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Environmental pollution and arthropod community change: Impact of quarry activities on invertebrate biodiversity in Ghana.

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Abstract

Quarry operations can have a negative impact on invertebrate biodiversity and threaten local species through a variety of factors, such as habitat loss and pollution. Quarrying is a common practice in Ghana, but little is known about its effects on local insect diversity and abundance. In this study, the relationship between quarry operations and insect communities on an active quarry site, the Mowire quarry site in the Ashanti region of Ghana was assessed. Transect counts, aerial nets, pitfall traps, Flight interception traps (FIT) and fruit baiting (Charaxes) traps were employed to assess arthropod assemblage, specifically insects as a surrogate for arthropod communities. A total of 2,902 individual insects belonging to 56 families and eleven orders were recorded in all transect points across the three sampling zones. Quarry operations had little impact on the relative abundance (N = 974) of insects at Transect point (TP) 400m in the Eastern Zone (EZ), species richness (S = 49) and the highest abundance (N = 302) corresponding with high diversity of flowering plants at this site that are a food source for pollinators and herbivorous insects. Quarry operations negatively affected the relative abundance (N= 541) and richness (S = 37) of insects in the Western zone (WZ), significantly affecting TP 400m in the WZ, corresponding to the low abundance of food plant as well as volumes of dust that settle at the WZ after every blast, as dust travels in the direction of this zone. It is recommended that interventions to prevent biodiversity habitat loss in and around the quarry operational site should focus on policies that ensure and enforce the establishment of a dust control mechanism system in the extractive industry.

Key words: indicator species, arthropods, mining, pollution, West Africa

Introduction

Quarry operations can have a major impact on tropical biodiversity and rare or endangered species (Lameed & Ayodele, 2010). Quarry operations negatively affects the environment in a variety of ways during exploration, blasting, transportation and disposal of waste rocks (Nisic, 2018). The extraction process normally depends on heavy machines and explosives, which are normally are associated with air pollution, noise pollution, and habitat destruction (Lameed & Ayodele, 2010). Pollution reduces biodiversity by either changing an organism biological functions or altering the environmental conditions that they need to survive. Major ecological impact of quarry operation is the destruction of vegetation, disturbance of invertebrate and vertebrate territories, preoccupation and soil disintegration (Nwachukwu, Ojeaga & Chinelo, 2018). Africa has a rich insect biodiversity community, however only few taxa have been collected extensively and studied in detail (Mokam, Djiéto-Lordon & Bilong Bilong, 2014). Arthropods occupy the broadest microhabitat and niche variety and perform more ecological roles than any other assemblage of animals (Maleque, Ishii & Maeto, 2006). Their abundance, diversity and short generation times allow for an assessment of habitat pollution, ecosystem functioning at various trophic levels and environmental health.

Insects are serious natural resource in the ecosystem and are significant bioindicator in the management of ecosystem. Indicator species are living organisms whose presence or absence can be used to predict the environmental scenario in which they are situated (Díaz et al., 2020). Indicator species could be used to observe ecological variations and offer warnings for impending ecological modifications.

The level of land degradation caused by quarry operations in Ghana has put forth questions as to whether or not the activity should be allowed to continue (Nartey, Nanor & Klake, 2012). In Ghana, increasing evidence indicates that the rate of environmental degradation has increased in recent times (Koranteng & Adu-Asare, 2018). In this study, we assessed the relationship between quarry operations and the diversity of insects in an unprotected tropical forest site, with focus on diversity and relative abundance of insects generally, and butterflies as indicator species in the quarry operational area, in the Ashanti region of Ghana. We sampled insects for seven months across all zones and line transect points using a variety of nine sampling protocols to determine short- and mid-term effect of quarry site-associated impact on this diversity. Despite the general hypotheses that insect diversity and relative abundance would decline under quarry operations, we wanted to use indicator insect to monitor and assess both insect diversity and relative abundance at Mowire quarry concession as quarry operations continued. We also aimed to determine the relationship between quarry operations and relative abundance of insects at different sections of the quarry operational area using a radial transect point approach, whilst also provide a comprehensive inventory of insects over the sampling period, highlighting species richness and diversity in all habitats associated with disturbance.

Materials and Methods

Study Area

The research was conducted at Mowire near Kodie in the Ashanti Region of Ghana. The area lies between Latitude 6° 48' 21.38" (6.8347°) North, and Longitude: 1° 38' 25.43" (1.7172°) West with an elevation of 280m meters (918.64 feet), in the Afigya Kwabre District (Fig 1). The District is bounded by Kumasi Metropolitan Assembly to the South, Offinso Municipal to the West, Atwima to the South-West and Kwabre East District to the East. The average temperature here is 25.0 °C between July and August and 28.0 °C between March and April. The average annual rainfall is 1400 m (Bannerman et al., 2013). The district experiences relatively high humidity ranging from 90% to 98% in the rainy season. Night and early morning's drops to below 75% in the dry season (Bannerman et a*l*., 2013). The district has a current population density of 397.3 persons per square kilometer with increasing demand of land for residential purposes whiles available land for agriculture and natural vegetation has been depleted. The forest vegetation has been degraded by lumbering, quarry operations, settlement development and agriculture. Part of the forest has been disturbed by various human activities such as farming, logging and quarry operations. The economy of the district is mainly agrarian employing about 61% of the total workforce.

K.K Quarry and Brosa Mineral Resource Limited are located at Mowire Township about 6 km away from Kodie on the Offinso highway. These two quarry companies mine within the enclave in the town periphery. The mass presence of granite rocks in the district support quarry industry. The quarry operation has existed and been active for the past fourteen years. Stone quarry is the main activity engaged by the two quarry companies. Stones are crushed into relatively small pieces of gravel-sized particles which are transported by heavy duty vehicles daily. Blasting of rocks are done every Tuesday and Friday. KK Quarry company take their turn to blast on Tuesdays whiles Brosa Mineral Resource blast on Fridays. For this study, the quarry operational area was positioned on a radial map with three cardinal points (Northern, Eastern and Western Zones), and subdivided into four transect points (Figure1). A line transect of 200m, 400m, 600m and 800m in all the three cardinal points were set for data collection. The eastern zone (EZ) had significant quarry operations been undertaken there, and consisted of a primary secondary forest which stretches along to the Northern part of the quarry. The EZ had the rock cracker which was a compact, cost-effective and transportable piece of machinery used to split, break stones and rock blocks, to reduce rocks and to split reinforced concrete. Crushing of stones into small pieces of rocks were done here. The rock cracker works almost every day for 24 hours generating a lot of noise and small volumes of dust to the adjoining environment. The zone was divided into four transect points from the center of the quarry to the East. A line transect point from the center of the quarry was established with an interval of 200m to pick four sampling points (200m, 400m, 600m, 800m) (Table 7). A secondary forest (dense canopy with a lot of undergrowth and sweet nectar plants) located in the 400m and 600m transect points in the EZ and stretching along to the Northern part of the quarry operational area.

The Western zone (WZ) is from the center of the quarry to the west and has two secondary forest (degraded with less dense canopy) patches as well as a sacred grove (dense canopy with a lot of undergrowth and sweet nectar plants). The zone has a vast land which has been degraded by a lot of flying rocks from the quarry operations. The dust moves in this direction after every blast of the quarry. Blasting of the quarry was done every Tuesday and Friday. The zone was divided into four transect points from the center of the quarry to the West. A line transect point from the center of the quarry was established with an interval of 200m to pick four sampling points (200m, 400m, 600m, 800m) (Table 7). The first secondary forest was located at the 600m transect point and second secondary forest located at the 800m transect point. There was a sacred grove which shares boundary with the 200m transect point demarcation. The point also receives a lot of vibration whenever blasting of the rock was done. There was a small stream around the 400m transect point

The Northern zone (NZ) is from the center of the quarry to the northern part and comprises of a settlement forming a large community. Sampling points were located within the community. Key among the community is a hospital which was about 400m away from the quarry site and located at the 400m transect point. This zone experiences a lot of land vibrations as a result of heavy vehicles which transport rock particles from the quarry site every day. The zone was divided into four transect points from the center of the quarry to the North. A line transect points from the center of the quarry was established with an interval of 200m to pick four sampling points (200m, 400m, 600m, 800m) (Table 7). There was a secondary forest which linked the eastern zone to this zone, and a reservoir bush located at the 600m transect point. The study was carried out between the months of August 2018 and February 2019, which spanned within dry and wet seasons.

Sampling Method

Insect collection was done using a standard sampling collection. Traps were set on each of the transect point for passive insect sampling. A 50m × 50m demarcated plot in each of the transect points across all the three zones were used for sampling in the quarry operational area. In order to ensure that the traps were adequately spaced, a five meter tape was used to measure the distance between them. The traps set included pitfall trap (20 cm diameter, 15 cm depth) buried in the ground with opening on the soil surface, flight interception trap constructed using a rectangular black mesh (1 m × 1.5 m), joined to two wooden poles, turning of stones and wood logs, hand picking of insects, pan/bowl trap (yellow colour), yellow and blue sticky traps, flying insect and fruit feeding butterflies were captured by fruit-baited (Charaxes) trap (1m tall and 25 cm in diameter) with fermented banana mixed with beer (Lucci Freitas et al., 2014). Sweep net (38cm in diameter) was used to sweep the vegetation for insects that rest on the leaf canopy and vegetation cover during each visit. Direct counts of individuals were recorded and a transect walk sampling for butterfly species along an equal length of 800m in all the three zones was executed weekly in the quarry operational area. Monitoring butterflies on transects were done on active temperatures between 13°C and 33-35°C, with no rain or strong winds. Aerial net was also used to capture butterflies, especially those which were not easily identifiable in flight. These traps were randomly distributed in each of the twelve transect points for collections. The traps were retrieved every four days between 7:00am and 10:00am for catches and reset throughout the sampling period. The insects collected were stored separately for each transect point and zone in 70% alcohol prior to identification. Insect identification was done with reference to the collections at the Entomology Museum at Department of Animal Biology and Conservation Science, University of Ghana. Butterflies were identified to species level whiles other insects were identified to family level. Currently no generally accepted methodology exists to estimate floral resource availability (Szigeti *et al*., 2016). However floral density and diversity in each transect point was visually identified and counted. Flora sampling included scanning each transect point by walking through the transect point every three days for an hour per sampling.

Data Analysis

Statistical analysis on species richness, relative abundance, evenness, species diversity and habitat similarities or differences in all the zones were examined and computed. Data from all the three zones and transect points were pooled to obtain total diversity of insects for the entire study site and sampling period. Three diversity indices were computed using PRIMER 6 & PERMANOVA+ to compare data from all transect points and all three zones. These were preferred because they allowed for qualitative assessment of zones by comparing their diversity indices (Chao et al., 2005) which were treated for biodiversity assessment (Kleijn et al., 2006). Diversity indices (Margalef index, Shannon-index, Simpson index and Evenness) were calculated and compared between all three zones.

1. Species richness (Margalef): $d=(S-1)/\log(N)$ - This is a measure of the number of species present, making some allowance for the number of individuals.

2. Pielou's evenness: $J=H'/\ln(S)$ - this is a measure of equitability, a measure of how evenly the individuals are distributed among the different species

3. Shannon-Wiener index: $H=-\Sigma\, pi \ln(pi)$ – incorporates both species richness and equitability components.

4. Simpson index (D): It is influenced by dominant species (Measures dominance and evenness).

ni = the number of individuals of species in the sample, $\Sigma \ni ¿ N$. pi = the proportion of individuals of species in the sample, $pi = ¿/N$. S=the number of species in the sample, N= the total number of individuals in the sample.

RESULTS

A total of 2,902 individual insect were recorded from 56 families and eleven orders across all the three zones. These species belonged to the Order Coleoptera (12 families and 659 individuals), Order Lepidoptera (67 families and 417 individuals), Order Diptera (16 families and 385 individuals), Order Orthoptera (5 families and 892 individuals), Order Hymenoptera (5 families and 361 individuals), Order Hemiptera (5 families and 122 individuals) and the following five orders, had the lowest numbers; Dictyoptera (45 individuals), Homoptera (4 individuals), Phasmida (3 individuals), Dermaptera (6 individuals) and Odonata (8 individuals).

Relative abundance of indicator species in the quarry operational area

A total of 417 butterflies belonging to 68 species from 5 families in all three zones were collected during the entire sampling period. These species belonged to the families Nymphalidae (45 species, 106 individuals), Papilionidae (2 species, 21 individuals), Pieridae (14 species, 123 individuals), Hesperiidae (4 species, 17 individuals) and Lycaenidae (3 species, 150 individuals). At the family level Papilionidae and Hesperiidae recorded the lowest number of individuals while Lycaenidae had the highest number of individuals (Table 1)

Butterfly diversity and richness in the quarry operational area

The eastern zone (EZ) was the most diverse site for butterflies, with the highest relative abundance (N = 329) and the highest species richness (S = 55), which was corroborated with the highest Margalef index (d) of 9.317 with a Shannon Weiner index (H') of 2.616 (Table 2). Two families Lycaenidae and Pieridae had the highest abundance (42.9% and 30.7%) (Table 1).

The western zone (WZ) had low species richness (S = 22) and the lowest relative abundance (N= 41) with the highest Shannon Weiner index (H') of 2.807 corroborated by the highest Pielou evenness (J') of 0.908 (Table 2). Family Nymphalidae accounted for 61% of all the butterflies recorded in this zone (Table 1).

The Northern zone (NZ) had the lowest species richness (S = 21) as well as low relative abundance of individuals (N= 47) corroborated by the lowest Margalef index (d) of 5.195 with a Shanon Weiner index (H') of 2.696 (Table 2). Family Pieridae and Nymphalidae had the highest relative abundance (34.0%) and (32.0%) respectfully for all the butterflies recorded in this zone (Table 1).

Relative abundance of insect orders across the three zones using radial transect approach

In the EZ, a total of 974 individuals belonging to 35 families from 8 orders were collected from all four transect points (Table 3). These species belonged to the Orders Coleoptera (7 families, 240 individuals), Diptera (10 families, 146 individuals), Orthoptera (5 families, 391 individuals), Hymenoptera (4 families, 126 individuals), Hemiptera (6 families, 50 individuals), Dictyoptera (18 individuals), Phasmida (1 individual) and Dermaptera (2 individuals)

A total of 540 individuals belonging to 47 families from 8 orders were captured from all four transect points in the WZ during the sampling period (Table 3). These species in order of abundance belonged to the Orders Coleoptera (12 families, 176 individuals), Diptera (15 families, 104 individuals), Orthoptera (5 families, 107 individuals), Hymenoptera (5 families, 107 individuals), Hemiptera (7 families, 33 individuals), Dictyoptera (7 individuals), Homoptera (3 individuals) and Dermaptera (3 individuals).

A total of 970 insects belonging to 47 families from 9 orders were captured from all four transect points in the NZ (Table 3). These species belonged to the Orders Coleoptera (10 families, 243 individuals), Diptera (16 families, 135 individuals), Orthoptera (5 families, 394 individuals), Hymenoptera (5 families, 128 individuals), Hemiptera (7 families, 39 individuals), Dictyoptera

(20 individuals), Phasmida (2 individuals), Dermaptera (1 individual) and Odonata (8 individuals).

Diversity and species richness of insect orders across all the three zones using radial transect approach

Transect point 400m in the EZ had the highest relative abundance of individuals (N = 302) and low species richness (S = 28) in this zone. Transect point 200m had the highest diversity (H = 2.645) which was corroborated with the highest Simpson index (D = 0.892) in this zone.

Transect point 600m in the EZ had the highest species richness (S = 33), high relative abundance (N= 258) and highest Margalef index (d = 5.759) (Table 4). Insect orders Orthoptera and Diptera had the highest relative abundance of individuals in this zone (44.6% and 19.7% respectively).

Transect point 800m had the lowest species richness (S = 24), lowest diversity (H' = 2.193) and the lowest Margalef index (d = 4.206) in the EZ (Table 4). Two insect orders Orthoptera and Coleoptera had the highest relative abundance of individuals (42.9% and 27.3%) recorded in this zone.

In the WZ, transect point 200m had the highest relative abundance of individuals (N = 192), highest species richness (S = 27) and supported with the highest Margalef index (d = 4.945) (Table 4). Transect point 600m had the highest diversity (H' = 2.371) supported with the highest Simpson index (D = 0.868) for this zone.

Transect point 400m had the lowest relative abundance of individuals (N=73) and lowest species richness (S = 16) as well the lowest diversity (H' = 2.157) in the WZ (Table 4).

Transect point 400m in the NZ had the highest relative abundance (N = 293) and highest species richness (S = 33). Transect point 200m had the highest diversity (H' = 2.537) corroborated with the highest Simpson index (D = 0.871) in this zone.

Transect point 800m had the lowest species richness (S = 24) as well the lowest diversity (H' = 2.188) which was corroborated with the lowest Margalef index (d = 4.193) for this zone (Table 4).

Comprehensive inventory of insect orders in the respective zones

A total of 2,485 individual insects were recorded from 56 families and ten orders across all three zones. These species belonged to Coleoptera (12 families and 659 individuals), Diptera (16 families and 385 individuals), Orthoptera (5 families and 892 individuals), Hymenoptera (5 families and 361 individuals), Hemiptera (5 families and 122 individuals), Dictyoptera (45 individuals), Homoptera (4 individuals), Phasmida (3 individuals), Dermaptera (6 individuals) and Odonata (8 individuals).

Diversity indices of insect inventories across all the three zones

The EZ had the highest relative abundance of individuals (N = 974), species richness (S = 49) and highest Shannon Weiner index (H'=2.620) which was corroborated with the highest Margalef index (d = 6.975) (Table 2). Coleoptera and Orthoptera together had the highest relative abundance of individuals (40.1% and 24.6% respectively) (Table 1). Conversely, the WZ had the lowest species richness (S = 37), relative abundance of individuals (N= 541) and was corroborated by the highest Pielou evenness (J' = 0.682) (Table 2).

The Northern zone (NZ) had high species richness (S = 47), high relative abundance of individuals (N= 970), high Margalef index (d = 6.696) and the lowest diversity (H'= 1.523)

(Table 2). Again, Coleoptera and Orthoptera were the most common orders recorded in this zone (40.6% and 25.0%, respectively) (Table 1).

Number of plant species recorded in all three zones

A total of 386 individuals belonging to 25 genera were identified across all the four transect points (200m, 400m, 600m and 800m) in all three zones. The Eastern zone had highest abundance (N = 175) followed by the Western zone (N = 111) and the least from the Northern zone (N = 100) (Table 5).

Diversity indices of plant species for all the three zones

The Eastern zone (EZ) had high species richness (S = 16), highest relative abundance of individuals (N= 175) and a diversity (H'= 2.173) (Table 6). The Northern zone had the lowest relative abundance (N = 100), lowest species richness (S = 13) and the lowest diversity (H'= 1.992)

Similarity of zones and transect points

The EZ and NZ were similar in diversity, abundance and richness of species at 87.02% and both EZ, WZ and NZ combined were similar at 68.79%. Also EZ (TP) 600m and NZ (TP) 600m were very similar at 85.13%. EZ (TP) 400m and NZ (TP) 400m were also similar at 83.35%. EZ (TP) 600m, NZ (TP) 600m, EZ (TP) 400m and NZ (TP) 400m were similar at 71.05%

Discussion

Butterfly diversity and abundance

High butterfly abundance typically implies a healthier ecosystem (Moranz et al., 2012). High relative abundance of individuals and species richness of butterflies (329 individuals and 55 species richness) in the EZ of the quarry may be attributed to the presence of a large secondary forest (dense canopy with a lot of undergrowth and sweet nectar plants) in the zone which served as a refuge for butterfly species. In this study, the high abundance of tree species (175) correlated positively with butterfly diversity in the EZ of the quarry site. This support work done by Begum, Habiba & Howlader. (2014) suggesting that butterflies are attracted to flower garden and nectar produced from flowers, which contains nutritious vitamins, lipids, sugar, amino acid which are important food source for pollinators. The movement of dust particles towards the WZ after every blast of the quarry might have contributed to the low relative abundance of individuals and low species richness in the zone, whiles dust and vibrations from heavy vehicles movement in the NZ could possibly have caused the decline in butterfly relative abundance and species richness in the zone. This agrees with work done by Eshiwani (2014) who suggested that, quarrying carries the potential of destroying habitats and the species they support.

Relative abundance and diversity of insect orders across the three zones using radial transect approach

The forest ecosystem at Monwire quarry site is seriously disturbed due to the continuous overexploitation of rocks and natural resources, impacting negatively on flora and fauna communities. High relative abundance of insects (N=302) at transect point 400m (TP 400m) and high species richness (S=33) at transect point 600m (TP 600m) recorded in the Eastern zone (EZ) might have been caused by less disturbance at these transect points, which favours foraging of flowering plants by insects. This was supported by a work done by Kyerematen, Kaiwa & Acquah-Lamptey (2018) suggesting that abundance and diversity of insects at a particular habitat depends on a wide range of factors including the availability of food. There was positive correlation between host plant high diversity (H = 1.874) and insect high diversity (H = 2.616) at TP 600m compared to the other points in the Eastern Zone (EZ).

High relative abundance of insects (N=192) and high species richness (S=27) recorded at TP 200m in the Western zone (WZ) could be due to the sacred groove located at the TP 200m proximity. This was supported with work done by Wang et al. (2006) who suggested that spatial distribution of resources in heterogeneous environment strongly influence how animals inhabit a landscape and ultimately their abundance. Animals are expected to select areas with higher complementation to reduce travelling cost (Dunning, Danielson & Pulliam, 1992). However TP 400m had the lowest relative abundance of individuals (N=73) and lowest species richness (S=16) as well as lowest diversity (H=2.157). This might have been due to the continuous disturbance of the habitat by quarry operations through blasting, vibration and disposal of waste rocks. This confirmed work done by Nisic (2018), who indicated that quarry operations negatively affects the environment in a variety of ways during exploration, blasting, transportation and disposal of waste rocks. In the Northern zone (NZ), high relative abundance of insects (N=293) and high species richness (S=33) recorded at TP 400m could be due to the secondary forest located in the transect point proximity. However TP 200m had the highest diversity (H=2.537). This may be due to the dominance of a single species at the point. This was supported by the highest Simpson index (D=0.8711) than the other points in the zone.

Comprehensive inventory of insect orders in the respective zones

The distribution of any species is restricted by the suitability of its habitat in terms of availability of food and other resources (Marciniak et al., 2007). The Western Zone (WZ) had the lowest relative abundance of individuals and species richness. This could be due to the negative impact of the quarry operations on the zone resulting from the high volumes of dust that move in that direction after every blast at the quarry. Stankovic & Stankovic. (2013) reported that the effect of active quarry operation on insects, affect the abundance of phytophagous insects which represent a significant percentage of the invertebrate group. When the frequency of disturbance is very high diversity decreases because only good colonizers or highly tolerant species can persist (Msalilwa et al., 2019). It is also not surprising that the Northern Zone (NZ) had the least diversity because of the destruction of vegetation cover, species habitat as well as destruction of farmlands for housing, road construction, and human settlements. Roads can fragment habitats, degrade environment, increase edge effect, isolate breeding population, reduce population size, and cause genetic bottlenecks (Muñoz, Torres & Megías, 2015).

Similarity of zones and transect points

Species composition in the EZ and NZ were more similar than the WZ mainly due to the fact that the EZ and NZ are geographically closer to each other than WZ. Less similarity of species between the three zones may be because of habitat preference. This is an indication of the negative effect of quarry operations on the diversity of insect species in the area.

Conclusion

The Mowire quarry site exhibited a clear case of how quarry operations affects biodiversity. Habitats loss and fragmentation poses the greatest threat to the long term survival of species on earth, main threat to insect biodiversity and ecological function of tropical ecosystems. The quarry operations had little effect on the diversity, abundance and richness of species in the EZ. However the quarry operations negatively affected the WZ, resulting in the zone having the lowest relative abundance of individuals and species richness. Active quarry operations affected the abundance of phytophagous insects which represent a significant percentage of the invertebrate group. Destruction of vegetation cover, species habitat, farmlands and other anthropogenic activities accounted for the low diversity of species in the NZ. Quarry operations however had a negative impact on the abundance and richness of indicator species in all the zones.

Quarry operation had little impact on the relative abundance of insects at TP 400m and species richness at TP 600m in the EZ. However TP 400m in WZ was negatively affected by the quarry operations resulting in the lowest relative abundance of individuals and lowest richness as well as lowest diversity. The EZ retained a suitable environment for insect abundance, richness and diversity as compared to WZ and NZ which were negatively affected by the quarry operations in the study area. It is recommended that interventions to prevent biodiversity habitat loss in and around the quarry operational site should focus on policies that ensure and enforce the establishment of a dust control mechanism system in the extractive industry.

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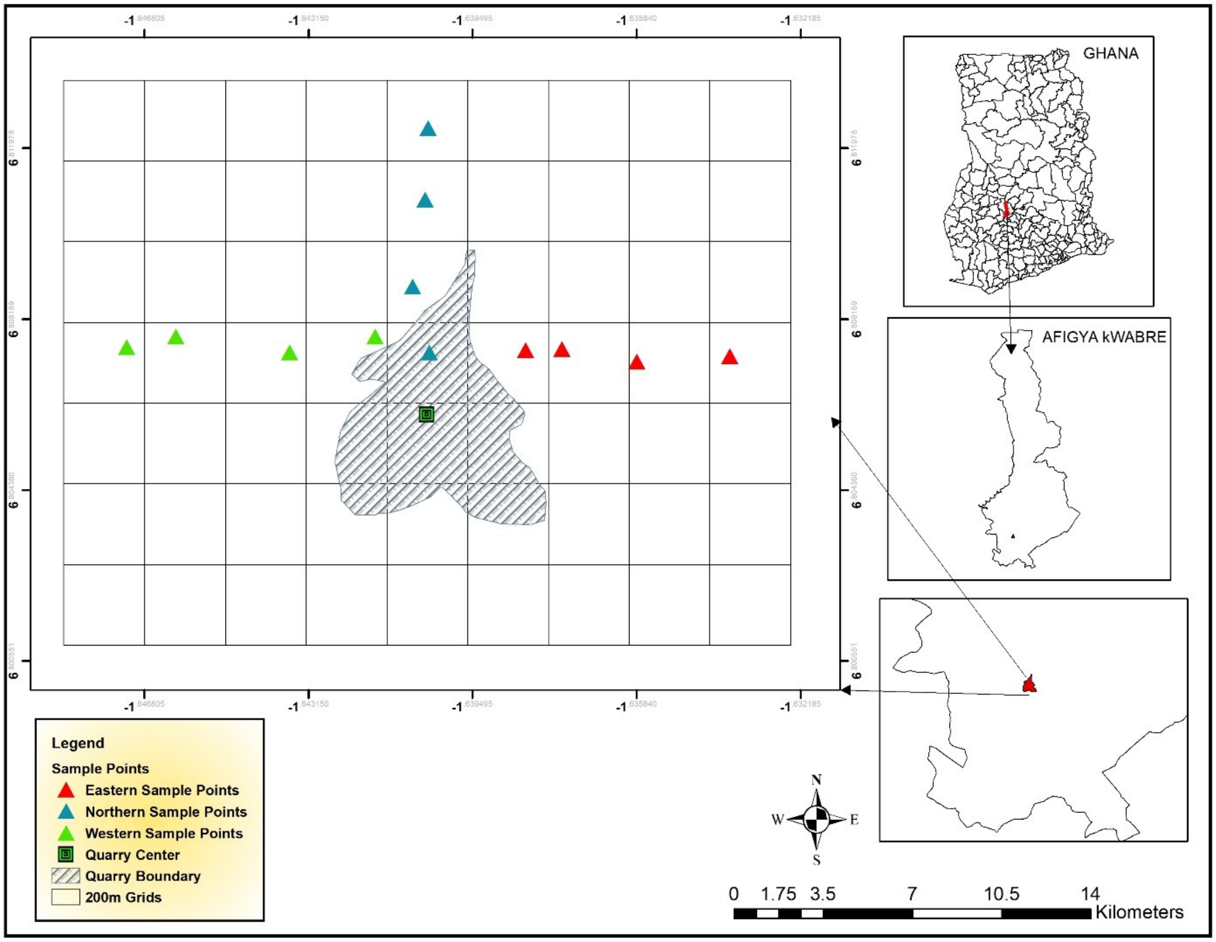

Figure 1: Map showing transect points in all the three zones (**Source:** Addae, 2019)

Table 1: Relative abundance of insect orders/families recorded in all three zones.

Order	Eastern	Western	Northern	**Total**	**Family (Butterfly)**	Eastern	Western	Northern	**Total**
COLEOPTERA	240(24.6%)	176(32.5%)	243(25.0%)	659(26.5%)	HESPERIIDAE	10(3.0%)	4(9.8%)	3(6.4%)	17(4.1%)
DERMAPTERA	2(0.2%)	3(0.6%)	1(0.1%)	6(0.2%)	LYCAENIDAE	141(42.9%)	5(12.2%)	4(8.5%)	150(36.0%)
DICTYOPTERA	18(2.0%)	7(1.3%)	20(2.1%)	45(1.8%)	NYMPHALIDAE	66(20.1%)	25(61.0%)	15(32.0%)	106(25.4%)
DIPTERA	146(15.0%)	104(19.2%)	135(14.0%)	385(15.5%)	PAPILIONIDAE	11(3.3%)	1(2.4%)	9(19.1%)	21(5.0%)
HEMIPTERA	50(5.0%)	33(6.1%)	39(4.0%)	122(5.0%)	PIERIDAE	101(30.7%)	6(14.6%)	16(34.0%)	123(29.5%)
HOMOPTERA	0 (0)	4(0.7%)	0(0)	4(0.1%)	**Total**	**329**	**41**	**47**	**417**
HYMENOPTERA	126(13.0%)	107(19.8%)	128(13.2%)	361(14.5%)					
ODONATA	0(0)	0(0)	8(0.8%)	8(0.3%)					
ORTHOPTERA	391(40.1%)	107(19.8%)	394(40.6%)	892(36.0%)					
PHASMIDA	1(0.1%)	0(0)	2(0.2%)	3(0.1%)					
Total	**974**	**541**	**970**	**2,485**					

Table 2. Diversity indices for insect orders/butterflies recorded in all three zones.

Diversity index (Other insects)	East	West	North	Diversity index (Butterflies)	East	West	North
H'	2.620	2.461	1.523	H'	2.616	2.807	2.696
D	0.869	0.855	0.865	D	0.822	0.921	0.907
J'	0.673	0.682	0.666	J'	0.653	0.908	0.886
d	6.975	5.720	6.696	d	9.317	5.655	5.195
N	974	541	970	N	329	41	47
S	49	37	47	S	55	22	21

*Simpson index (D), Shannon-Weiner diversity index (H'), Pielou evenness (J'), Margalef (d), Number of individuals (N) and Number of species / species richness (S).

Table 3. Relative abundance of insect orders captured in transect points in all zones.

	Eastern Zone					Western Zone				
Order	200m	400	600m	800m	Total	200m	400m	600m	800m	Total
COLEOPTERA	48(27.3%)	80(26.5%)	47(18.2%)	65(27.3%)	240(24.6%)	85(44.3%)	10(13.6%)	40(27.8%)	41(31.3%)	176(32.6%)
DERMAPTERA	0(0)	0(0)	2(0.8%)	0(0)	2(0.2%)	1(0.5%)	0(0)	0(0)	2(1.5%)	3(0.5%)
DICTYOPTERA	6(3.4%)	3(0.9%)	7(2.7%)	2(0.8%)	18(2.0%)	5(2.6%)	1(1.4%)	0(0)	1(0.8%)	7(1.3%)
DIPTERA	28(16.0%)	27(9.0%)	51(19.7%)	40(16.8%)	146(15.0%)	31(16.1%)	7(9.6%)	29(20.1%)	37(28.0%)	104(19.3%)
HEMIPTERA	8(4.5%)	17(5.6%)	12(4.7%)	13(5.5%)	50(5.0%)	9(4.7%)	8(11.0%)	5(3.5%)	11(8.4%)	33(6.1%)
HOMOPTERA	0 (0)	(0)	0(0)	0(0)	0(0)	0 (0)	1(1.4%)	2(1.4%)	0(0)	3(0.5%)
HYMENOPTERA	41(23.3%)	45(15.0%)	24(9.3%)	16(6.7%)	126(13.0%)	28(14.6%)	29(39.7%)	29(20.1%)	21(16.0%)	107(19.8%)
ORTHOPTERA	45(25.5%)	129(42.7%)	115(44.6%)	102(42.9%)	391(40.1%)	33(17.2%)	17(23.3%)	39(27.1%)	18(14.0%)	107(19.8%)
PHASMIDA	0(0)	1(0.3%)	0(0)	(0)	1(0.1%)	0(0)	0(0)	0(0)	0(0)	0(0)
Total	**176**	**302**	**258**	**238**	**974**	**192**	**73**	**144**	**131**	**540**

Northern Zone

Order	200m	400m	600m	800m	**Total**
COLEOPTERA	45(26.0%)	78(26.6%)	52(19.7%)	68(28.2%)	243(25.0%)
DERMAPTERA	0(0)	0(0)	1(0.4)	0(0)	1(0.1%)
DICTYOPTERA	6(3.5%)	6(2.0%)	6(2.3%)	2(0.8%)	20(2.1%)
DIPTERA	27(15.6%)	28(9.5%)	36(13.6%)	44(18.2%)	135(14.0%)
HEMIPTERA	9(5.2%)	11(3.8%)	12(4.6%)	7(3.0%)	39(4.0%)
HYMENOPTERA	38(22.0%)	50(17.1%)	28(10.6%)	12(5.0%)	128(13.2%)
ODONATA	0(0)	0(0)	2(0.8%)	6(2.5%)	8(0.8%)
ORTHOPTERA	48(27.7%)	118(40.3%)	126(48.0%)	102(42.3%)	394(40.6%)
PHASMIDA	0(0)	2(0.7%)	0(0)	(0)	2(0.2%)
Total	**173**	**293**	**263**	**241**	**970**

Table 4. Diversity indices for transect points in all three zones

	Eastern Zone				Western Zone				Northern Zone			
Diversity index	200m	400m	600m	800m	200m	400m	600m	800m	200m	400m	600m	800m
H'	2.645	2.342	2.616	2.193	2.164	2.157	2.371	2.255	2.537	2.475	2.427	2.188
D	0.8919	0.8401	0.8832	0.8066	0.7833	0.8155	0.8677	0.8527	0.8711	0.8556	0.8624	0.8111
J'	0.7855	0.703	0.7482	0.69	0.6566	0.7779	0.7669	0.7803	0.7533	0.7078	0.7208	0.6885
d	5.415	4.728	5.759	4.206	4.945	3.496	4.22	3.487	5.477	5.634	5.025	4.193
N	176	302	258	238	192	73	144	131	173	293	263	241
S	29	28	33	24	27	16	22	18	29	33	29	24

*Simpson index (D), Shannon-Weiner diversity index (H'), Pielou evenness (J'), Margalef (d), Number of individuals (N) and Number of species / species richness (S).

Species	Local Name	East	West	North	Total
Antiaris toxicaria	Kyenkyen	4(2.3%)	0	4(2.3%)	8(2.1%)
Albizia adianthifolia	Pampena	1(0.6%)	0	9(5.1%)	10(2.6%)
Albizia zygia	Okoro	6(3.4%)	0	2(1.1%)	8(2.1%)
Amphimas pterocarpoides	Yaya	2(1.1%)	0	0	2(0.5%)
Baphia nitida	Odwen	30(17.1%)	10(9.0%)	0	40(10.4%)
Baphia pubescens	Odwenkobiri	10(5.7%)	3(2.7%)	8(4.6%0	21(5.4%)
Blighia sapida	Akye	1(0.6%)	0	0	1(0.3%)
Ficus sur	Nwadua	7(4.0%)	0	0	7(1.8%)
Ficus exasperate	Nyankyerene	11(6.3%)	11(10.0%)	21(12.0%)	43(11.1%)
Margaritaria discoidea	Pepea	1(0.6%)	22(19.8%)	0	23(6.0%)
Millettia zechiana	Fafraha	9(5.1%)	0	0	9(2.3%)
Morinda lucida	Konkroma	5(2.8%)	17(15.3%)	3(1.7%)	25(6.5%)
Newbouldia laevis	Sesemasa	0	0	6(3.4%)	6(1.6%)
Broussonetia papyrifera	York	6(3.4%)	18(16.2%)	11(6.3%)	35(9.1%)
Chromolaena odorata	Acheampong	25(14.3%)	0	0	25(6.5%)
Elaeis guineensis	Abe	55(31.4%)	7(6.3%)	16(9.1%)	78(20.2%)
Pseudospondias microcarpa	Akatawani	2(1.1%)	2(1.8%)	0	4(1.0%)
Leucaena leucocephala	Lucaena	0	4(3.6%)	0	4(1.0%)
Spondias mombin	Atoa	0	2(1.8%)	0	2(0.5%)
Cocos nucifera	Kobe	0	0	10(5.7%)	10(2.6%)
Caragana arborescens	Pea	0	0	4(2.3%)	4(1.0%)

Citrus medica	Akutoo	0	12(10.8%)	0	12(3.1%)
Mangifera indica	Mango	0	2(1.8%)	4(2.3%)	6(1.6%)
Tectona grandis	Tek	0	0	2(1.1%)	2(0.5%)
Alstonia boonei	Sinuro	0	1(1.0%)	0	1(0.3%)
Total		**175**	**111**	**100**	**386**

Table 5. Relative abundance of plant species captured in all three zones.

Table 6: Diversity indices of plant species for all transect points in all the three zones.

Diversity index	Eastern				Western				Northern			
	200m	400m	600m	8000m	200m	400m	600m	8000m	200m	400m	600m	8000m
H'	1.898	1.618	1.874	1.653	1.143	1.691	1.249	1.276	1.871	1.208	1.526	1.748
N	87	49	55	42	29	25	37	27	36	20	20	35
S	10	7	9	7	5	6	6	4	8	4	5	7

Diversity index	Eastern	Western	Northern
H'	2.173	2.241	1.992
N	175	111	100
S	16	13	13

* Shannon-Weiner diversity index (H'), Number of individuals (N) and Number of species /species richness (S).

Table 7: Coordinate points for all transect points across the three zones

Transect point	Eastern zone	Western zone	Northern zone
		Coordinate points	
200m	(92°E 6° 48' 32"N 1° 38' 27"W) 270m	(271°W 6° 48' 30"N 1° 38' 18"W) 280m	(200°S 6° 48' 28"N 1° 38' 46"W) 270m
400m	(103°E 6° 48' 31"N 1° 38' 30"W) 270m	(268°W 6° 48' 27"N 1° 38' 15"W) 280m	(177°S 6° 48' 39"N 1° 38' 26"W) 260m
600m	(96°E 6° 48' 30"N 1° 38' 30"W) 280m	(270°W 6° 48' 26"N 1° 38' 12"W) 290m	(178°W 6° 48' 40"N 1° 38' 28"W) 250m
800m	(87°E 6° 48' 28"N 1° 38' 30"W) 280m	(264°W 6° 48' 26"N 1° 38' 9"W) 290m	(179°S 6° 48' 41"N 1° 38' 29"W) 240m