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Ants response to mining prospection disturbances across vegetation zones in tropical mountain chains of Mount Nimba, Guinea, West Africa

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ABSTRACT

Even though ants have been successfully used as biological indicators of mine site rehabilitation, studies focused on these insects during the early mining prospecting activities are rare. We conducted a snapshot study with the aim to provide data on possible rehabilitation success in mining sites after disturbances using ant as biological indicators. In this sense, we compared ant richness and species composition across three distinct vegetation zones (Highland meadows, transition savannahs and altitudinal forests) at six mining prospecting sites (Mining Area) and compared them with those of six nearby without mining activities (World heritage Site), all located in the Mount Nimba Strict Nature Reserve. Ants were sampled using pitfall traps and tuna lures. A total of 119 ant species and morphospecies ranged from 95 species at World Heritage Site to 69 species genera were recorded. Ant richness and species composition did not differ significantly among Meadows and Savannah habitats of both study sites, while there was a significant difference among forest habitats. The comparison of weather and soil variables showed only a significant difference for soil pH among surveyed sites. We found that weather and soil variables did not play a significant role in the segregation of ant assemblage, thus, suggesting that the structure of vegetation result in changes of ant assemblage, and consequently, future restoration action should be focused on the protection and rehabilitation of native forest.

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Keywords: Ant communities, mining, rehabilitation, Mount Nimba Strict Nature Reserve.

INTRODUCTION

Biodiversity is defined as the variety of life forms at all levels of biological organisation, including taxonomic, genetic and ecosystem diversity (Gaston and Spicer, 2004). For biodiversity conservation and sustainable management, our understanding of how habitat features influence species

distribution is essential for determining rehabilitation strategies, specifically in natural ecosystems under pressures. Mountain ecosystems are known to be a well-organised natural laboratory which provides a unique opportunity to study biodiversity distribution (Lomolino et al., 2001), because the zonation of the mountain landscapes due to the

elevational gradient. In Africa, the Mount Nimba chains located in the Guinean Forest of West Africa biodiversity hotspots, is considered as a priority area for conservation by its high degree of endemism and diversity. Unfortunately, the Mount Nimba Strict Nature Reserve (MNSNR), a Biosphere Reserve and World Heritage Site, located in the biodiversity hotspot, has its status compromised since 1992 (WHC, 2018). In fact, this transboundary Reserve between Guinea, Côte d'Ivoire and Liberia supports an exceptional variety of forest and savannah habitats. It also contains some of the highest-grade iron ores in the world. Consequently, this protected area undergoes pressures due to forest exploitation, poaching and mining activities which have already taken precedence in the Liberian sector (Bene et al., 2013). Despite these pressures, many taxa have received little attention, specifically insects which may reflect trends in species richness and community composition more accurately than vertebrates (Samways et al., 2010; Kone et al., 2018). Among insects, ants are a diverse and highly abundant insect group which plays an important functional role in tropical ecosystems (Iboudo-Tapsoba et al., 2011; Andersen, 2019). In this sense, they are widely used as bioindicators in monitoring and rehabilitation programs (Fernandes and Souza, 2018), and reflect the trend that the conservational status of an area may determine the number and identity of species inhabiting it (Santiago et al., 2018). Although, these insects have been successfully used as bioindicators of mine site rehabilitation (Jamison et al., 2016), little studies have documented their predictive abilities.

This work was conducted in the framework of an environmental and social impact study of mining project "Nimba Iron" conducted by the "Société des Minerais de Fer de Guinée (SMFG)". The general objective of the present work is to establish how ants could serve as biological indicators by considering soil and climatic variables in different vegetation zones of Mount Nimba Strict Nature Reserve, and thus, provides indications on rehabilitation success in mining sites after disturbances. Specifically, this study aimed at comparing ant richness and

species composition following vegetation zones and environmental variables in Mining area and World Heritage Site.

MATERIALS AND METHODS

Study Sites

The study was conducted within the Nimba Mountain chains in the South-east of Guinea (altitude 809 -1576 m). The study sites lie in Biosphere Reserve and World Heritage Site (WHS) of Mount Nimba Strict Nature Reserve (07°36'11".448N to 008°23'27".492W), and its declassified portion referred as Mining Areas (MA) since 1968 (Figure 1). Climate in the area is a sub-equatorial mountain type, with total annual precipitation averages of 2,800 mm and mean annual temperature fluctuating between 18 °C and 33 °C. Twelve locations were sampled (Table S1), all representing the main vegetation zones commonly found in the area, namely highland meadows, altitudinal forests and transition savannah between them. Highland meadows are vegetation zones which cover the ridges of Nimba Mounts. It is grassy vegetation without trees or shrubs dominated by *Loudetia kagerensis* and composed of orophilic species (*Polystachya sp.*), species of lowland areas and mountain species from the flora of the plains (Lamotte et al., 2003). Vegetation of this area relay on ferralitic soils with indurated layers and hard and consistent breastplate (Diallo, 2017). The altitudinal forests cover mountain slopes from valleys to ridges and dominated by *Parinari excelsa*, a vegetation type characteristic of the West African rocky massif. The altitudinal forests of Nimba Mountains relay on deep ferralitic soils with homogeneous layers. The transition savannah is herbaceous vegetation consisting of trees and shrubs found at the edges of altitudinal forest. These transition savannahs are supported by gravelly soils and contain species typical of deforested areas dominated by *Setaria ckevalieri*, *Pieridium lanuginosum*, *Dissotis jacquesii* and *Harungana madagascariensis* (Lamotte et al., 2003).

Ant Sampling and Environmental Data

Sampling was conducted between April and May 2017, along two 200 metres

transects. Each transect included 20 sampling points separated by 10 m from each other. Ants were captured using pitfall and baiting traps method on the same transect (Underwood and Fisher, 2006). Pitfall traps were plastic beverage cups (330 ml, depth 8 cm, mouth diameter 7 cm) filled with trapping fluid (70° alcohol + few drops of glycerine) (Yeo, 2006). Pitfall traps were serviced 2 days after the placement. Baiting was tuna lures placed along transect at 5 m apart from the pitfall traps. All the samples collected were preserved in an individual Eppendorf minitube of 2 ml filled with alcohol (96%) and labelled before processing. Ants were identified into genus level and into morphospecies level using the key given by Fisher and Bolton (2016). Species were named using the following keys: *Tetramorium* (Bolton, 1980); *Cataulacus* and *Cardiocondyla* (Bolton, 1982); *Monomorium* (Bolton, 1987); *Nylanderia* (LaPolla et al., 2011) and Doctor Yeo ant collection. Identified specimens were deposited at the Lamto Ecology Research Station in Côte d'Ivoire. Environmental data comprised weather and soil variables. Weather data included air temperature (°C) and relative humidity (%). We collected weather data by installing iButton DS1923 data logger to record air temperature and relative humidity. We then summarized these data to obtain a mean temperature and relative humidity for each surveyed site. We also collected three soil random cores for each surveyed site and analysed the samples at the soil analysis laboratory of "Institut de Recherche Agronomique de Guinée (IRAG)" at Kindia, in Guinea. Soil samples analysis included pH, apparent density (g.cm^{-3}), organic matter content (%).

Data analysis

For statistical analysis, data were pooled for the two traps on each transect. The number of occurrences (absence/presence) of species was used as a measure of abundance rather than the number of individuals. To evaluate the inventory reliability, sampling coverage was calculated as the ratio of observed species richness and expected

species richness obtained using non-parametric Chao 2 estimator included in Estimates 9.1.0 (Colwell et al., 2013). Then, data were generated to construct species accumulation curves which are a plot of observed species richness and expected species richness against sampling points. Ant communities were then described and compared following: species richness (S) which is not sensitive to abundance and gives disproportionate weight to rare species; Shannon diversity index (H') and Evenness (E) which weight each species according to its abundance and can be interpreted as the number of typical species in the community; and finally Simpson Dominance diversity index (D) which can be interpreted as the very abundant or the dominant species in the community (Jost, 2006). One-way analysis of Variance (ANOVA), Friedman test and Wilcoxon test were used to study variation in species richness and abundance after checking the normal distribution of our data. F and T-tests were conducted for paired comparison of weather and soil variables among the surveyed areas of both study sites. Then a multiple linear regression was conducted to test the effect of these environmental variables on ant species richness and abundance, formerly log-transformed. To investigate change in ant species composition and turnover between vegetation zones of each study site, a non-metric multidimensional scaling (NMDS) was built to visualize variation in composition among the study area. Furthermore, Bray-Curtis index values were used to perform an analysis of similarity (ANOSIM) based on 999 permutations to compare the difference in ant species composition among vegetation zones from each study site. ANOSIM generates a R statistic that indicates the degree of average dissimilarity between the assemblage being compared. Values close to 1 indicate distinct differences, whereas values close to 0 indicate high level of similarity in species composition. Statistical analyses were performed using PAST 3.1.0 (Hammer et al., 2001).

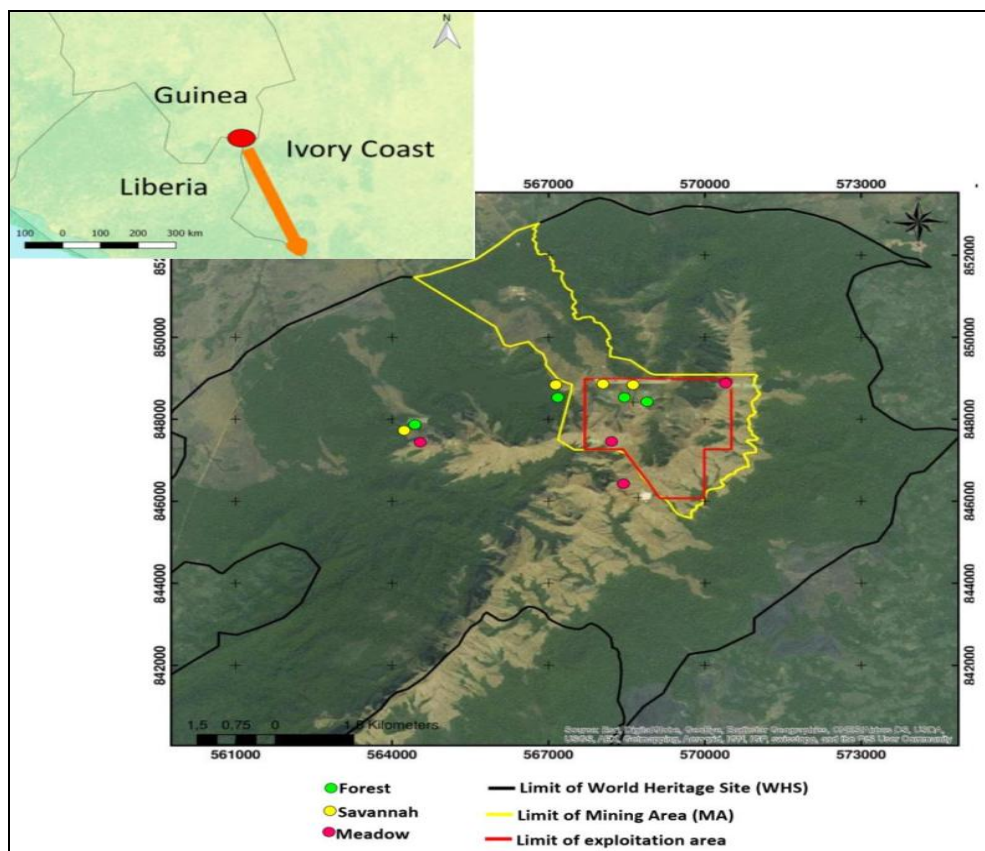


Figure 1: Location of study sites and sampling areas in vegetation of Guinean Nimba Mountain chains.

Table S1: Location and coordinates of study sites.

Sites	Vegetation Zones	Sampling areas	Latitude	Longitude	Altitude
World Heritage Site	Highland Forest	Mt. Leclerc	N 07°40'07.6''	W 08°25'01.1''	874
		Mt. Gba valley	N 07°40'34.1''	W 08°23'27.6''	1077
	Savannah transition	Mt. Leclerc	N 07°40'14.7''	W 08°24'54.9''	809
		Mt. Zougué	N 07°40'43.2''	W 08°23'25.1''	1122
	Highland Meadow	Mt. Leclerc	N 07°40'00.1''	W 08°24'44.8''	1140
	Mt. Grand Rocher	N 07°39'23.1''	W 08°22'47.8''	1683	
Mining Area	Highland Forest	River Zié valley	N 07°40'24.0''	W 08°22'21.6''	1273
		Mt. Génie	N 07°40'48.8''	W 08°22'24.6''	1161
	Savannah transition	Mt. Château 1	N 07°40'35.4''	W 08°22'39.6''	1149
		Mt. Château 2	N 07°40'42.4''	W 08°22'56.6''	1111
	Highland Meadow	Mt. Pierré Richaud	N 07°40'43.6''	W 08°21'41.9''	1556
Mt. Sempéré	N 07°40'03.5''	W 08°22'50.5''	1576		

RESULTS

The pitfalls and baiting traps have yielded 119 species and morphospecies for the whole study. Chao 2 estimator have predicted a maximum of 166 expected ant species collected with pitfall traps and baiting, thus, our sampling effort has shown that 71.1% of expected ant species was captured in both the study sites. However, we found that sampling coverage values were high for Meadow and Savannah, while low in forest areas (Table 1). The species accumulation curves continue to grow (Figure 2).

Ant species diversity and richness

In total, 95 ant species were recorded for the World Heritage Site and 69 species for the Mining area (ANOVA: $F= 6.25$, $df= 5$, $p < 0.0001$). The number of ant species collected was significantly different among vegetation zones in the World Heritage Site (ANOVA: $F= 7.94$, $df= 2$, $p < 0.0001$), while there was not a difference in Mining Area (ANOVA: $F=0.94$, $df= 2$, $p= 0.37$). In addition, observed species richness and Shannon's diversity index were high in forests and savannahs, whereas low values were noted in Meadows. However, Simpson's dominance index was relatively high in Meadows when compared with forests and savannahs (Table 1). Exceptionally, this metric was very low in the forests of World Heritage Site. Evenness values were ranged between 0.47 and 0.63. The number of ant species richness differed significantly when comparing ant communities between vegetation zones for World Heritage Site and Mining areas (Friedman test: $X^2 = 14.17$, $df=5$, $p<0.0001$). Post-hoc pairwise comparison did not show a difference in the number of observed species richness among Meadows (Wilcoxon: $Z= 1.33$, $p= 0.182$). In contrast, a significant difference was noted between the observed species richness among forests ($Z= 3.72$, $p< 0.0001$) and among savannahs ($Z= 2.03$, $p= 0.042$). The comparison of the number of unique species detected showed that more species occurred in the forest and savannah habitats of World Heritage Site in contrary to Mining Area. As for Meadows few

unique species occurred in this vegetation type (Table 1). Otherwise, except the pH ($F= 8.35$, $df=1$, $p= 0.036$), soil apparent density ($F= 4.36$, $df=1$, $p= 0.13$), organic matter ($F=2.75$, $df= 1$, $p= 0.29$) and climatic variable temperature ($F=1.21$, $df= 1$, $p= 0.83$) and relative humidity ($F= 2.12$, $df= 1$, $p= 0.43$) did not vary significantly when performing pairwise comparison among vegetation zones (Figure 3a, 3b). Likewise, the results have not shown any effect of weather and soil variables on ant species richness (ANOVA: $F= 1.71$; $p = 0.26$) and Abundance ($F= 2.01$; $p= 0.21$).

Species composition and Abundance

Analysis of change in ant species composition showed that out of 119 ant species collected, World Heritage Site and Mining area shared 45 species. Ant species composition did not change significantly between both study site (ANOSIM: $R= -0.14$, $p= 0.71$). However, the NMDS plot indicated that differences were more pronounced among forests, while an inverse trend was observed for Meadow and Savannah habitats (Figure 4). The pairwise comparison of vegetation zones revealed that Savannah habitats shared more ant species (22 species), followed by forest habitats with 18 shared species despite their high dissimilarity. As for the Meadows they shared 15 species (Table 2). In addition, this study recorded 1576 ants species occurrences representing 29 genera and 5 subfamilies. Myrmicinae was the most speciose subfamily, with 65 species followed by Formicinae (24 species), Ponerinae (16 species), Dorylinae (9 species) and Dolichoderinae (5 species) (Table 3). Ant abundance differed significantly among World Heritage Site and Mining Area (Friedman test: $X^2 = 16.51$, $df= 5$, $p< 0.0001$). The Post-hoc pairwise comparison did not show a difference among the Meadows (Wilcoxon: $Z= 0.06$, $p= 0.95$), and among Savannah ($Z= 1.33$, $p= 0.182$). Conversely, a difference was found among the Forest habitats ($Z= 2.93$, $p= 0.003$). The most abundant species were *Pheidole sp.14* with 134 occurrences (8.5%) followed by *Camponotus acvapimensis* with 129 occurrences (8.2%), *Pheidole sp.13* with 97

occurrences (6.15%), *Paltothyreus tarsatus* with 79 occurrences (5.01%) and *Nylanderia scintilla* with 71 occurrences (4.5%) (Table 3). Moreover, the study indicated that some ant species like *Paltothyreus tarsatus* occurred more in forests of Mining area and in all vegetation zones of World Heritage Site. *Tetramorium brevispinosum* occurred more in forests of Mining Area, while *Technomyrmex andrei* was common in forests of World Heritage Site. As for Meadows and

Savannahs, the most abundant species included *Camponotus acvapimensis*, *Camponotus cinctellus*, *Lepisiota sp.7*, *Mesoponera cafraria*, *Nylanderia scintilla*; *Pheidole sp.20* and *Polyrhachis schistacea*. Exceptionally, *Pheidole sp.14* was more abundant in the Meadow of World Heritage Site where the endemic viviparous toad *Nimbaphrynoides occidentalis* occurs at high abundance.

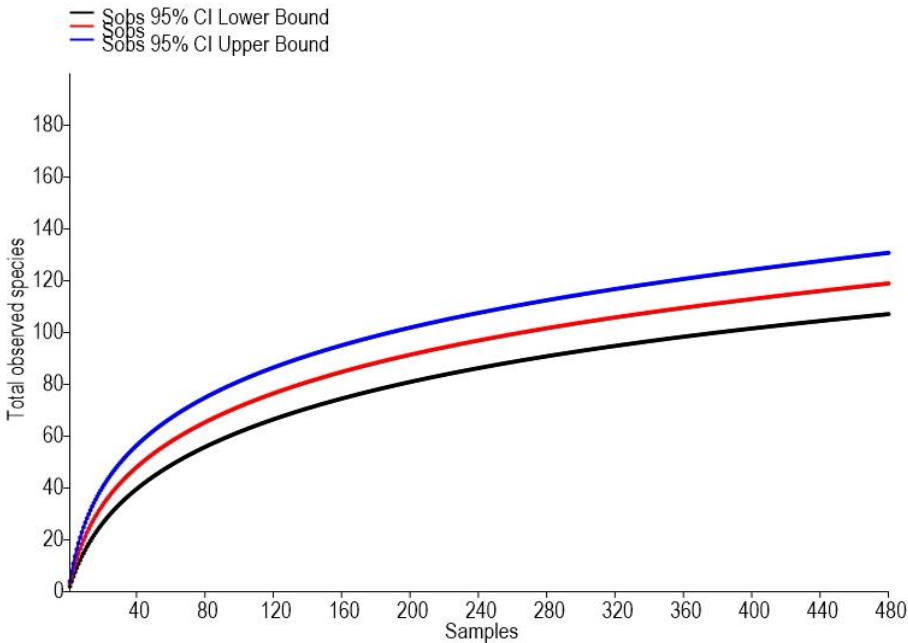


Figure 2: Species accumulation curves based on the total collection data set (n= 480) in both World Heritage Site and Mining area in the Mt. Nimba Strict Nature Reserve.

Table 1: Sampling coverage and diversity metrics of ant community in vegetation zones.

	World Heritage Site (WHS)			Mining Area (MA)		
	Meadow	Forest	Savannah	Meadow	Forest	Savannah
Sample coverage (%)	83	45	85	78	40	89
Abundance (N)	215	285	313	186	183	295
Species richness (Sobs)	27	56	48	25	33	33
Chao 2 (Sest)	32.53	125.13	56.56	31.91	81.39	36.95
Simpson diversity (1/D)	0.12	0.04	0.06	0.11	0.07	0.08
Shannon diversity (H')	2.54	4.02	3.87	2.76	3.50	3.50
Evenness (E)	0.47	0.59	0.51	0.63	0.57	0.53
Unique species	8	21	13	7	14	8

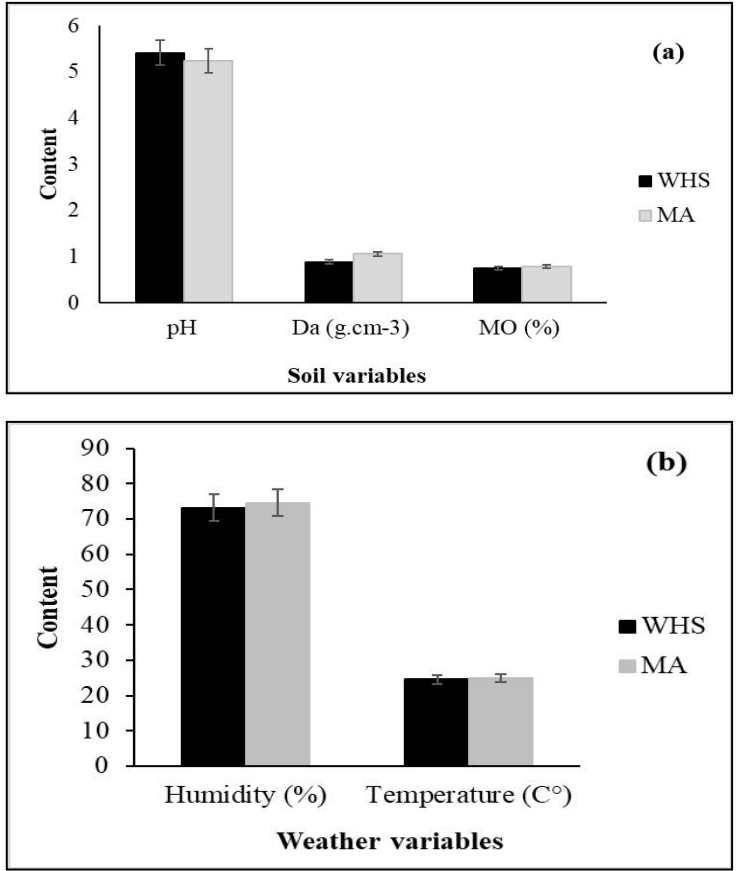


Figure 3: Soil and weather characteristics in two study sites: (a), pH ($p= 0.036$), apparent density (Da) and soil organic matter (MO) (not significantly different); (b) Relative humidity and Temperature (not significantly different). WHS = World Heritage Site, MA = Mining Area.

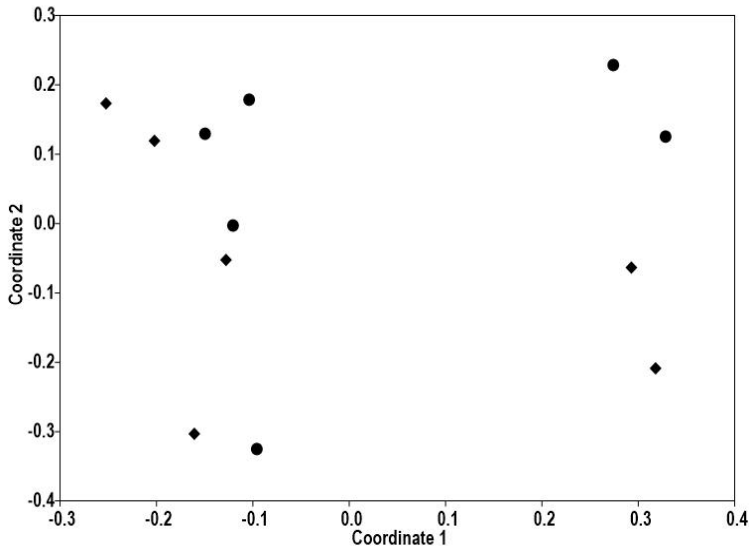


Figure 4: Ordination by non-metric multidimensional scale (NMDS) analysis showing the change in ant species composition among vegetation in the study sites (Axis 1 = 62,7%; Axis 2 = 12,6%; Stress = 0,11).

Table 2: Bray-Curtis similarity index (MA = Mining Area; WHS = World Heritage Site). The upper diagonal shows the number of ant species that occur in both vegetation zones.

	MA Meadow	MA Savannah	MA Forest	WHS Meadow	WHS Savannah	WHS Forest
MA Meadow	-	14	5	15	16	8
MA Savannah	0.48	-	6	15	22	10
MA Forest	0.17	0.18	-	4	8	18
WHS Meadow	0.54	0.5	0.16	-	19	12
WHS Savannah	0.44	0.54	0.20	0.53	-	14
WHS Forest	0.20	0.22	0.43	0.28	0.27	-

Table 3: Abundance (occurrences) of ant species according to different vegetation type in World Heritage Site and Mining Area.

Species	Mining Area			World Heritage Site		
	Mw	Sh	Ft	Mw	Sh	Ft
<i>Aenictus sp.1</i> (D)	0	0	0	0	0	1
<i>Aenictus sp.2</i> (D)	0	0	0	0	0	1
<i>Aenictus sp.3</i> (D)	0	0	0	0	0	1
<i>Aenictus sp.4</i> (D)	0	0	0	0	1	0
<i>Anochetus africanus</i> Mayr, 1865 (P)	0	0	0	0	0	3
<i>Anochetus sp.2</i> (P)	0	0	0	0	0	1
<i>Anochetus sp.3</i> (P)	0	0	0	0	0	6
<i>Anochetus sp.4</i> (P)	0	3	0	0	0	0
<i>Bothroponera soror</i> Emery, 1899 (P)	23	0	0	4	2	3
<i>Calyptomyrmex nummuliticus</i> Santschi, 1914 (M)	0	0	0	0	1	0
<i>Camponotus acvapimensis</i> Mayr, 1862 (F)	19	45	0	19	46	0
<i>Camponotus cinctellus</i> Gerstäcker, 1859 (F)	6	17	0	0	11	0
<i>Camponotus compressiscapus</i> Andre, 1889(F)	0	2	0	0	1	0
<i>Camponotus maculatus</i> Fabricius, 1782 (F)	0	2	3	0	7	10
<i>Camponotus osiris</i> Forel, 1911(F)	3	6	0	1	5	0
<i>Camponotus puberulus</i> (F)	0	3	0	0	0	0
<i>Camponotus sp.1</i> (F)	0	0	5	0	0	0
<i>Cardiocondyla neferka</i> Bolton, 1982 (M)	0	0	0	2	0	0
<i>Carebara sp.5</i> (M)	0	0	0	0	1	7
<i>Carebara sp.6</i> (M)	0	0	0	0	0	3
<i>Carebara Lilith</i> (M)	0	0	0	0	0	1
<i>Carebara villersi</i> (M)	0	0	0	0	0	3
<i>Carebara distincta</i> Bolton & Belshaw, 1993 (M)	0	0	0	0	0	5

<i>Carebara silvestrii</i> Santschi, 1914 (M)	0	0	1	0	1	1
<i>Parasyscia nitidulus</i> Brown, 1975 (D)	0	0	0	0	0	1
<i>Parasyscia sp.1</i> (D)	0	0	0	0	0	1
<i>Crematogaster sp.10</i> (M)	0	1	0	0	0	0
<i>Crematogaster sp.13</i> (M)	0	0	2	0	0	0
<i>Crematogaster sp.16</i> (M)	0	9	0	3	22	0
<i>Crematogaster sp.17</i> (M)	0	0	0	0	3	0
<i>Crematogaster sp.21</i> (M)	0	0	0	0	0	1
<i>Crematogaster striatula</i> Emery, 1892 (M)	0	0	14	0	2	9
<i>Dorylus sp.3</i> (D)	0	0	0	0	0	2
<i>Dorylus sp.4</i> (D)	0	0	1	0	0	0
<i>Dorylus sp.5</i> (D)	0	0	0	2	0	0
<i>Hypoponera dulcis</i> Forel, 1907 (P)	0	0	0	0	0	1
<i>Hypoponera punctatissima</i> Roger, 1859 (P)	0	0	1	0	0	0
<i>Hypoponera sinuosa</i> Bernard, 1953 (P)	0	0	0	0	0	1
<i>Hypoponera sp.1</i> (P)	0	0	0	0	2	0
<i>Hypoponera sp.2</i> (P)	0	1	0	0	0	0
<i>Lepisiota sp.2</i> (F)	0	0	0	2	2	0
<i>Lepisiota sp.3</i> (F)	0	4	0	0	0	0
<i>Lepisiota sp.5</i> (F)	0	0	0	4	0	0
<i>Lepisiota sp.6</i> (F)	0	0	0	0	16	3
<i>Lepisiota sp.7</i> (F)	0	40	0	5	4	1
<i>Lepisiota sp.8</i> (F)	0	0	0	1	1	0
<i>Lepisiota sp.9</i> (F)	6	0	0	0	0	0
<i>Lepisiota sp.10</i> (F)	2	0	0	0	0	0
<i>Lepisiota sp.11</i> (F)	0	0	0	0	2	0
<i>Lepisiota sp.12</i> (F)	0	0	0	10	0	0
<i>Lepisiota sp.13</i> (F)	0	0	0	0	0	1
<i>Leptogenys Ferrari</i> Forel, 1913 (P)	2	1	0	0	1	1
<i>Meranoplus inermis</i> Emery, 1895 (M)	0	2	0	0	4	0
<i>Meranoplus amaretti</i> Andre, 1884 (M)	0	0	0	0	3	0
<i>Mesoponera caffraria</i> Smith, 1858 (P)	1	20	0	8	21	8
<i>Monomorium bicolor</i> Emery, 1877 (M)	1	0	0	0	3	0
<i>Monomorium dictator</i> Santschi, 1937 (M)	0	2	0	5	6	0
<i>Monomorium invidium</i> Bolton, 1987 (M)	0	0	0	0	0	2
<i>Monomorium occidentale</i> Bernard, 1953 (M)	0	0	0	0	16	0
<i>Monomorium rosae</i> Santschi, 1920 (M)	0	0	0	2	0	1
<i>Monomorium sp.1</i> (M)	0	0	1	2	0	3
<i>Monomorium sp.2</i> (M)	5	0	0	6	5	0
<i>Nylanderia boltoni</i> LaPolla, Hawkes & Fisher, 2011 (F)	0	1	0	12	0	0

<i>Nylanderia lepida</i> (Santschi, 1915) (F)	0	0	10	0	0	5
<i>Nylanderia scintilla</i> LaPolla, Hawkes & Fisher, 2011 (F)	21	4	0	36	10	0
<i>Odontomachus assiniensis</i> Emery, 1892 (P)	0	0	10	0	0	1
<i>Oecophylla longinoda</i> (Latreille, 1802) (F)	0	0	0	0	0	4
<i>Paltothyreus tarsatus</i> Fabricius, 1798 (P)	0	2	18	15	15	29
<i>Parparatrechina sp.1</i> (F)	0	0	0	0	0	6
<i>Pheidole buchholzi</i> Mayr, 1901 (M)	0	0	4	0	0	1
<i>Pheidole pulchella</i> Santschi, 1910 (M)	0	0	3	0	0	11
<i>Pheidole sp.2</i> (M)	0	0	0	0	1	0
<i>Pheidole sp.4</i> (M)	0	0	0	1	16	0
<i>Pheidole sp.8</i> (M)	1	10	0	0	0	0
<i>Pheidole sp.9</i> (M)	6	39	1	0	0	0
<i>Pheidole sp.10</i> (M)	14	14	13	4	3	1
<i>Pheidole sp.11</i> (M)	0	1	6	0	5	9
<i>Pheidole sp.13</i> (M)	25	0	28	41	0	3
<i>Pheidole sp.14</i> (M)	16	11	6	94	7	0
<i>Pheidole sp.16</i> (M)	0	0	5	0	0	6
<i>Pheidole sp.17</i> (M)	0	0	1	0	0	0
<i>Pheidole sp.18</i> (M)	0	0	3	0	0	0
<i>Pheidole sp.19</i> (M)	0	0	0	0	1	0
<i>Pheidole sp.20</i> (M)	0	12	0	2	31	9
<i>Pheidole sp.21</i> (M)	0	0	1	0	0	27
<i>Pheidole sp.22</i> (M)	0	0	0	0	0	1
<i>Phrynoponera gabonensis</i> Andre, 1892 (P)	0	0	1	0	0	6
<i>Polyrhachis militaris</i> Fabricius, 1782 (F)	0	0	0	0	0	5
<i>Polyrhachis schistacea</i> Gerstäcker, 1859 (F)	9	17	0	1	11	0
<i>Pseudolasius sp.1</i> (F)	0	0	0	0	3	0
<i>Solenopsis sp.1</i> (M)	0	0	0	0	1	0
<i>Solenopsis sp.2</i> (M)	7	0	0	0	0	0
<i>Strumigenys ludovici</i> Forel, 1904 (M)	0	0	1	0	0	0
<i>Strumigenys nimbrata</i> Bolton, 1983 (M)	0	0	0	0	1	0
<i>Strumigenys ninda</i> Bolton, 1983 (M)	0	1	0	0	1	0
<i>Strumigenys rukha</i> Bolton, 1983 (M)	0	0	0	0	1	0
<i>Technomyrmex andrei</i> Emery, 1899 (DI)	0	0	5	0	0	29
<i>Technomyrmex morens</i> Santschi 1913 (DI)	0	0	0	0	0	1
<i>Technomyrmex sp.2</i> (DI)	0	0	0	1	0	3
<i>Technomyrmex sp.3</i> (DI)	0	1	0	0	0	0
<i>Technomyrmex voeltzkowi</i> Forel 1907 (DI)	0	2	0	0	0	0
<i>Tetramorium aculeatum</i> Mayr, 1866 (M)	0	0	1	0	0	0
<i>Tetramorium anxium</i> (Santschi, 1914) (M)	3	2	0	1	2	0

<i>Tetramorium ataxium</i> Bolton, 1980 (M)	0	6	0	0	3	0
<i>Tetramorium brevispinosum</i> Stitz, 1910 (M)	0	0	30	0	0	4
<i>Tetramorium delagoense</i> Forel, 1894 (M)	0	0	0	0	0	6
<i>Tetramorium distinctum</i> Bolton, 1976 (M)	0	0	0	0	0	1
<i>Tetramorium edouardi</i> Forel, 1894 (M)	0	0	7	0	4	0
<i>Tetramorium flavithorax</i> Santschi, 1914 (M)	0	0	1	0	0	5
<i>Tetramorium furtivum</i> Arnold, 1956 (M)	6	12	0	1	0	6
<i>Tetramorium gracile</i> Forel, 1894 (M)	0	0	1	0	0	0
<i>Tetramorium guineense</i> Bolton, 1980 (M)	6	0	17	0	0	14
<i>Tetramorium intonsum</i> Bolton, 1980 (M)	1	2	0	1	2	5
<i>Tetramorium invictum</i> Bolton, 1980 (M)	0	0	0	0	0	5
<i>Tetramorium kestrum</i> Bolton, 1980 (M)	0	0	1	0	0	0
<i>Tetramorium minimum</i> Bolton, 1976 (M)	1	0	0	0	0	0
<i>Tetramorium muralti</i> Forel, 1910 (M)	1	0	0	1	2	0
<i>Tetramorium pylacum</i> Bolton, 1980 (M)	0	0	1	0	0	0
<i>Tetramorium sericeiventre</i> Emery, 1877 (M)	1	0	0	7	4	0

(DI): Dolichoderinae, (D): Dorylinae, (F): Formicinae, (M): Myrmicinae, (P): Ponerinae; Mw: Meadow, Sh: Savannah, Ft: Forest.

DISCUSSION

This study uses ant communities of distinct vegetation zones to provide indications on the environmental conditions in a mining area located at the core of Mount Nimba Strict Nature Reserve. Because ants are sensitive to the disturbance process (Andersen et al., 2006; Vasconcelos et al., 2000), we used these insects as biological indicators in sight to forecast the possible success of habitat rehabilitation after mining activities. Even with limited sampling, this study enabled to collect more of the half of expected species with pitfall traps and baiting (sample coverage =71.1%), and so, showed that sampling was representative of surveyed ant community. However, species accumulation curves failed to reach an asymptotic allure, implying that additional sampling was required to fit the pool of local species richness (Koné, 2013), specifically for forest habitats. It is important to mention that the low value of sampling coverage in forest habitats may be explained by trapping methods used here. In fact, pitfall and bait trapping are not only enough for sampling in

the forest because these methods do not collect leaf-litter ant efficiently (Underwood and Fisher, 2006). The sampling coverage will have to be probably different if ant communities associated to leaf litter have been sampled. However, the needs to conduct additional sampling does not invalidate the data of this study, as the sample coverage indicates a good sampling effort.

In this study, ant species richness varied strongly, both among study sites and among vegetation zones. That may be explained by the level of disturbance between surveyed sites. The decreasing of species richness along a gradient of disturbance is common in tropical areas (Yeo et al., 2011, Garcia-Martinez et al., 2017). In fact, the Mining area is strongly subject to continue prospecting activities, implying a high level of human-induced disturbance in comparison to the protected area of World Heritage Site. These disturbances may have reduced the ant species richness by changing habitat structure or microclimate and resource availability as reported in other studies (Ribas et al., 2012; Arnillas et al., 2017). Another possible

explanation could be the influence of vegetational formation or latitudinal gradients on the structure of the ant community (Silva et al., 2017; Vasconcelos et al., 2018). It is the case in this study, where, even though the objective was not focused on how latitudinal gradient affect ant species richness, a notable difference of ant species richness was recorded when the Meadow, Forest and Savannah habitats were compared. The value of Shannon diversity index reinforces the pattern observed with Species richness. However, the high value of Simpson dominance index in Meadow habitats may be due to the high abundance of some ant species compared to other. This finding is consistent with those of other studies documenting arthropods diversity in Alpine meadows (Maveety et al., 2013; Hiramatsu and Usio, 2018).

In contrast to the pattern observed with species richness, the comparison of species composition indicated a similar ant assemblage between World Heritage Site and Mining area. This pattern of similarity, albeit not extremely high, could indicate that both World Heritage Site and Mining Area have similar habitat features. This observation is reinforced by the fair resemblance of ant species composition as indicated by NMDS. Conversely, the dissimilarity of ant species composition among forest was more slightly pronounced when comparing this habitat for both study sites. This finding may suggest that ant assemblage of forest habitats could be more sensitive to mining prospecting activities than Meadow and Savannah habitats.

Interestingly, this study showed that the taxonomic structure of ant community of both study sites was dominated by Myrmicinae, followed by Formicinae and Ponerinae. Dolichoderinae and Dorylinae were less abundant in this study. The high abundance of Myrmicinae may be due the biology of the species belonging to this subfamily. As reported by Koné (2013), the Myrmicinae are widely distributed because of their biology which facilitates their resistance to environmental disturbances and their generalist attributes which favour their

prevalence in all habitats. In addition, with the observed pattern in abundance and the absence of effect of measured environmental variables on ant species richness and abundance, the findings of this study may support the hypothesis of species composition responds to vegetation zonation. These finding are consistent with those of Wenninger and Inouye (2008) and Cardoso et al., (2010) who reported that changes in the structure of vegetation result in changes of composition of organisms living there. In addition, this study indicated that many ant species, namely *Pheidole sp.14*, *Camponotus acvapimensis*, *Pheidole sp.13*, *Paltothyreus tarsatus* and *Nylanderia scintilla* were more prevalent within the vegetation zones of the study sites. Amongst these species, several were more typical (i.e. found at higher occurrences) of a given vegetation zone when considering their occurrences. For instance, *Paltothyreus tarsatus* occurred more in forest habitats of Mining area and in all vegetation zones of World Heritage Site. This species belonging to Ponerinae is a predator generalist, sensitive to disturbances which lead the lack of nourishment throughout the lack prey diversity (Kone, 2013). Its occurrence in all habitats of World Heritage Site could indicate a good conservation state of this area. Other species like *Tetramorium brevispinosum* occurred more in forests of Mining Area, while *Technomyrmex andrei* was common in forests of World Heritage Site. As for Meadows and Savannahs, species adapted to open areas like *Camponotus acvapimensis*, *Camponotus cinctellus*, *Lepisiota sp.7*, *Mesoponera caffraria*, *Nylanderia scintilla*; *Pheidole sp.20* and *Polyrhachis schistacea*, were more common.

Conclusion

This study shown evidence that the ant species diversity, richness and abundance were impacted by mining prospecting activities independently of soil and climatic variables. Likewise, when considering the assemblage of ant species across vegetation zones and the bioindicator capacity of these insects, the forest habitats in mining area

could be more impacted by mining activities rather than Meadows and transition Savannahs. Rehabilitation action should be focused on the protection and rehabilitation of native forest. Finally, although this study provides relevant conclusion on the possible impact of mining activities on ant community and certainly on all other components of biodiversity, the time devoted to the sampling was short. We suggest a continue monitoring using ant and other taxonomic groups in order to develop more environmental planning instruments for rehabilitation actions.

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

Conceptualization: KY. Investigation, writing original draft: KY, LMMK and MKTEG. Specimens' identification: LMMK, KO and ANS. Writing, review and editing: KY, LMMK, MKTEG, KO and ANS.

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