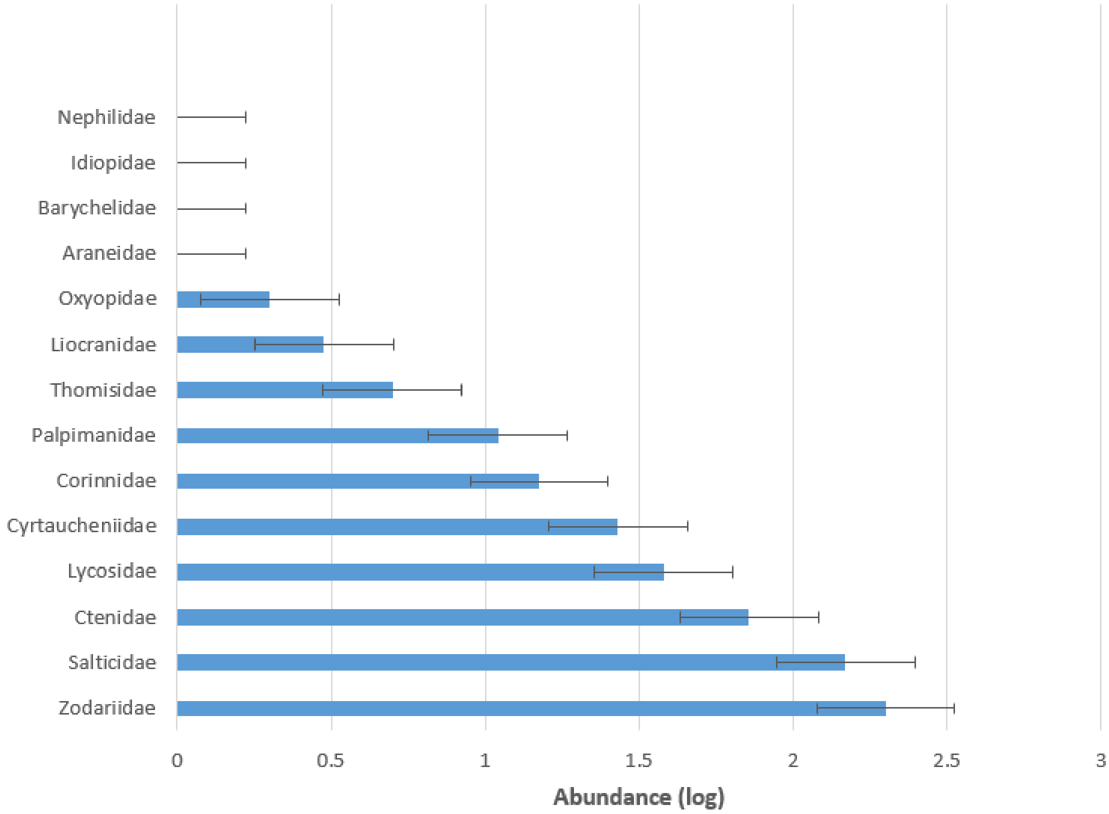

Figure 11: Spider family abundance of the restored forest. Error bars are presented

3.5 Relationship between Salticidae and plant abundance

Salticidae abundance decreases with increasing plant abundance.

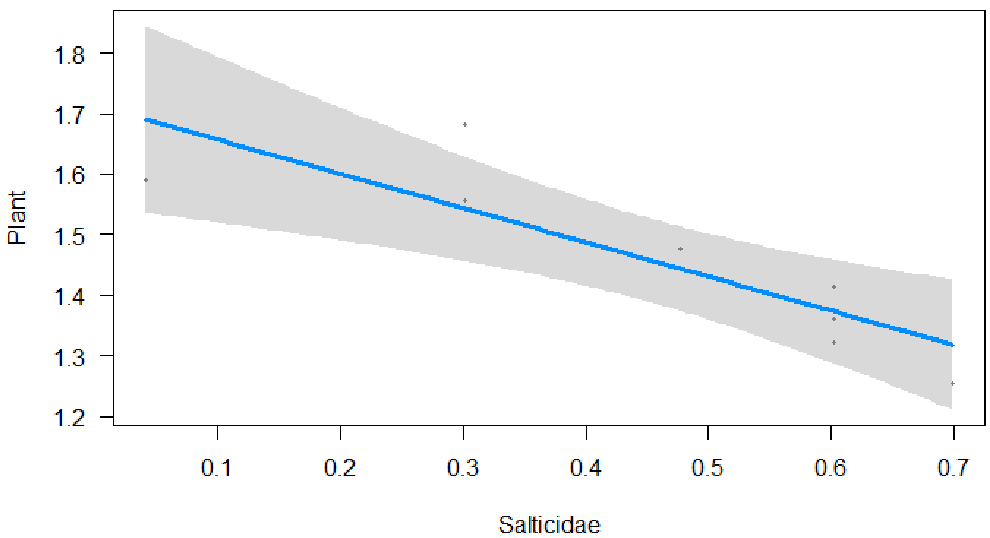

Figure 12: Relationship between Salticidae abundance and plant abundance

3.6 The relationship between deadwood volume and Coleoptera (Family: Carabidae and Scarabaeidae) abundance

Carabidae abundance increases with increasing deadwood volume in the restored forest. The same increasing trend holds for Scarabaeidae (Figures 13 and 14).

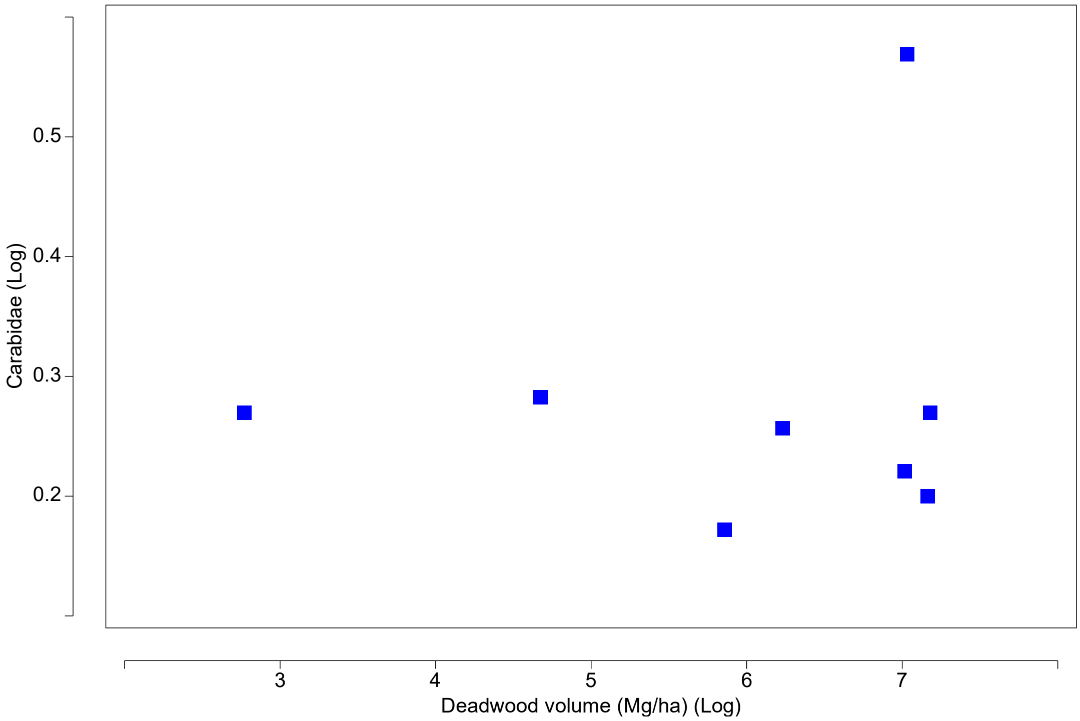

Figure 13: Relationship between Carabidae abundance and deadwood volume in the restored forest

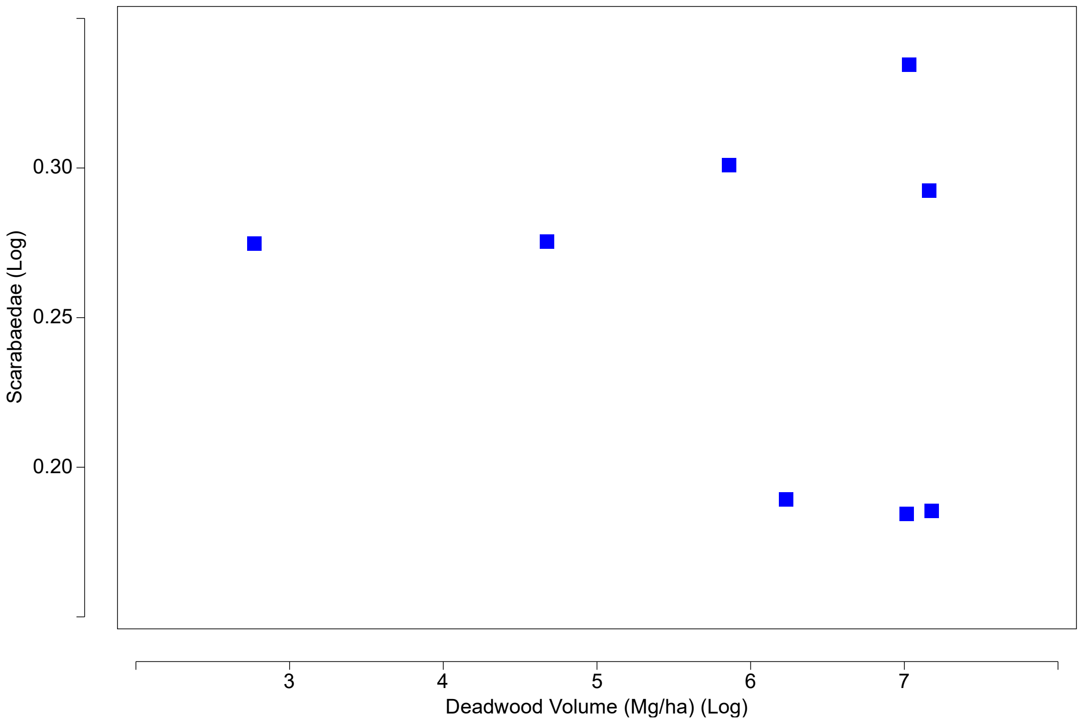

Figure 14: Relationship between Scarabaeidae abundance and deadwood volume in the restored forest

3.7 Relationship between spiders (Family: Zodariidae) and food availability (ants).

Zodariidae abundance increases with increasing Hymenoptera (ants) abundance in the restored forest. Ants serve as food for this family of spiders

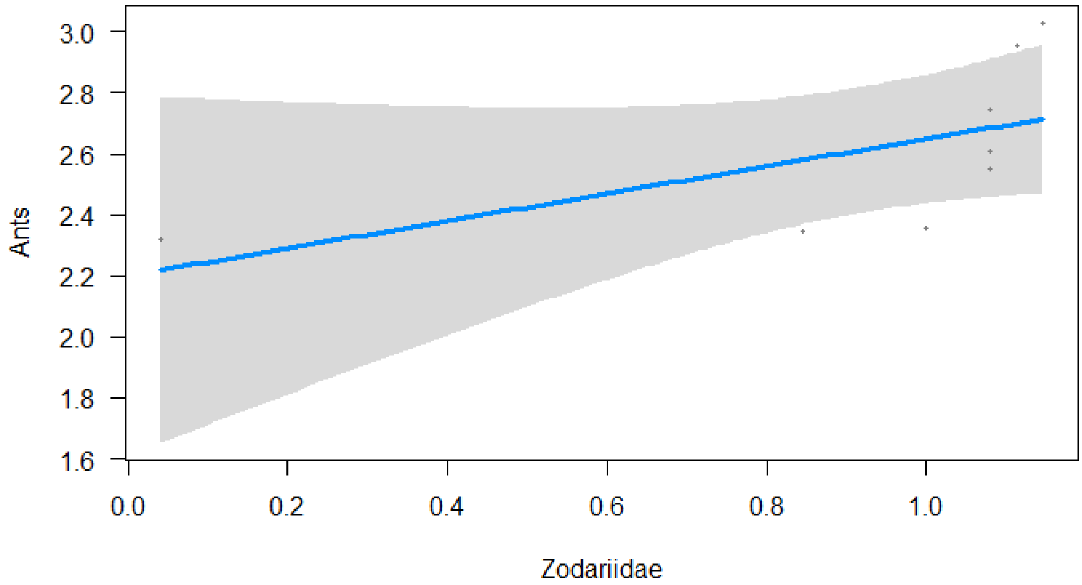

Figure 15: Relationship between Zodariidae abundance and Ants abundance in the restored forest

3.8 Other taxa in the restored forest

A unique endemic species was recorded in the restored forest. This is the Tick hooded Spider – *Ricinoides atewa* (Order: Ricinulei, Arachnida).

4.0 Discussion

In evaluating the current state of forest restoration projects, several attributes and indicators, including arthropod diversity and composition, are assessed. Usually, these arthropods served as bio-indicators to measure the current condition of a particular restoration project because of their abundance and availability (S. M. Pearce and Venier 2006), their sensitivity to environmental change (Guo et al. 2011; Mauricio da Rocha et al. 2010), ecological balance (Acquah-Lamptey et al. 2013), diverse behaviour and life histories (Racelis et al. 2013). Longcore (2003) highlighted the recovery of native fauna as an indicator of forest restoration success. Seminal authors (Arthur 2017; Lawes et al. 2017) relied on Hymenoptera as an ecological indicator for assessing reforestation success. Other arthropods mostly used in restoration project assessment include Coleoptera (Sullivan et al. 2018), Araneae (Pearce and Venier 2006), Orthoptera (Borchard et al. 2013) and a host of others.

In this study, citizen scientists and researchers assessed how a restored area in Ghana is performing using arthropod taxonomic units. To this end, we compared arthropod order diversity and activity density of the restored area with a nearby natural forest acting as a reference system.

In general, arthropod abundance was higher in the natural forest than the restored forest. These differences were mainly driven by the response of common, abundant taxa such as Coleoptera, Glomerida, Blattodea, Hymenoptera, and Orthoptera. The study displayed some characteristic dominant arthropod orders with few rare ones. All taxa were recorded for both sites with the exception of Glomerida, which was never recorded at the restored site. Diversity of orders on the other hand, were almost the same between the natural forest and the restored forest, confirming the hypothesis of this study; the restored forest is on a trajectory towards the reference forest, almost resembling arthropod diversity of the natural forest. This could be mainly attributed to the fact that forest cover in the restored forest has developed with attributes similar to the natural forest to serve as habitat and also food resources that are required for growth and survival of most arthropods. In a similar study, (Lachat et al. 2006), confirmed the role of forest cover as a result of restoration intervention to facilitate the movements of arthropods leading to their higher diversity. Another reason for the similar diversity between the sites could be the higher litter biomass associated with the restored forest (Unpublished data). Celentano et al. (2011) asserted that planted forest (restored) usually have much higher litter biomass than natural forest which relies solely on natural regeneration. Litter biomass is often associated with greater arthropod abundance and diversity (Sayer et al. 2010; Kaspari and Yanoviak 2008).

The higher abundance of arthropods in the natural forest in comparison to the restored forest could also be the result of the variability in canopy openness in the natural forest. The restored forest is characterised mostly by a more homogenous canopy layer because of the uniform growth rate of planted stands. This inhibits light penetration at the understory zone, which is required for arthropod activities. Holl et al. (2013) confirmed the influence of greater variability in canopy openness in supporting arthropod abundance. Furthermore, the role of complex habitat structure in providing more niches and diverse ways for exploiting environmental resources has been discussed by other seminal studies (Cole et al. 2016; Tews et al. 2004). A study conducted by Pearce and Venier (2006) revealed a higher abundance of arthropods in a natural forest and an intermediate abundance in a restored site (plantation sites).

Matured forests (natural forest in the case of this study) harbour significant proportions of the global species pool (Zou et al. 2019), whiles secondary forest (the restored forest in the case of this study) is assumed to harbour less diverse species assemblages (Gibson et al. 2011). Natural forests hence form a more complex and suitable environment for the activities of various arthropods (Perry et al. 2016). The complex habitat structure could offer multiply functions, including serving as primary producers, providers of resources, and modulating the physical environments (Liu et al. 2013).

6.0 Conclusion

Decades after restoration, the results of this study confirm that arthropod diversity of the restored forest is on a trajectory almost resembling the reference forest with time. Active restoration has proven successful in restoring ecosystem attributes such as arthropod community structure. The tremendous response of arthropods such as Hymenoptera, Coleoptera, Orthoptera, Araneae, and other taxa indicates a successful restoration project. Strategic and continuous management of the restored forest is highly recommended to ensure full recovery of the ecosystem and its attributes.

6.1 Other matters

Data storage: Samples have been preserved in 70 % ethanol and stored in a dry, cool, aerated place. They shall be made available for reuse by other interested researchers and programs.

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