Introduction

Tropical forest ecosystems serve as a home to many animal species, including many threatened and endangered species. Butterflies depend on tropical forests for survival through the provision of favourable habitats and resources such as cover, camouflage, litter, moderate temperature and humidity, and food sources (Humpden & Nathan 2010). Tropical forests also support most local endemic butterflies over the globe (cf. Hill 1999; Benedick *et al*. 2006). The sensitivity of some butterfly species to anthropogenic disturbance (Koh 2007) accounts for the reason why some butterflies are used in environmental monitoring and evaluation (Brown 1997). Given the important role of tropical forest ecosystems in maintaining butterfly diversity, any disturbance agents impacting structure and composition of tropical forests may also exert enormous pressure on their complex butterfly assemblages.

In view of the fact that butterflies have the ability to respond dramatically to forest disturbance, it is imperative that regular ecological studies are conducted to determine how human disturbance affects their assemblages. Such studies may provide useful information about the conservation needs of butterfly species, and indirectly reflect the need for protection of other species within the ecosystem. Thus, studies relating human disturbance to butterfly assemblages could be useful for conservation, mostly for the particular tropical forest biota. Differences in intensity of disturbance may lead to differential effects on plant diversity and community structure (Mishra *et al.* 2004). In turn, changes in these vegetation characteristics, as a consequence of disturbance can significantly impact on butterfly diversity, composition and abundance. However, there is little information about how differences in disturbance intensity influence butterfly assemblages in most tropical forests. Although quite a number of studies have been conducted to examine the effects of disturbance on butterfly species richness in tropical forests, there are no consensus concerning the findings, as mixed results have been reported. For instance, many studies have reported that higher butterfly species richness occurs in non-disturbed forests relative to disturbed forests (Hill *et al*. 1995; Beck & Schulze 2000). Additionally, a study conducted in western Thailand revealed that butterfly diversity and abundance decreased with increasing disturbance intensity (Ghazoul 2002). On the other hand, other works reported of an opposite trend in which butterfly diversity was higher in disturbed forests than non-disturbed forests (Hamer *et al*. 1997; Willott *et al*. 2000; Fermon *et al.* 2005). Another pattern in which butterfly species richness remained similar in non-disturbed and disturbed forests was also reported in another study (Luk *et al.* 2011). A study conducted in India revealed that a moderately disturbed forest harboured higher butterfly diversity and abundance than undisturbed and highly disturbed forests (Joshi 2007). Currently, there is limited information about the role of disturbance on butterfly species composition since only a few studies have been conducted on this subject matter. Available information indicates that disturbance can impact considerably on butterfly species composition (Spitzer *et al*. 1997; Hogsden & Hutchinson 2004). Thus, intact primary forests can offer higher value for conservation of butterfly species composition than disturbed forests (Nyafwono *et al*. 2014).

Even though a lot of butterfly studies have been conducted in many parts of the world, there is dearth of information about butterfly assemblage response to disturbance in Africa. To enhance our understanding of the patterns of butterfly assemblages relative to disturbance, more studies should be conducted in this region. The Atewa Range Forest Reserve is an important forest in Ghana and West Africa because it harbours many endemic and rare species including several endemic butterfly species (Larsen 2006; Aduse-Poku & Doku-Marfo 2007; Naskrecki & Alonso 2007). Many of the endemic butterfly species in Ghana and West Africa as a whole are found in the Atewa Range Forest Reserve. Consequently, the forest reserve has been designated as a Globally Significant Biodiversity Area (Abu-Juam *et* *al*. 2003). Biodiversity in the Atewa Forest Reserve is threatened by different forms of human disturbances. Major anthropogenic activities such as bauxite mining, farming and logging are currently taking place in the forest reserve. Though some studies have been conducted in the Atewa Range Forest Reserve which demonstrate the significance of the forest reserve in maintaining butterfly diversity (Larsen 2006; Naskrecki & Alonso 2007; Adue-Poku & Doku-Marfo 2007), none of them examined the effects of human disturbance on butterflies in the area. As a result, there is no information on butterfly assemblages in relation to human disturbance in the forest reserve. The purpose of this study was to determine butterfly diversity, species composition and abundance in relation to human disturbance in the Atewa Range Forest Reserve, Ghana. The following research questions were addressed in the study: (a) what are the patterns of butterfly diversity, species composition and abundance in response to human disturbance? (b) How does butterfly diversity and abundance relate with plant diversity and forest structure?

Material and methods

Study area

The current study was conducted in the Atewa Range Forest Reserve (latitude 0° 36.00' W and longitude 6° 10.00' N) from January to June 2011. The forest reserve is one of the most important and largest forests in Ghana. It covers a total area of 23,663 ha and stretches over several towns and villages in the Eastern Region of Ghana. The reserve has distinctive upland forest vegetation which is rich in biological resources (Naskrecki & Alonso 2007) but parts of the forest have been disturbed by various human activities such as farming, logging and mining due to large bauxite deposits.

The current study was conducted in sites that were sampled by Addo-Fordjour *et al*. (2013). Based on human disturbance intensity, three different forest types namely, non-disturbed, moderately disturbed and heavily disturbed forests were selected for the study (see Addo-Fordjour *et al*. 2013). The three forest types differ significantly in plant diversity and community structure (abundance, basal area, canopy cover), being highest in the non-disturbed forest and lowest in the heavily disturbed forest (Addo-Fordjour *et al*. 2013). The heavily disturbed forest has undergone major disturbances in the form of logging and farming activities, whereas only selective logging activities have taken place in the moderately disturbed forest. The non-disturbed forest which has been protected from human activities, remains free from disturbance. In spite of the human-induced disturbance in the moderately and heavily disturbed forests, each of them remains as a contiguous forest without fragmentation.

Vegetation sampling

Within each forest type, two sampling sites were randomly selected for the study. A total of five 50 m × 50 m plots were randomly demarcated in each site and used for vegetation sampling. Thus, a total of ten 50 m × 50 m plots were sampled in each forest type. The minimum distance between the forest types was 5 km, and the sampling sites within each forest type were separated by at least 1.5 km. The plots in a sampling site were separated by a minimum distance of 200 m. In the plots, trees and shrubs with diameter at breast height ≥ 10 cm were identified and counted, whereas lianas with diameter ≥ 1 cm were enumerated. Liana diameter was measured at 1.3 m from the soil surface. Diameter of plants was measured with a diameter tape. Canopy cover of each plot was determined using a spherical densitometer. Plants were identified with the assistance of a plant taxonomist, and cross-checked with local manuals and Floras (Hawthorne 1990; Arbonnier 2004; Poorter *et al*.

2004; Hawthorne & Jongkind 2006) and herbarium specimens at the KNUST, Kumasi and the Forestry Commission, Kumasi herbaria.

Butterfly sampling

Although most butterfly studies use line transect for sampling, the quadrat sampling method was employed in this study because it allows for greater sampling effort in a given location (cf. Levanoni *et al*. 2011). Butterflies were therefore, sampled within the 50 m × 50 m plots used for the vegetation sampling.

Modified IKEA® fruit baited traps (Aduse-Poku 2006) were used to trap butterflies in the forest types. In each plot, two traps, stocked with bait were hanged on trees at the canopy and under-storey layers (DeVries *et al*. 1997). The understorey layer traps were suspended at about 2 m from the forest floor and the canopy traps were about 39-42 m from the forest floor. The bait was made by mixing over-ripped banana mashed with fermented palm wine. The traps were inspected for butterflies and re-baited simultaneously every 24 hours in the forests (between 10:00 and 12:00 h). Additional sampling was done with a swoop net during the same period of the day with the view to capturing fast or swift moving butterflies that were not caught by the traps. The net sampling was also conducted simultaneously in the forest types for a standard amount of time (10 minutes) per each plot. To avoid sampling bias, three teams of experienced collectors sampled butterflies simultaneously in the forest types. The net collectors were rotated among the plots in each forest type and also among the forest types so as to reduce collector bias (Watt *et al*. 1997). These measures ensured that sampling effort was constant in the forest types. Butterfly sampling was conducted for a period of ten weeks, amounting to 70 sampling days. Net sampling was conducted early in the morning (between 7:00 and 10:00 h) when butterflies were most active. Butterflies were identified by entomologists, and with recourse to butterfly specimens and plates at the Bobiri Forest Reserve butterfly sanctuary, and identification guide (Larsen 2005).

Data analyses

Because of possible under-detection of species in forest samples, it is important to estimate species richness from possible incomplete samples in order to account for any incomplete sampling (Kéry *et al*. 2009; Walther & Morand 1998). Additionally, sampling efforts required to properly assess butterfly richness could differ among different areas leading to incorrect variation in species abundance. This in turn, could affect the number of species enumerated, resulting in abundance-mediated variation in species richness. Nevertheless, variations in the number of individuals of species sampled may be due to real and biologically meaningful patterns in nature (cf. Schuldt *et al*. 2011). Consequently, to determine whether observed species richness variations among different areas are due to sampling incompleteness or difference in sampling efforts, species abundance data are usually subjected to rarefaction analysis and/or species richness estimation in order to assess species richness patterns of different areas. In this study, two types of analyses were used to estimate species richness of the forest types. Firstly, we used a recently developed technique which combines rarefaction and extrapolation analyses to estimate species richness based on a standardised number of individuals (Colwell *et al*. 2012; Hsieh *et al*. 2013; Chao *et al*. 2014). Individual-based (abundance) data of butterflies was used for this analysis. Fifty bootstrap replicates were used to construct confidence intervals for the estimates in the rarefaction-extrapolation curves. The confidence intervals were used to assess significant differences in the estimated species richness among the forest types. The rarefaction-extrapolation analysis was conducted with the online version of the software iNEXT (Hsieh *et al*. 2013). The use of rarefaction-extrapolation analysis in the current study was important because although sampling of butterflies was designed to reduce biasness among the forest types, butterfly abundance differed considerably among the forest types. Consequently, this analysis made it possible to determine whether differences in species richness among the forest types were real or abundance-mediated. Secondly, a non-parametric species richness estimator, Chao1, was used to estimate butterfly species richness in the forest types. This estimator was chosen for this study due to the following reasons: (1) it is valid under all types of species abundance distributions, making it a universal species richness estimator (Chao *et al*. 2009), and (2) the proportion of singletons in the data was below 50%. Chao1 estimation of butterfly species richness was conducted by SPADE version 2.0. The following equation was used by the software:

$$S_{\mathrm{Chao1}} = S_{\mathrm{ob}} + (F_1)^2 / 2(F_2),$$

Where, F_1 = number of singleton species, and F_2 = number of doubleton species, S_{Chao1} = estimated number of species, and S_{ob} = total number of species observed in a sample.

Shannon diversity index was computed for the forest types using the PAST program. Significant differences in Shannon diversity index and observed species richness among the forest types were determined using the pair-wise permutation tests in the PAST program. The version of Shannon diversity index used in the PAST program is indicated in the following formula (Hammer *et al*. 2001):

$$H' = -\sum_{i=1}^{s} pi\,(\ln pi)$$

where, pi = proportion of
the ith species, and Inpi = natural log of pi

Thus in this study, diversity of butterflies in the forest types was represented by Shannon diversity index and species richness (observed and estimated species richness). Observed species richness was determined for each forest type by counting the number of species identified in a particular forest. In addition, observed species richness per plot was determined for plants and butterflies and used in regression analysis described below.

Butterfly abundance was compared between the forest types using one-way nested analysis of variance (ANOVA), with sites nested within forest types. By this analysis, variability in butterfly abundance among the sampling sites in the forest types was determined. Tukey's HSD tests were used to determine differences of means among the forest types. Assessment of normality and homogeneity of variance on residuals was performed by probability and homogeneity tests, respectively in GenStat software. The data passed all the above mentioned tests. The ANOVA was conducted at a significance level of 5% using GenStat software (VSN International Ltd, Hemel Hempstead, UK).

Non-metric Multidimensional Scaling (NMDS) and cluster analysis (using single linkage with Bray-Curtis similarity measure) were conducted to determine butterfly species composition patterns among plots of the forest types. The NMDS was conducted using the Bray-Curtis similarity measure. Because rare species can reduce the reliability of clustering, only species that were found in more than 10 % of the plots (and with $n \geq 5$ individuals) in at least one forest type were included in the cluster analysis (Kraichak *et al*. 2009). Similarly, rare species were excluded from the NMDS analysis so as to reduce noise effect (see Kennen 2005; Vonlanthen *et al*. 2006). The NMDS ordination dimension which produced the best compromise between stress and interpretability was selected as the best dimensionality (see Johnson *et al*. 2010). ANOSIM (analysis of similarities) was also used to test for the significance of composition differences found in the NMDS (Knief *et al*. 2010; Lacorte *et al*. 2013; Addo-Fordjour & Rahmad 2014). The ANOSIM was based on 10,000 permutations of the data. SIMPER (similarity percentage) was conducted to identify butterfly species which accounted most to the variations in butterfly composition (top 50 %) among the forest types. The Bray-Curtis measure of similarity was employed for this analysis. The NMDS, ANOSIM and SIMPER analyses were conducted with the PAST programme (version 2.17c).

In order to determine vegetation characteristics related with butterfly abundance and diversity, stepwise multiple regression analysis was performed between butterfly diversity (Shannon diversity index and species richness) and abundance, and vegetation characteristics (plant species richness, Shannon diversity index, plant abundance, canopy cover). The forward selection procedure was used to eliminate redundant vegetation variables and also reduce collinearity. The stepwise regression analysis was conducted at a significance level of 5 % using the Minitab 15 software (Minitab Inc.).

Results

Butterfly diversity

A total of 79 species of butterflies belonging to 28 genera and 4 families were sampled in the study area (Table 1). Sixty four species of butterflies (26 genera and 4 families) were identified in the non-disturbed forest. In the moderately disturbed forest, 59 species (26 genera and 4 families) were identified, and the heavily disturbed forest recorded 48 species (21 genera and 4 families). Variation in observed butterfly species richness between the non-disturbed and moderately disturbed forests was not significant (pair-wise permutation tests; $P = 0.440$) even though each of these forest types had significantly higher observed butterfly species richness than the heavily disturbed forest (pair-wise permutation tests; non-disturbed vs. heavily disturbed: $P = 0.002$, moderately disturbed vs. heavily disturbed: $P = 0.007$). The rarefaction-extrapolation curves in the forest types approached asymptote (Fig. 1). They revealed a pattern similar to that of the observed species richness. The confidence interval of the curve in the heavily disturbed forest did not overlap with that of the non-disturbed forest curve, suggesting that butterfly species richness was higher in the non-disturbed forest than the heavily disturbed forest. However, the confidence intervals of the other curves overlapped, making it impossible to determine statistical significance of the estimates among those forest types. Estimated species richness (Chao1) of butterflies was highest in the non-disturbed forest and lowest in the heavily disturbed forest (Table 2). This trend was similar to that of the observed and rarefaction-extrapolation species richness of the forest types. Shannon diversity index of butterflies was similar for the non-disturbed and moderately disturbed forests (pair-wise permutation tests; $P = 0.526$). Nonetheless, each of these forest types had significantly higher Shannon diversity index than the heavily disturbed forest (pair-wise permutation tests; non-disturbed vs. heavily disturbed: $P = 0.001$, moderately disturbed vs. heavily disturbed: $P = 0.002$).

Butterfly species composition

The cluster analysis indicated clear distinction in butterfly species composition and distribution among the forest types, resulting in three distinct butterfly assemblages (Fig. 2). The above mentioned pattern of butterfly species composition was confirmed in the NMDS analysis. A two-dimensional NMDS ordination provided a stress of 0.18, and the best interpretability, and thus was chosen as the appropriate dimension. The first two axes of the NMDS clearly distinguished between the three forest types (Fig. 3). Axis 1 clearly distinguished between the moderately disturbed forest and heavily disturbed forest plots. This axis further separated the non-disturbed forest plots from those in the heavily disturbed forest. On the other hand, axis 2 separated the plots in the non-disturbed forest from the plots in the moderately disturbed forest as well as those in the heavily disturbed forest. The results of

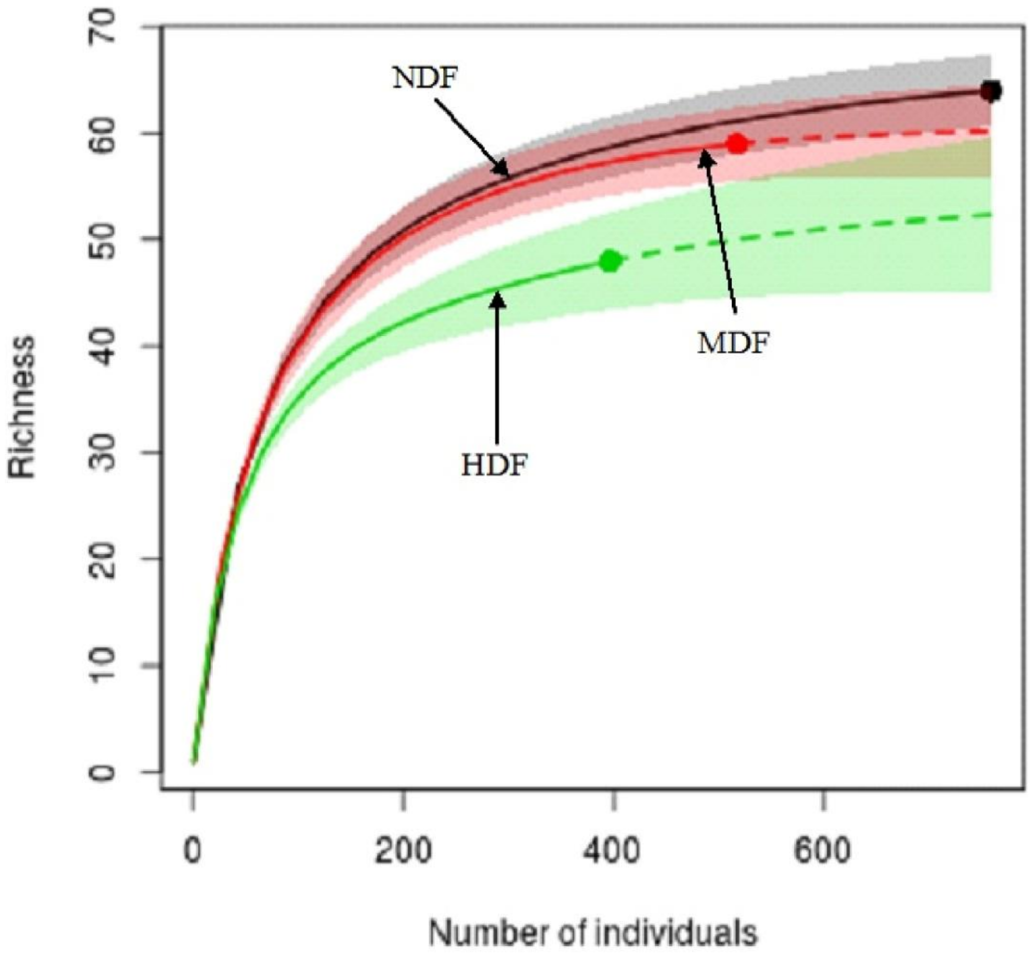

Figure 1. Individual-based rarefaction-extrapolation curves for the three forest types (ND: non-disturbed forest, MOD: moderately disturbed forest, HD: heavily disturbed forest). The solid lines represent the rarefaction curves from the reference sample. The dashed lines stand for the extrapolation curves. Each dot represents observed number of individuals.

ANOSIM revealed that butterfly species composition as expressed by the NMDS differed significantly among all the forest types (non-disturbed vs. moderately disturbed forests: R = 0.81; P = 0.0001, non-disturbed vs. heavily disturbed forests: R = 0.74; P = 0.0001, and moderately disturbed vs. heavily disturbed forests: R = 0.61; P = 0.0002). SIMPER analysis also showed considerable dissimilarities in species composition (> 50 %) among the three forest types (Appendix 1). The ANOSIM results suggest that the dissimilarities in species composition of the forest type pairs expressed by the SIMPER analysis are also significant. The SIMPER analysis further identified 20 butterfly species as accounting for the top 50 % of the dissimilarity that was observed between the non-disturbed and moderately disturbed forests. The species formed 26 % of the total number of species identified in the two forest types. A total of 17 species explained the top 50 % of the dissimilarity between the non-disturbed and heavily disturbed forests. This number of species made up of about 24 % of the total number of species that were observed between the non-disturbed and heavily disturbed forests. The moderately and heavily disturbed forests had 18 species which were responsible for the top 50 % of the dissimilarity between them. They formed 26.5 % of the total number of species that occurred in the moderately and heavily disturbed forests.

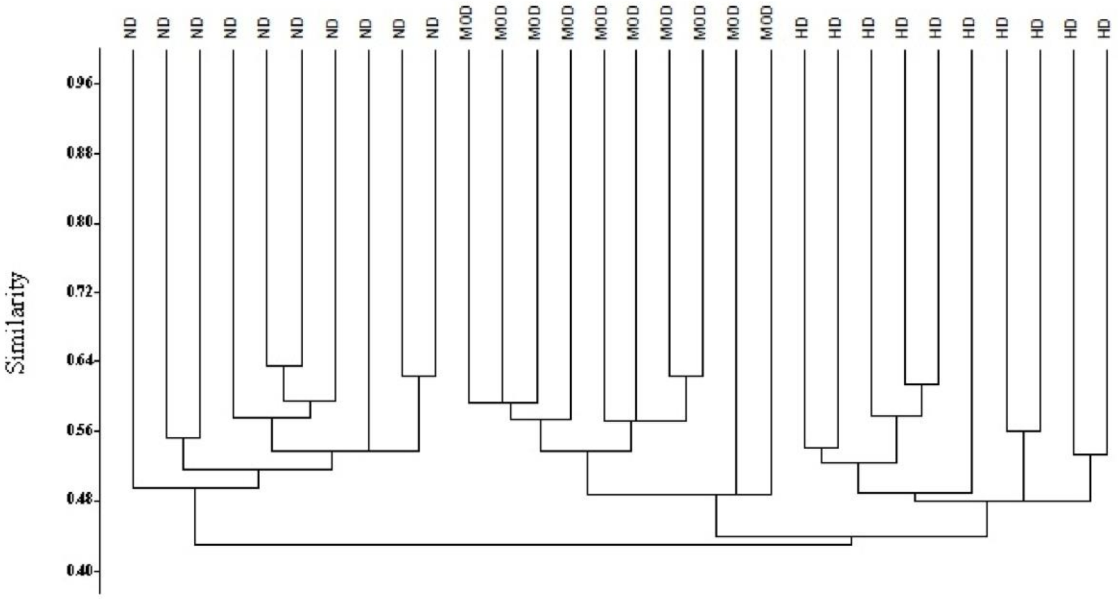

Figure 2. Cluster analysis showing distinct grouping of 30 sampling plots into three butterfly communities that correspond to the three forest types (ND: non-disturbed forest, MOD: moderately disturbed forest, HD: heavily disturbed forest).

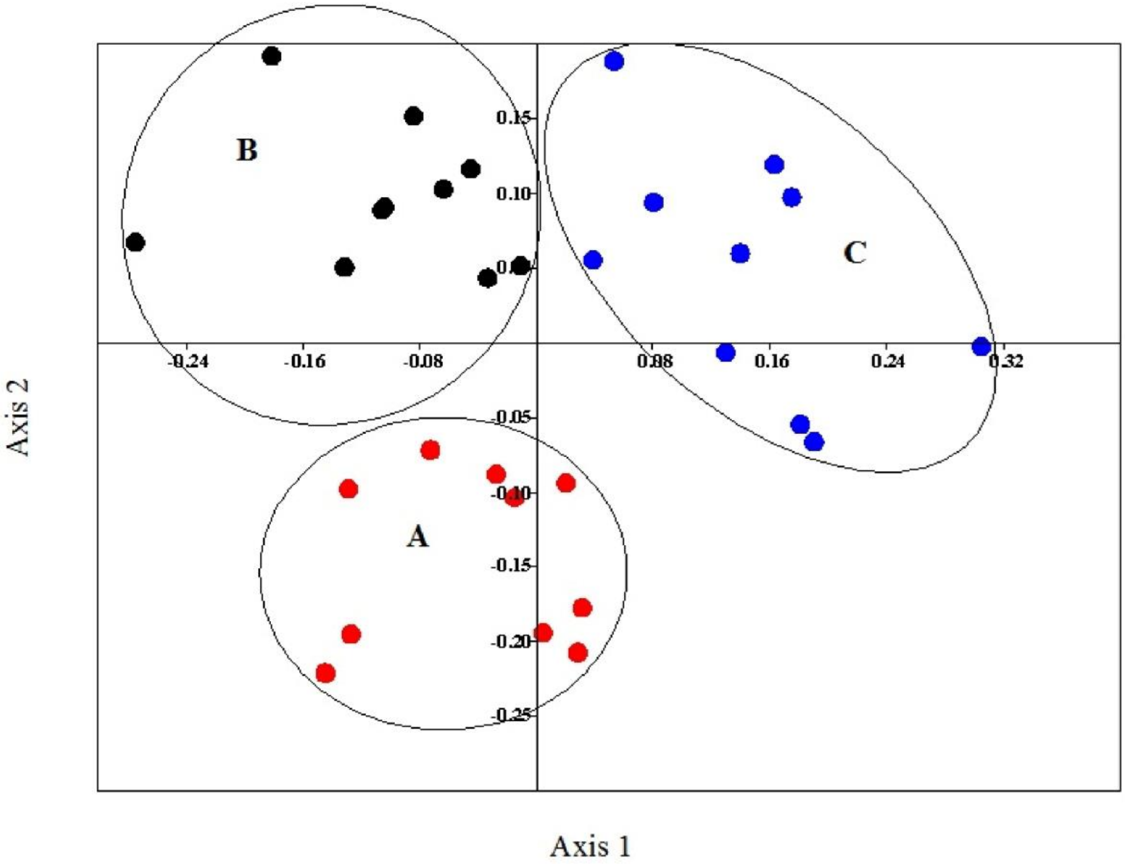

Figure 3. Non-metric multidimensional scaling (NMDS) of butterfly species composition in 30 sampling sites. The three clusters A, B and C represent the sampling plots in the non-disturbed, moderately disturbed and heavily disturbed forests, respectively.

There were some butterfly species that occurred in only one forest type but not the others. For instance, species such as *Aslauga* sp., *Belenois creona*, *Euriphene aridatha*, *Papilio chrapkowskoides*, *Pseudopontia paradoxa*, *Papilio zenobia* etc. were recorded only in the non-disturbed forest. *Aterica galena*, *Bebearia aurora*, *Charaxes eupale*, *Charaxes* sp. 1, *Charaxes* sp. 2, *Euremia* sp., *Graphium leonidas*, etc occurred only in moderately disturbed forest whereas *Euphaedra hebes*, *Melanitis leda* and *Palla publius* were distributed only in the heavily disturbed forest (Table 1).

Table 1. Abundance of butterfly species in non-disturbed (NDF), moderately disturbed (MDF) and heavily disturbed (HDF) forests in the Atewa Range Forest Reserve.

Species	**Abundance**		
	NDF	**MDF**	**HDF**
LYCAENIDAE			
Aslauga marginalis (Kirby, 1890)	11	5	-
Aslauga sp.	2	-	-
Neaveia lamborni (Druce, 1990)	15	17	10
Tetrarhanis baralingam (Larsen, 1998)	14	5	5
NYMPHALIDAE			
Acraea alcinoe (Felder & Felder, 1765)	20	4	7
Acraea epaea (Cramer, 1779)	16	13	22
Acraea vestalis (Felder & Felder, 1765)	25	1	9
Aterica galene (Brown, 1776)	-	10	-
Bebearia aurora (Aurivillius, 1896)	-	2	-
Bebearia paludicola (Holmes, 2001)	-	2	-
Bebearia sophus (Fabricius, 1793)	26	8	12
Bebearia sp.	9	1	1
Bebearia tentyri (Hewitson, 1866)	-	2	-
Bebearia zonara (Butler, 1871)	4	12	2
Bicyclus auricruda (Butler, 1868)	24	11	13
Bicyclus dorothea (Cramer, 1779)	8	5	4
Bicyclus ephorus (Weymer, 1892)	1	5	-
Bicyclus istaris (Plötz, 1880)	2	-	-
Bicyclus nobilis (Aurivillius, 1893)	-	2	1
Bicyclus madetes (Hewitson, 1874)	16	6	9
Bicyclus safitza Westwood, (1850)	6	16	9
Bicyclus sangmelinae (Condamin, 1963)	2	14	8
Bicyclus taenias (Hewitson, 1877)	4	14	1
Charaxes brutus (Cramer, 1779)	27	15	14
Charaxes cedreatis (Hewitson, 1874)	14	-	2
Charaxes cynthia (Butler, 1866)	11	4	6
Charaxes eupale (Drury, 1782)	-	3	-
Charaxes sp. 1	-	2	-
Charaxes sp. 2	-	2	-
Charaxes zelica (Butler, 1869)	6	-	4
Cymothoe egesta (Cramer, 1775)	4	3	-
Cyrestis Camillus (Fabricius, 1781)	1	11	-
Danaus chrysippus (Linnaeus, 1758)	23	22	5
Euphaedra edwardsii (van der Hoeven, 1845)	2	13	2
Euphaedra eupalus (Fabricius, 1781)	11	-	-
Euphaedra hebes (Hecq, 1980)	-	-	8

Euphaedra janetta (Butler, 1871)	4	11	2
Euphaedra perseis (Drury, 1773)	8	1	-
Euphaedra phaethusa (Butler, 1866)	-	4	8
Euriphene amicia (Hewitson, 1871)	2	3	-
Euriphene ampedusa (Hewitson, 1866)	8	-	1
Euriphene aridatha (Hewitson, 1866)	2	-	-
Euriphene barombina (Aurivillius, 1894)	1	3	-
Euriphene atossa (Hewitson, 1865)	2	-	-
Euriphene sp.	4	-	1
Hypolimnas bolina (Linnaeus, 1758)	5	2	7
Hypolimnas salmacis (Drury, 1773)	46	18	14
Junonia orithya (Linnaeus, 1758)	16	4	2
Junonia terea (Drury, 1773)	49	37	32
Kallimoides rumia (Doubleday, 1849)	15	10	18
Melanitis leda (Linnaeus, 1758)	-	-	6
Palla decius (Cramer, 1777)	-	4	1
Palla publius (Staudinger, 1892)	-	-	5
Palla ussheri (Butler, 1870)	3	-	4
Protogoniomorpha parhassus (Drury, 1782)	7	5	-
Pseudacraea eurytus (Linnaeus, 1758)	24	12	15
PAPILIONIDAE			
Graphium latreillianus (Godart, 1819)	13	4	9
Graphium leonidas (Fabricius, 1793)	-	10	-
Papilio antimachus (Drury, 1782)	9	-	-
Papilio chrapkowskoides (Storace, 1952)	7	-	-
Papilio cynorta (Fabricius, 1793)	15	8	11
Papilio cyproeofila (Butler, 1868)	35	30	26
Papilio dardanus (Brown 1776)	12	15	14
Papilio menestheus (Drury, 1773)	8	1	-
Papilio nireus (Linnaeus, 1758)	10	7	-
Papilio nobicea (Suffert, 1904)	3	2	1
Papilio zenobia (Fabricius, 1775)	1	-	-
PIERIDAE			
Appias phaola (Doubleday, 1847)	15	18	-
Belenois aurota (Fabricius, 1793)	15	5	4
Belenois creona (Cramer, 1776)	1	-	-
Belenois hedyle (Cramer, 1777)	6	9	7
Belenois sp.	2	1	1
Eurema brigitta (Cramer, 1780)	13	4	3
Eurema sp.	-	4	-
Mylothris atewa (Berger, 1980)	38	29	23
Mylothris schumanni (Suffert, 1904)	4	-	-
Nepheronia pharis (Boisduval, 1836)	7	-	5
Nepheronia thalassina (Boisduval, 1836)	43	26	23
Pseudopontia paradoxa (Felder, 1869)	1	-	-

Butterfly abundance

A total of 1672 specimens (individuals) were sampled in the study area (Table 1). There were more individuals sampled in the non-disturbed forest (758 individuals) compared to the moderately disturbed forest (517 individuals) and heavily disturbed forest (397 individuals). Mean butterfly abundance per plot differed significantly among all the forest types (Table 2; $F = 38.08$, $df = 2$, $P = 0.000$) in the following order of decreasing abundance: non-disturbed > moderately disturbed > heavily disturbed. Nevertheless, there was no significant difference in butterfly abundance among the sampling sites of the forest types ($P > 0.05$).

Table 2. Butterfly diversity and abundance in the non-disturbed (NDF), moderately disturbed (MDF) and heavily disturbed (HDF) forests in the Atewa Range Forest Reserve (± Standard error of mean). Means in the same row that have different superscripts are significantly different ($P < 0.05$).

Attribute	Abundance		
	NDF	MDF	HDF
Observed species richness*	64^a	59^a	48^b
Estimated species richness (Chao1) (Confidence interval)	66 (64.4-77.0)	61 (59.2-69.5)	54 (49.4-77.8)
Rarefaction-extrapolation species richness	64	60	52
Shannon diversity index*	3.76^a	3.72^a	3.52^b
Abundance per plot	$75.8^a \pm 4.64$	$51.7^b \pm 1.08$	$39.7^c \pm 1.80$

*Significant differences were determined according to pair-wise permutation tests in PAST version 2.17c

Regardless of forest type, *Junonia terea*, *Nepheronia thalassina*, *Papilio cyproeofila* and *Mylothris atewa* were the overall most abundant butterfly species in the forest reserve (Table 1). *Junonia terea*, *Hypolimnas salmacis*, *N. thalassina* and *M. atewa* were the most abundant species in the non-disturbed forest. In the moderately disturbed forest, *J. terea*, *P. cyproeofila* and *M. atewa* were the most abundant species. Two species namely, *J. terea*, and *P. cyproeofila* were the most abundant species in the heavily disturbed forest.

Relationships of vegetation characteristics with butterfly diversity and abundance

Butterfly species richness and Shannon diversity index correlated significantly with plant abundance ($T = 2.83$; $P = 0.009$ and $T = 2.11$; $P = 0.045$, respectively) and canopy cover ($T = 2.59$; $P = 0.015$ and $T = 2.63$; $P = 0.014$, respectively) in the forest reserve (Table 3). Plant species richness and canopy cover were significant correlates of butterfly abundance in the study area ($T = 4.72$; $P = 0.000$ and $T = 2.97$; $P = 0.006$, respectively). The total variation explained by butterfly abundance-vegetation characteristics regression was highest in the study ($R^2 = 73.1$ %).

Table 3. Multiple regression (stepwise) analysis showing the relationships of vegetation characteristics with butterfly diversity and abundance in the Atewa Range Forest Reserve. The final model included only those variables which made significant influence on the dependent variables.

Dependent variable	R^2 (adjusted)	Independent variable	*P*-value
Butterfly species richness	56.8	Plant abundance Canopy cover	0.009 0.015
Shannon diversity index	52.2	Canopy cover Plant abundance	0.014 0.045
Butterfly abundance	73.1	Plant species richness Canopy cover	0.000 0.006

Discussion

The present study indicated that butterfly diversity differed considerably among the forest types, and it was related positively and significantly with plant abundance and canopy cover in the study area. This phenomenon might have been due to the presence of significant heterogeneity in vegetation characteristics observed among the forest types following human disturbance (see Addo-Fordjour *et al*. 2013). In the current study, higher butterfly diversity was observed in the non-disturbed forest in relation to the heavily disturbed forest. This phenomenon is consistent with some previous studies (Hill *et al*. 1995; Beck & Schulze 2000) although other works reported of a reverse trend (Hamer *et al*. 1997; Willott *et al*. 2000; Fermon *et al*. 2005), and another study reported similar levels of butterfly diversity in non-disturbed and disturbed forests (Luk *et al*. 2011). A previous study revealed that moderately disturbed forests supported relatively higher butterfly diversity in relation to heavily disturbed forests (Joshi 2007). This pattern was confirmed in the current study, as the moderately disturbed forest harboured higher butterfly diversity than the heavily disturbed forest. Overall, the results of the present study suggest that vegetation and human disturbance can be important factors that affect butterfly diversity in forest ecosystems (Bobo *et al*. 2006; Humpden & Nathan 2010; Rajagopal *et al*. 2011). Two of the butterfly species recorded in the present study namely, *Neaveia lamborni* and *Bicyclus auricruda* were identified as endemic to Atewa Range Forest Reserve in a previous study (Aduse-Poku & Doku-Marfo 2007). Larsen (2006) also recorded 10 butterfly species as endemic to the Atewa Range Forest Reserve, Ghana. Out of the 10 species, only *M. atewa* was recorded in the present study. While some of the endemic species might have been missed due to the relatively small area sampled (compared to the overall area of the forest), it is possible that some of the species were affected by human activities in the disturbed parts of the forest reserve, resulting in their possible extinction. Further studies on a larger spatial scale may be useful for determination of the status of those butterfly species in the Atewa Range Forest Reserve.

The composition analyses revealed significant differences in butterfly composition among the forest types. Butterfly species composition and distribution in the Atewa Range Forest Reserve revealed three distinct butterfly communities, each of which corresponded with a specific forest type. The presence of considerable variations in butterfly species composition with respect to the forest types implies that human-induced disturbance probably influenced butterfly species composition and distribution in the Atewa Range Forest Reserve. This finding is corroborated by previous studies which reported that changes in vegetation characteristics following human disturbance could lead to variations in butterfly species composition among different sites (Beccaloni 1997). In each of the pair-wise comparisons of the forest types (SIMPER analysis), only a small fraction of the butterfly species enumerated in the forest types (< 30 %) contributed much towards the dissimilarity that occurred between the forest types being compared. This group of species had either high frequency of occurrence or abundance or both in the sampling plots. Interestingly, most of the butterfly species that were limited to single forest types did not contribute much to dissimilarity among the forest types because they had low frequency of occurrence and/or abundance.

Some previous studies have reported of the importance of forest vegetation in influencing butterfly abundance (Bobo *et al*. 2006; Rajagopal *et al*. 2011). The current study recorded significant correlations of butterfly abundance with plant species richness and canopy cover of the forests, suggesting that forest vegetation was possibly an important determinant of butterfly abundance. The above finding suggests that the lower abundance of butterflies in the disturbed forests may be due to fewer plant resources provided by those forest types. Most of the butterfly species either showed low abundance in some of the forest types or were absent in them. Despite the low abundance of some species in certain forest types, other species such as *J. terea, N. thalassina* and *P. cyproeofila* were highly abundant in all the forest types. These dominant species appear to possess broader ecological amplitudes that enable them to thrive in both non-disturbed and disturbed forests. Three butterfly species namely, *M. atewa*, *N. lamborni* and *B. auricruda* reported as endemic to Atewa Range Forest Reserve in previous studies (Larsen 2006; Aduse-Poku & Doku-Marfo 2007) were present in all the forest types in reasonable numbers. The continuous presence of these species in the disturbed forests suggests that they still provide favourable conditions and resources for these butterfly species. In terms of both species richness and abundance of butterflies, family Nymphalidae was the most dominant in all the forest types. This confirms the dominance of this family in some tropical forests (Aduse-Poku & Doku-Marfo 2007; Sundufu & Dumbuya 2008; Humpden & Nathan 2010).

Implications of the study for conservation

The present study recorded three butterfly species endemic to the Atewa Range Forest Reserve (*M. atewa, N. lamborni, B. auricruda*) (Aduse-Poku & Doku-Marfo 2007). Although these species were present in all the forest types, they occurred in lower numbers in the disturbed forests than in the non-disturbed forest. The presence of human disturbance over some areas of the forest might have rendered them less favourable for these butterfly species. Therefore, any human activity that threatens the existence of these species in the Atewa Range Forest Reserve can facilitate their rarefaction and possible extinction. For this reason, human activities in the forest reserve should be carefully regulated.

Due to the importance of tropical forests to butterflies, it is essential for forests to be conserved so as to maintain butterfly diversity and abundance. The findings of the current study indicated that butterfly diversity was similar in the non-disturbed and moderately disturbed forests, although it was significantly lower in the heavily disturbed forest. Besides, butterfly diversity and abundance were significantly related with plant species richness, diversity, abundance and canopy cover, suggesting the important role of vegetation in determining butterfly assemblages in the forest. These results suggest that for butterfly diversity to be maintained in tropical forests, they should be protected from human activities or only minimal/moderate forms of disturbance be allowed in them. To this end, selective logging should be encouraged in areas earmarked for exploitation in order to enhance and maintain butterfly diversity in the forest. In areas with high level of human disturbance, tree species enrichment could be practiced so as to improve upon plant diversity and forest structure, thereby increasing and maintaining butterfly diversity. Although the moderately disturbed forest was able to maintain butterfly diversity, its species composition differed markedly from that of the non-disturbed forest. This variation is most likely related to differences in vegetation characteristics. This is consistent with a previous study in which butterfly diversity did not differ much between non-disturbed and selectively logged forests, even though butterfly composition differed markedly (Hamer *et al*. 2003). Thus, the findings of the present study and Hamer *et al*. (2003) demonstrate that even minimal form of human disturbance could not maintain species composition of butterflies in the moderately disturbed forests. This implies that management of tropical forests should include a regime that conserves non-disturbed areas of forest reserves so as to prevent butterflies from undergoing local extinction, and thus maintaining their species composition. In addition, silvicultural activities that promote natural regeneration should be carried out in disturbed sites in order to increase vegetation heterogeneity, and help improve butterfly species composition and diversity.

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Appendix 1. The most important species contributing to the top 50 % dissimilarity in butterfly species composition between the forest type pairs (Av. Dis. = Average dissimilarity, % contri. = Percentage contribution, % cum. contr. = Percentage cumulative contribution).

Species	**Abundance**		
	Av. Dis.	**% contr.**	**% cum. contr.**
Non-disturbed versus moderately disturbed forests			
Hypolimnas salmacis	2.16	3.83	3.83
Nepheronia thalassina	2.07	3.66	7.49
Acraea vestalis	1.94	3.43	10.92
Mylothris atewa	1.77	3.14	14.06
Bebearia sophus	1.72	3.04	17.10
Papilio cyproeofila	1.59	2.81	19.91
Junonia terea	1.52	2.68	22.59
Pseudacraea eurytus	1.40	2.47	25.06
Acraea alcinoe	1.36	2.41	27.47
Neaveia lamborni	1.34	2.37	29.84
Bicyclus auricruda	1.29	2.29	32.13
Charaxes brutus	1.29	2.29	34.42
Appias phaola	1.26	2.23	36.65
Junonia orithya	1.21	2.15	38.80
Danaus chrysippus	1.15	2.04	40.84
Kallimoides rumia	1.14	2.02	42.86
Acraea epaea	1.05	1.87	44.73
Bicyclus madetes	1.04	1.86	46.59
Tetrarhanis baralingam	1.02	1.81	48.40
Bicyclus taenias	0.99	1.76	50.16
Non-disturbed versus heavily disturbed forests			
Hypolimnas salmacis	2.73	4.73	4.73
Nepheronia thalassina	2.49	4.31	9.04
Junonia terea	2.25	3.89	12.93
Mylothris atewa	2.12	3.67	16.60
Papilio cyproeofila	1.91	3.31	19.91
Charaxes brutus	1.81	3.14	23.05
Bebearia sophus	1.80	3.13	26.18
Danaus chrysippus	1.78	3.08	29.26
Acraea vestalis	1.69	2.93	32.19
Pseudacraea eurytus	1.47	2.55	34.74
Acraea epaea	1.42	2.46	37.20
Appias phaola	1.38	2.39	39.59
Acraea alcinoe	1.32	2.29	41.88
Junonia orithya	1.24	2.14	44.02
Neaveia lamborni	1.24	2.14	46.16
Bicyclus auricruda	1.22	2.11	48.27
Papilio cynorta	1.20	2.08	50.35
Moderately disturbed versus heavily disturbed forests			
Junonia terea	2.32	4.14	4.14
Appias phaola	2.00	3.57	7.71

Danaus chrysippus	1.96	3.50	11.21
Nepheronia thalassina	1.77	3.15	14.36
Mylothris atewa	1.70	3.03	17.39
Charaxes brutus	1.67	2.98	20.37
Kallimoides rumia	1.63	2.90	23.27
Papilio cyproeofila	1.60	2.84	26.11
Acraea epaea	1.59	2.83	28.94
Bicyclus safitza	1.58	2.81	31.75
Bicyclus taenias	1.52	2.71	34.46
Pseudacraea eurytus	1.36	2.43	36.89
Neaveia lamborni	1.32	2.35	39.24
Bebearia zonara	1.31	2.33	41.57
Euphaedra edwardsii	1.26	2.25	43.82
Bebearia sophus	1.26	2.25	46.07
Cyrestis camillus	1.22	2.18	48.25
Papilio dardanus	1.21	2.15	50.40

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