Estimating bat abundance and diversity in a modified tropical environment in central Ghana

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Abstract: Sub-Saharan Africa is the leading producer of *Theobroma cacao* (cocoa) in the world and this agro-ecosystem continues to replace the natural forest ecosystem in the region. These anthropogenic perturbations have particularly disturbed the tropical rainforests of the Upper Guinean area. Currently, we do not understand how bats are responding to this change. We therefore quantified bat occurrence in a Ghanaian agro-ecosystem by recording species richness, abundance and diversity in cocoa farms, fallow lands and traditional farms. Over 31 nights of mist netting, we recorded 264 individuals belonging to 10 species, while the Jack 1 estimator predicted the occurrence of 12 species. Our results suggest impoverished bat assemblages in the agro-ecosystem as a result of the loss of native forest habitats, with cocoa farms being lowest in species richness. The highest relative abundance was recorded for *Hipposideros jonesi* with large numbers found within fallow lands. Rényi diversity profiling indicated cocoa farms had the highest diversity of common species but lowest for rare species, while fallow lands ranked lowest for common species but second highest for rare species after traditional farms. Generally, the highest diversity was maintained in traditional farms which are not perennially cultivated and do not provide sufficient roosting options for bats. We, therefore, advocate the maintenance of the fallow matrices as potential conservation units to augment biodiversity conservation efforts outside protected areas, especially for species using agro-ecosystems such as *Hipposideros jonesi*.

Key words: Agro-ecosystem, cocoa, fallow lands, *Hipposideros jonesi*, sub-Saharan Africa, traditional farms.

Introduction

Protected areas undoubtedly play a critical role in biodiversity conservation, however, they alone may not be able to achieve all conservation goals (Ferrier *et al.* 2004). In the current era of massive anthropogenic disturbance of natural habitats, conservation efforts need to extend beyond the protected areas in order to maintain biodiversity (Perfecto & Vandermeer 2008). This is particularly important for the conservation of species that are not protected in any reserves or parks but are found in modified environments such as agro-ecosystems. Some agro-ecosystems remain the only available habitats for certain species, a trend that is predicted to increase over the coming decades as
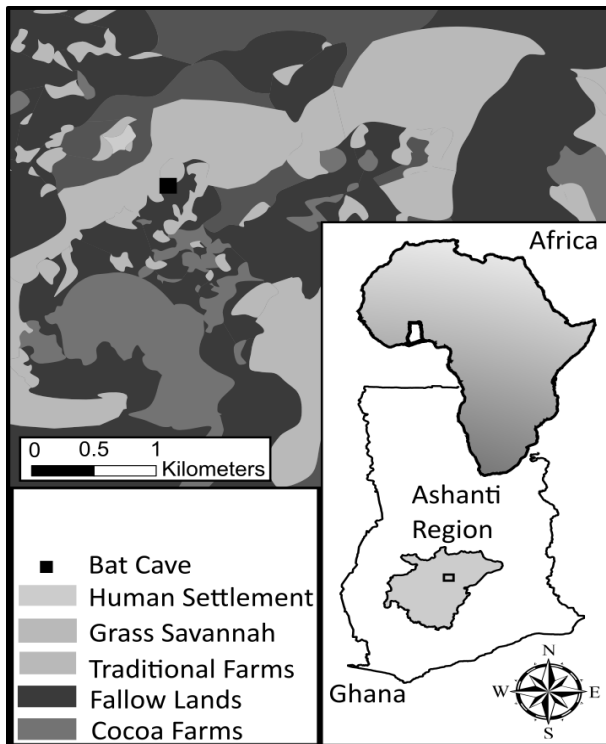
Fig. 1. Location of the study area in the Ashanti region of Ghana showing the Kwamang agro-ecosystem where bats were sampled.

agricultural areas increase (Tilman *et al.* 2001; Tylianakis *et al.* 2007; Yu *et al.* 2007). The rapid expansion of agro-ecosystems through the conversion of primary forest for agricultural purposes has been a major driver behind bio-diversity loss (Cruz-Elizalde *et al.* 2016; Sala *et al.* 2000; Tilman *et al.* 2001).

Despite a generally negative impact on global biodiversity, a growing number of studies have also demonstrated a certain value of some of these modified environments for maintaining a signi-ficant level of biodiversity (Perfecto *et al.* 1996; Pimentel *et al.* 1992; Robertson & Swinton 2005). Particularly in the Neotropics, some agro-ecosystems such as shaded coffee plantations have drawn attention as reservoirs of tropical biodiversity (Daily *et al.* 2003; Moguel & Toledo 1999; Perfecto *et al.* 1996; Somarriba *et al.* 2004). Similarly, shaded cocoa farms may also sometimes preserve native biota (Rice & Greenberg 2000; Schroth & Harvey 2007). This is mainly due to certain similarities some of these agro-ecosystems share with the natural forest ecosystem in vegetation diversity and complexity that can support at least some of the original, forest-adapted species (Perfecto *et al.* 1996).

Studies on biodiversity in sub-Saharan Africa have traditionally focused on natural ecosystems such as forest reserves and gave only limited attention to the native biodiversity found within modified environments such as agro-ecosystems. The region harbours with Ghana, Cameroon, Nigeria and Côte d'Ivoire the world's leading producers of *Theobroma cacao* (cocoa) (Asare 2006). Cocoa farms have mainly been developed at the expense of natural forest vegetation and are the leading reason for deforestation in these areas. There is, however, a glimmer of hope as the structurally complex shade canopies in some of these agro-ecosystems may retain a significant proportion of the original biodiversity (Rice & Greenberg 2000; Schroth *et al.* 2004).

In many tropical ecosystems, bats form the second largest mammalian order after rodents (Simmons 2005). As integral components of these ecosystems, they regulate complex ecological processes through insect predation (Findley 1993), seed dispersal (Hodgkison *et al.* 2003; Taylor *et al.* 2000), and pollination (Hodgkison *et al.* 2003) and are even used as food (Kamins *et al.* 2011). Given that some insects consumed by bats are important agricultural pests (Peters *et al.* 2006), it is estimated that bats provide in North America pest control ecosystem services in excess of $3.7 billion/year (Boyles *et al.* 2011). Despite this importance and the abundance of bats in many ecological systems, data on species composition, diversity and abundance in the ever-increasing agro-ecosystems of sub-Saharan Africa are rather limited. Cocoa farms dominate the agro-ecosystems around the Upper Guinean biodiversity hotspot and Ghana is no exception (Myers *et al.* 2000). Investigating the community of bats within the different land use types in these agro-ecosystems will inform where priorities for off-reserve conservation should focus. Our main objectives were twofold: (1) to study bat species richness, diversity and relative abundance in cocoa farms, fallow lands and traditional farms within a Ghanaian agro-ecosystem located in an area originally belonging to the Upper Guinean forest ecosystem; and (2) to integrate this information with a conservation perspective on how agro-ecosystems could make a greater contribution to biodiversity conservation especially in the Kwamang agro-ecosystems in Ghana. We hypothesised that highest bat abundance within the Kwamang agro-ecosystem is maintained on fallow

Table 1. Description of the land use types within the agro-ecosystem.

Land use type	Description
Cocoa farms	Homogeneous; No understorey vegetation under a closed cocoa canopy; Very few timber trees present but isolated from each other; Identified fruiting trees include *Cola gigantea.*
Fallow lands	Generally varying in degrees of succession in the agro-ecosystem, however, selected sites were all estimated to be ca. 20 years old. Earlier succession stages are open fields with shrubs and herbaceous plants. Identified fruiting trees include *Spathodea campanulata, Cola gigantea, Ceiba pentandra*, and *Ficus* spp.
Traditional farms	Cultivated mixture of: maize (*Zea mays*), cassava (*Manihot esculenta*), plantain and banana (*Musa spp*.). Identified fruiting trees include *Cola gigantea, Ceiba pentandra, Ficus* spp. Isolated trees with no canopy on the farm. Selected sites were about 30% infested with weeds.

Table 2. Sampling efforts, species and number of individuals within the three land use types in the agro-ecosystem.

Land use type	Sampling efforts			Total number	
	Number of nights	Length of net (m)	Hours worked (h)	Species	Individuals
Cocoa farms	11	264	74	6	86
Traditional farms	10	180	66	9	78
Fallow lands	10	180	66	8	100

lands due to its higher structural complexity than the cocoa and traditional farms.

Methods

Study area

We studied the bat community in Kwamang (6°58′33″N, 1°16′31″W) agro-ecosystem in the Ashanti Region of Ghana (Fig. 1). The surrounding vegetation of the village originally was part of the moist semi-deciduous Upper Guinean rainforest (Pappoe *et al.* 2010), but at present, the vegetation cover is dominated by a mosaic of agricultural crops (Nkrumah *et al.* 2016b). Bats were sampled at three different land use types: (1) cocoa farms; (2) fallow lands; and (3) traditional farms (Table 1). Also, the agro-ecosystem contains three known caves inhabited by ca. 3500 bats each, mostly by *Hipposideros* aff. *ruber*, *Nycteris* cf. *gambiensis* and *Hipposideros abae* (Nkrumah *et al.* 2016a).

Bat sampling and analysis

Bats were caught in mist nets between June and September 2012 in all three land use types using 6 m long and 2.5 m high nylon mist nets set across potential flight paths. Two sites were selected for capture from each of the land use types. Nets were operated from 18:30 pm to 12:30 am and monitored at intervals of 30 m. Sites were equally sampled for different phases of the moon to minimize the impact of potential lunar-phobic effects on capture success. Sampling efforts for each land use type are presented in Table 2. Bat capture data were analysed for: (1) relative abundance; (2) species richness; and (3) species diversity. We evaluated inventory completeness by predicting the number of ground-flying species to be found in the agro-ecosystem using the first-order Jacknife (Jack 1) richness estimator. Jack 1 was chosen for its robustness in accounting for movement hetero-geneity of mobile animals such as bats. The predicted richness was used to calculate the percentage inventory completeness by dividing observed species richness (S_{obs}) by the predicted or estimated species richness (S_{pre}) multiplied by 100 (Estrada-Villegas *et al.* 2010).

To test our hypothesis, we fitted a generalized linear mixed effects model (GLMM) using the package "lme4" in R statistical software (Bates *et al.*
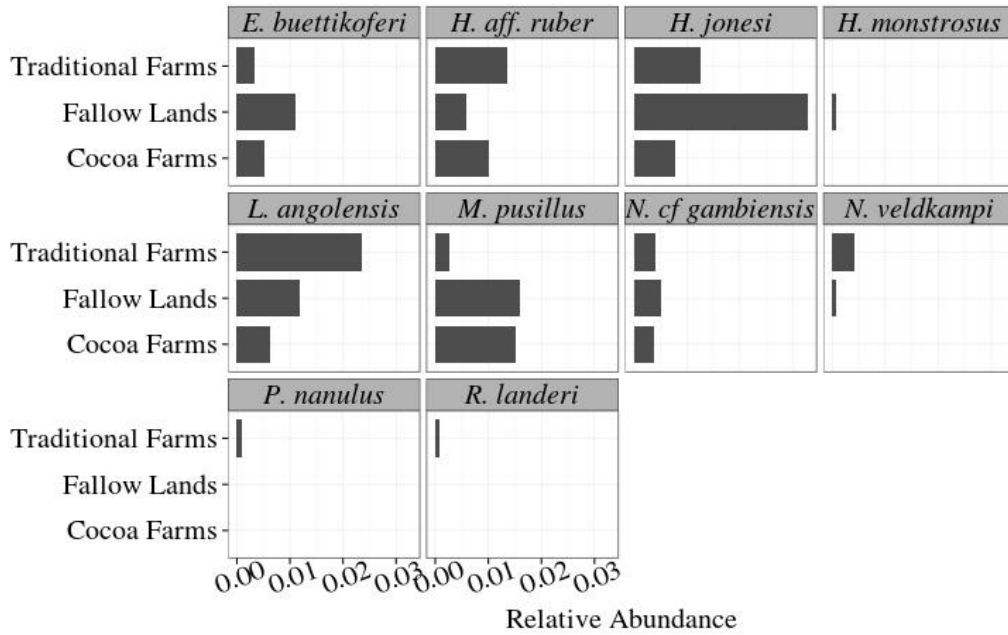
Fig. 2. Relative abundance of sampled bat species in the three landuse types within the agro-ecosystem.
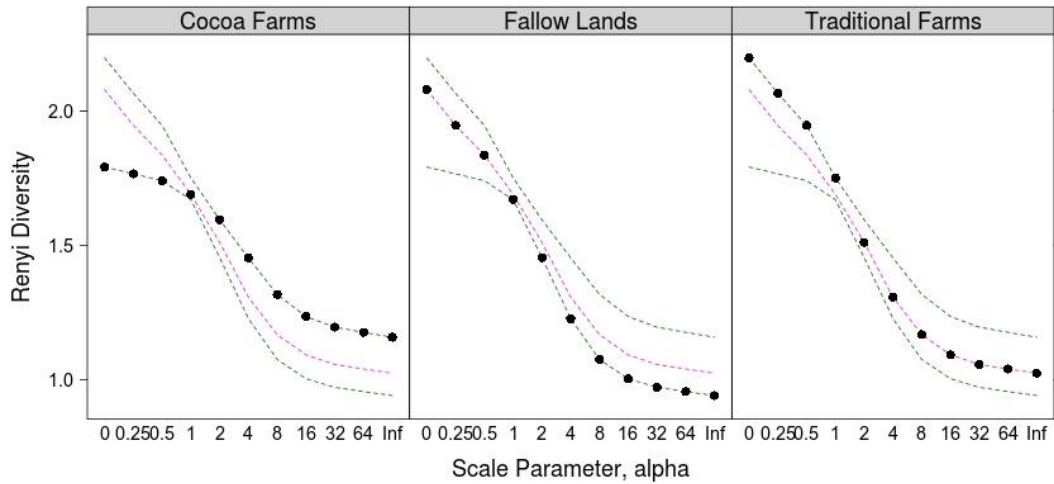

Fig. 3. Rényi diversity profile for the three land use types in the agro-ecosystem.

2014). We accounted for the nested design to remove site-specific effects by including sites and nights of sampling as random effects. The Likelihood ratio tests (LRT) were then used to assess the level of significance of terms in the models. To compare species diversity among the three land use types within the agro-ecosystem, diversity profiles were created using Rényi diversity (Tóthmérész, 1998). The Rényi diversity, $HR(\alpha)$ is calculated as:

$$HR(\alpha) = \frac{1}{1-\alpha}\left(\log \sum_{i=1}^{s} p_i^{\alpha}\right)$$

where s denotes the total number of species, p_i is the relative frequency of the i-th species, and α is the scale parameter ($\alpha \geq 0$, $\alpha \neq 0$) (Magura *et al.* 2010). The scale parameter corresponds to four well-known diversity indices (Lövei 2005; Tóthmérész 1998), and is very robust in scaling abundance data. When $\alpha = 0$ *HR* corresponds to the logarithm of the species numbers in the community, as α increases towards 1 *HR* corresponds to Shannon diversity, as $\alpha = 2$ *HR* corresponds to Simpson diversity and lastly as α approaches

infinity (∞) *HR* becomes closely related to Berger-Parker dominance index (Berger & Parker 1970). This indicates at minimal of alpha (α ≥ 0, α ≠ 0) *HR* is influenced by the rare species in the community while as alpha values approaches infinity (∞), *HR* is influenced by the most common species. This analysis was performed with the 'vegan' package in R statistical software.

Results

The study yielded a total of 264 individuals belonging to 10 species after 31 nights of sampling (Table 2). The Jack 1 estimator predicted 12 species to occur in the agro-ecosystem. Our inventory completeness was therefore 83%. The difference in bat abundance between the three land use types was not significant (LRT: χ^2 (1) = 0.33, *P* = 0.56). *Hipposideros jonesi* was generally the most common captured species (Fig. 2). The most abundant species recorded within traditional farms was *Lissonycteris angolensis* while *Micropteropus pusillus* was frequently captured in cocoa farms and on fallow lands (Fig. 2). All species were captured in all three land use types with the exception of *Hypsignathus monstrosus*, *Nanonycteris veldkampi*, *Pipistrellus nanulus* and *Rhinolophus landeri* (Fig. 2).

A general diversity comparison of the three land use types is difficult as diversity changed on the alpha scale with respect to dominant/common and rare species (Fig. 3). Species diversity of common or most dominant species in the entire agro-ecosystem was highest on cocoa farms, followed by traditional farms and fallow lands. On the contrary, species diversity of rare species in the agro-ecosystem was highest in the traditional farms, followed by fallow lands, and least inside the cocoa farms (Fig. 3).

Discussion

Bat abundance in the agro-ecosystem

To the best of our knowledge, our study is the first to examine bat abundance and diversity in agro-ecosystems consisting of cocoa farms, fallow lands, and traditional farms in sub-Saharan Africa. Our hypothesis that fallow lands maintain highest bat abundance was rejected. There was a uniform distribution of bat abundance within the agro-ecosystem. This is attributed to their ability to cross different land use types with relative ease. Contrary to our expectations, *H.* aff. *ruber* was not very common among the captured individuals, while *H. abae* was not captured at all in spite of the

considerable numbers of these species in the caves in the region (Nkrumah *et al.* 2016a; Nkrumah *et al.* 2016b; Nkrumah *et al.* 2017). *H.* aff. *ruber* is a cluttered vegetation forager (Fahr 2013; Monadjem *et al.* 2010), and the ability to recognize fine details from the environment through echolocation possibly assisted them to avoid our mist nets. The hunting behaviour of *H. abae* is largely unknown. Nevertheless, both *H. abae* and *H.* aff. *ruber* use echolocation calls of much higher frequency than *H. jonesi* (CF component: *H. abae* ca. 110 kHz, *H.* aff. *ruber* >130 kHz vs. *H. jonesi* 48 kHz). The very high echolocation frequencies of these two species translate into shorter wavelengths, which provide an increased spatial resolution capability, thus presumably helping to avoid our mist nets. The comparably low relative abundance of these species in spite of their high numbers in the nearby caves, e.g., at one of our fallow sites, indicate that our data are not just influenced by the proximity to the roost. This is also corroborated by the relatively high abundance of *H. jonesi* in the agro-ecosystem, although it is much less abundant in the cave roosts than *H.* aff. *ruber, H. abae* and *Nycteris* cf. *gambiensis* (E. E. Nkrumah, unpublished data).

The most abundant species captured in this study, *H. jonesi,* was present on all land use types within the Kwamang agro-ecosystem. The abundance of the species is a good indication of its ability to generally persist in agro-ecosystems. Abundant species generally have generalist requirements and are less prone to disturbance (Cosson *et al.* 1999). *H. jonesi* shows no distinct preference for any vegetation type and has been recorded from both the forests and savannahs within its distributional range in West Africa (Fahr 2013; Fahr & Ebigbo 2003). Species occurring at low abundance, on the contrary, are sensitive to disturbance and therefore face an increased threat of local extinction (Henle *et al.* 2004). Considering this, it might be concluded that *H. jonesi* is a generalist and might not be sensitive to increased disturbance. These results, however, have to be cautiously interpreted as the species was least abundant for example on homogenous cocoa farms and more than half of the individuals were captured on fallow lands. In addition, *H. jonesi* has been found at our study site to use a nearly 100% lepidopteran diet (E. K. Badu, unpublished data). Their marked abundance on fallow lands and to a lower extent also on traditional farms indicates that these areas may provide considerable resources that support their survival.

For frugivorous bat abundance, the traditional

farms and fallow lands seem to play an important role in the provision of fruit resources. Frugivorous bats have been found to benefit from natural vegetation altered into agricultural fields as well as from secondary growth such as fallow lands (Bobrowiec & Gribel 2010; Weber *et al.* 2009). The selected sites showed frequently fruit-bearing trees such as *Ficus* spp. and *Cola gigantea. Lissonycteris angolensis* was the second most abundant species with the highest numbers captured on traditional farms. This species has been recorded in agricultural landscapes (Helbig-Bonitz *et al.* 2013; Kock *et al.* 2002), and appears to benefit more than the other frugivorous bats from the availability of fruiting plants in the agro-ecosystem. Strangely, the most abundant species recorded from cocoa farms was *M. pusillus*. These farms offer not the best feeding grounds for fruit bats. Probably, *M. pusillus* used the cocoa farms mainly as roosting sites or for commuting between roosts and the actual foraging grounds. The presence of frugivorous bats within this agro-ecosystem underlines their role in regeneration and establishment of secondary forest stands. Although frugivorous bats may occasionally benefit from the conversions of forests to agro-ecosystems, they may, however, also suffer when their foraging and roosting sites are drastically modified (Jones *et al.* 2001), which is quite rampant in most agro-ecosystem in sub-Saharan Africa.

Bat species richness and diversity in the agro-ecosystem

The study area traditionally was part of the moist semi-deciduous forest type in southern Ghana (Pappoe *et al.* 2010). As a result, the 12 species that the Jack 1 estimator predicted to occur within the agro-ecosystem may represent an impoverished assemblage in comparison to the 35–40 species expected to occur in forested areas in southern Ghana (Weber & Fahr 2007). Modification of tropical environments has been found to decrease species richness as you move from the native forests to the transformed environments (Cruz-Elizalde *et al.* 2016). Further surveys in other agro-ecosystems within the region and the inclusion of canopy netting might significantly improve the recorded number of species.

Overall bat species richness was highest in traditional farms, followed by fallow lands and lowest in cocoa farms. This pattern is a likely consequence of the vegetation structure, as it has already been shown that bat species richness

responds positively to increasing vegetation complexity (Bobrowiec & Gribel 2010; Medellin *et al.* 2000). Cocoa farms showed lowest diversity for rare species but highest for the common species, while fallow lands were lowest in species diversity of common species but ranked second highest for rare species after the traditional farms. This pattern might result from a higher structural complexity on fallow lands, perhaps also supported by the maintenance of a higher plant diversity on traditional farms that is missing in the homogeneous cocoa farms. Structurally complex canopies and high plant diversity, as found in the fallow lands may also contribute to faunal diversity (Schroth & Harvey 2007). It is likely that the mosaic of fallow lands and traditional farms in our study area increases the number of available niches and accounts for the higher bat diversity compared to the cocoa farms. Especially for insectivorous species, diversity has been observed to improve significantly in traditionally managed heterogeneous gardens compared to homogeneous sugarcane fields in Uganda (Hauge 2010).

Implications for conservation

Shaded cocoa farms have gained recognition as a refuge for biodiversity within agro-ecosystem (Cassano *et al.* 2009; Rice & Greenberg 2000; Schroth 2004; Schroth & Harvey 2007). Their ability to retain forest-dependent native species as well as to have higher species diversity is directly dependent on their distance to native forest patches of considerable size (Faria & Baumgarten 2007; McNeely & Schroth 2006). These are missing in the Kwamang region, making cocoa farms species-poorer than the other two land use types studied. It is unlikely that the cocoa farms can present roost and food resources of similar quality and quantity to bats as the traditional farms and fallow lands. As indicated in the diversity profiling, the cocoa farms only maintain generalist diversity, suggesting an inability to support most forest-adapted species. Our results are consistent with studies that caution against an overrating of the conservation value of agro-ecosystems such as cocoa farms (Faria & Baumgarten 2007; Waltert *et al.* 2011). The usage of fallow lands by bats may be a consequence of the lack of natural forest patches in the agro-ecosystem that bats can utilize. The absence of the natural forest may potentially lead to the concentration of forest-adapted species (for example *H. jonesi*) in suitable habitats within the agro-ecosystem that closely resemble the natural forest in vegetation

complexity and structure, which in this case is the fallows. This crowding effect may affect intra- and interspecific interactions such as competition and predation risk, and consequently cause lowered fecundity and the final collapse of the population (Estrada *et al.* 1993). The largely on fallows recorded *H. jonesi* is a West African endemic species not reported from any protected area, and considered Near Threatened by the IUCN (Mickleburgh *et al.* 2013). The largest known population was found in Ghana five decades ago to be around 300 individuals (Mickleburgh *et al.* 2013; Rosevear 1965). Their current distribution and population trends are not yet known in Ghana. It is imperative that many fallow matrices are encouraged within the Kwamang agro-ecosystem that provide usable habitat for *H. jonesi* and other species. This is buttressed by the preference of *H. aff. ruber* in selecting the fallow lands at Kwamang for foraging purposes (Nkrumah *et al.* 2016b). This is also important for other areas within the sub-Saharan region where agro-ecosystems have replaced the natural forest ecosystem, to ensure the survival of species found outside protected areas. We recommend the maintenance of fallow matrices in sub-Saharan agro-ecosystems to provide habitat options that may contribute to preventing local stochastic extinctions of several forest-adapted species.

Acknowledgments

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