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Bat boxes as a tool for biological insect pest control on cocoa plantations in Ghana

By SARAH KOSCHNICKE*, LENA FRANKE*, FEHMKE VAN DOORMAAL*, HENRY KUIPERS, MARTIJN WETERINGS, Waageningen[1], FLORIAN GLOZA-RAUSCH, Bad Segeberg[2], and JUSTICE KONADU AMEYAW, Buoyem (Ghana)[3]

With 4 figures

Abstract

Ghanaian farmers suffer from a decline in cocoa production partly due to damages and diseases from insect pests. To increase predation by bats on insects on the cocoa plantations we installed two different types of bat boxes on 15 plantations around the village of Buoyem. Bat activity, bat species composition (numbers of insectivorous and frugivorous bats) and insect abundance were measured before and after bat box installation. Insectivorous bats were present on all of the sampled plantations, namely leaf-nosed bats (*Hipposideros* sp.), slit-faced bats (*Nycteridae* sp.), horseshoe bats (*Rhinolophus* sp.) and vesper bats (*Vespertilionidae* sp.). Furthermore, no correlation between insect abundance and bat activity could be detected. The bat boxes were not occupied yet during the research period since rainy season started in the second half of the measurements and bat activity decreases with increasing precipitation which is supported by our findings. Additionally, the available time period between installation and measuring of the effects of the boxes was very short when compared to similar researches. Bats also have different preferences per species for size and shape of bat boxes and the number of naturally available roosting sites also influences bat box occupancy. Our results suggest that bats are abundant above cocoa plantations in Buoyem and therefore bat boxes have the potential to be a helpful tool in insect pest control.

Zusammenfassung

Fledermauskästen als Hilfsmittel bei der biologischen Schädlingsbekämpfung auf Kakao-Plantagen in Ghana

Kakaofarmer in Ghana leiden gegenwärtig an einer Abnahme in der Produktion von Kakao, herbeigeführt durch Insektenplagen, welche Krankheiten verbreiten und die Kakaopflanzen enorm beschädigen. Ziel der vorliegenden Untersuchung war es herauszufinden, inwieweit Fledermäuse zur Insektenbekämpfung auf Kakaoplantagen von Nutzen sein können. Um die Jagd von Fledermäusen auf Insekten zu intensivieren, wurden zwei verschiedene Typen Fledermauskästen auf 12 Plantagen rund um das Dorf Buoyem aufgehängt. Fledermausaktivität, Artenzusammensetzung der Fledermäuse (Anzahl der Insekten- und Fruchtfressenden) und Insektenreichtum wurden jeweils vor und nach der Installation der Kästen gemessen. Insektenfressende Fledermäuse waren auf allen untersuchten Plantagen anwesend: Blattnasen- (*Hipposideros* spp.), Schlitznasen- (*Nycteridae* spp.), Hufeisennasen- (*Rhinolophus* spp.) und Glattnasenfledermäuse (*Vespertilionidae* spp.). Es konnte keine Korrelation zwischen Insektenreichtum und Fledermausaktivität festgestellt werden. Die Fledermauskästen wurden in der Zeit, in der die Untersuchungen durchgeführt wurden, noch nicht von Fledermäusen aufgesucht, was auf das

Einsetzen der Regenzeit in der zweiten Hälfte der Untersuchungen zurückzuführen ist. Diese lässt die Fledermausaktivität mit zunehmendem Niederschlag abnehmen, was von unseren Ergebnissen unterstützt wird. Des Weiteren war die Zeitspanne zwischen der Installation der Kästen und den Messungen des Effekts derselben sehr kurz verglichen mit anderen, vergleichbaren Untersuchungen. Fledermäuse haben außerdem verschiedene, artenabhängige Präferenzen für Größe und Form von Fledermauskästen und die Anzahl der natürlich vorhandenen Rast- und Schlafplätze beeinflusst den Gebrauch der Kästen zusätzlich. Unsere Ergebnisse lassen darauf schließen, dass Fledermäuse auf den Kakaoplantagen in Buoyem reichlich vorhanden sind und Fledermauskästen deshalb potenziell hilfreich sein könnten bei der Bekämpfung von Insektenplagen.

Keywords

Cocoa production, Insect pests, Cocoa plantations, Bat boxes, Ghana, Rainy season, Bat box occupancy.

[1] Van Hall Larenstein Institute, University of Applied Sciences – Part of Wageningen University an Research, The Netherlands

[2] Noctalis – Welt der Fledermäuse, Germany

[3] Citizen and guide of Buoyem, Ghana

* Equal authors

1 Introduction

Ghana occupies a key position in the world's cocoa production with a yearly export of 350,000 tons (Padi & Owusu 2009). A decline in cocoa production because of agricultural factors, shade management due to ongoing deforestation (Padi & Owusu 2009) and damages and diseases from insect pests (mainly mirid species) (Dungeon 1910) leads to an annual crop loss of about 100,000 tons. Twenty five to thirty percent of the cocoa plantations in Ghana are suffering from pests, but spraying insecticides is a rather expensive method for the local farmers (Tiffen 2000) and moreover environmentally unfriendly (Padi & Owusu 2009). An alternative solution could be biological control. All developmental stages of the mirid species in West Africa are subject of predation by other insect species like ants, salticid spiders, reduviids, mantids and *Grillidae* (Lodos 1968, Entwistle 1972, King 1971), but with minimum effect (Entwistle 1972, Marchart & Leston 1969).

Mirid species do not feed during the heat of the day (Padi & Owusu 2009). Kalka & Kalko (2006) suggest that insectivorous, nocturnal gleaning bats are important predators of herbivorous insects and might be underestimated reducers of herbivory. Furthermore, Kalka et al. (2008) indicate that bats should be considered in agricultural management strategies based on natural pest control.

Sixty six insectivorous bat species are known in Ghana (Kingdon 1997, Nowak & Paradiso 1983), but are less abundant above agricultural plantations as a result of deforestation (Neuweiler 2000) leading to a lack of roosting sites and natural shelters.

Offering new roosting sites to attract bats to agricultural areas can be accomplished by reforestation or the creation of small, structured and insect rich habitat patches along plantations as practiced in the neotropics (Estrada et al. 1993, Estrada & Coates-Estrada 2002). Another, alternative solution is the provision of artificial roosting sites, i. e. bat boxes, that function as temporary night roosts during feeding (Kunz & Lumsden 2003). From several researches in the more temperate regions bat boxes are known to provide good alternative roosts for bats when natural roosting sites are limited (e. g. Richarz & Limbrunner 1992, Chambers et al. 2002, White 2004) and even succeeded in the (re-)introduction of bat species in some regions (Schober & Grimmberger 1987).

Therefore, the goal of this research is to provide an insight into the differences between bat species composition (focusing on numbers of fruit and insectivorous bats) and bat - and insect abundance before – and after bat box installation.

2 Methods

2.1 Research area and sampling protocol

The research took place during March and April 2010, near the village of Buoyem which is located in the region "Brong Ahafo" in Ghana (8 00° N, 2 00° W), West Africa. Ghana is located a few degrees north of the Equator and has a tropical, wet and dry climate (Hendrickx et al. 2005). Ghana is characterized by a strong and clear north-south rainfall gradient. The mean annual precipitation changes from over 2000 mm/yr in the south to below 1000 mm/yr in the north (Hendrickx et al. 2005). The climate in the Brong Ahafo region is hot and wet, thereby giving it a tropical flora (i. e. *Afzelia africana*, *Milicia* spp., *Sterculia tragacantha* and *T. scleroxylon* (Wagner et al. 1992) which is broadly composed of the closed moist forest (Kingsley et al. 2009).

The direct surrounding of Buoyem is mainly dry semi-deciduous forest and rocky hills (Voltaian sandstones) (Hendrickx et al. 2005). The local people harvest their own crops for food but also cocoa for production. Farmland are located around the village which is usually surrounded by trees such as Papaya and Mango trees (personal observation, F. van Doormaal 2010) which are also providing shade for crops.

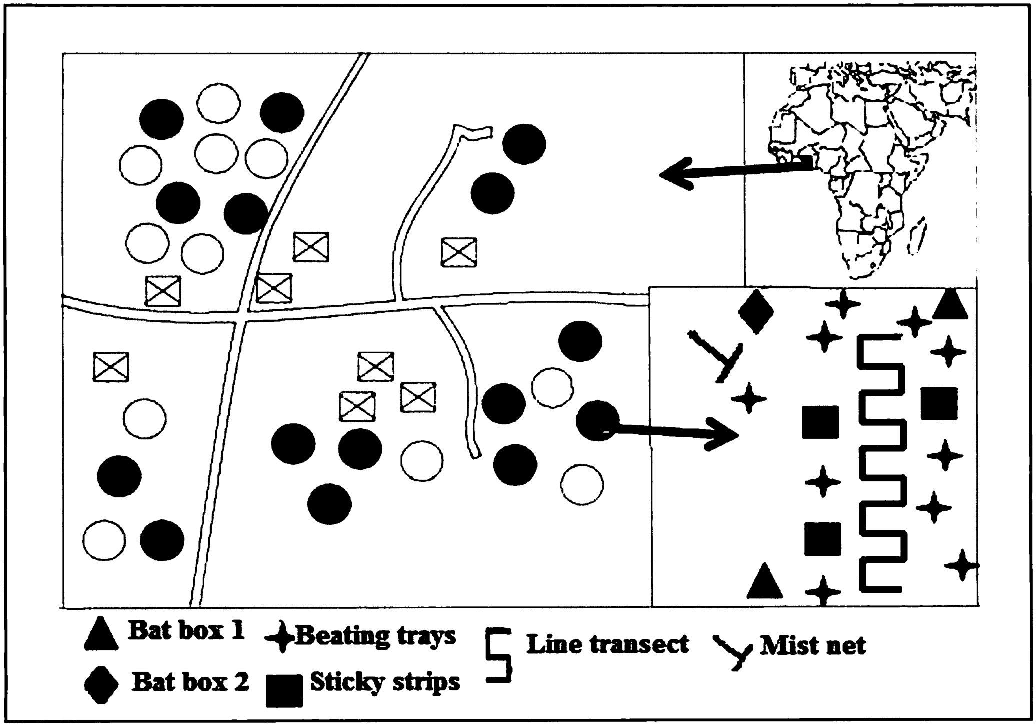

Figure 1. Overview research area and data collection set-up.

The 26 cocoa plantations in the study area were visited and investigated (see fig. 1) in the period from 18th of March 2010 to 21th of March 2010. Seventeen were found to be suitable and 15 were sampled which all shared the following characteristics: An average cocoa tree height of 2-5 m, a minimum cocoa tree density of 1 tree/m^2, at least 50 % adult trees (based on a tree height of approx. 4-5 m and presence of cocoa fruits on the tree) per field and a minimum field size of 140 x 40 m.

The research consisted of two measuring periods, one before (three weeks) and one after bat box installation (three weeks). Immediately, after the before-measurements the bat boxes were installed on 13 fields. They were hanging for 17.46 ± 3.53 days before the after-measurements were taken. The two other fields were functioning as control fields, where no bat boxes were installed.

The fields were visited in a previously assigned order to avoid sampling on fields that were next to one another on consecutive nights, so that measurements weren't influenced by the disturbances caused by measurements from previous nights. On the 15 fields bat- and insect measurements took place by using bat detectors, mist nets, beating trays and sticky strips. Data collection took place at night (from 18.30 until 01.00 in three blocks of two hours) due to the nocturnal activity of bats, their nocturnal insect prey (KALKA & KALKO 2006) and the decrease in bat activity after midnight (ESTRADA et al. 1993).

Five control variables (field characteristics) were measured at the beginning of each sampling night (BARLOW 1999) of the before-measurements: ground vegetation density (classified into sparse and dense), the presence or absence of a stream on or near the plantation, tree maturity, tree density and tree height. Furthermore, the following weather conditions were written down at the beginning of each sampling night during before- and after-measurements: Rainfall (absence or presence), cloud cover and temperature.

Sampling did not take place during rainfall (FARIA & BAUMGARTEN 2007) and strong winds (≥20 km/h) (JOHNSON et al. 2008) and continued after the weather conditions have eased (MEDELLIN et al. 2000) since mist nets cannot be operated during those conditions and because it affects bat activity (BARLOW 1999).

2.2 Bat box installation

Two kinds of bat boxes were installed because of different preferences of bat species after the first sampling night. This is also supported by NEUWEILER (2000) who states that different bat species prefer different kinds of resting places.

Bat boxes were hung up at four corners of the field (see fig. 1 and fig. 2). One was outfitted with chambers whereas the other was not, allowing the bats to hang free. Bat boxes were self-built from 20-25 mm thick using rough wood (i. e. *Monopetalanthus* spp.) and are of the size 400 x 250 x 300 mm (pers. comment GLOZA-RAUSCH 2010).

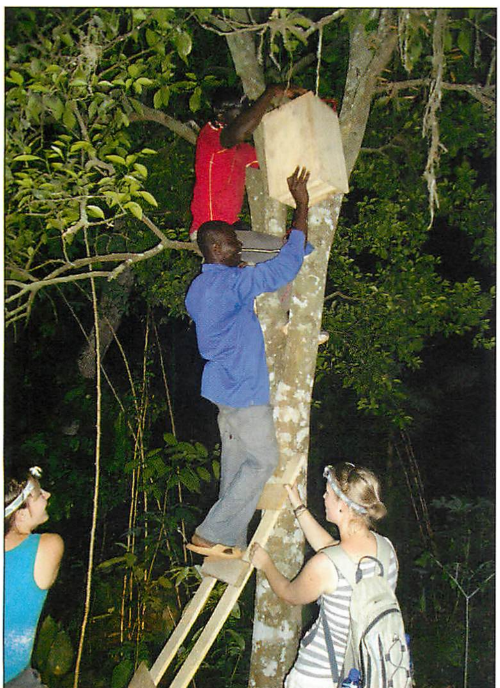

Figure 2. Bat box in cocoa plantation. Photo: FEMKE VAN DOORMAAL

Bat boxes were installed on different trees (cocoa and shade trees) within the cocoa plantation at a height of 3-5 m, along paths or clearings (SCHOBER & GRIMMBERGER 1987). The entrances of each of the boxes were free from cover, whereas the bat box itself was covered by a low canopy (e. g. WHITE 2004, KALCOUNIS-RUPPELL et al. 2005, CHAMBERS et al. 2002).

2.3 Bat monitoring

Data collection for bat activity started at 19.00 h, 21.00 h and 23.00 h since different bat species are active during different times at night (NEUWEILER 2000, RYDELL et al. 1996) and to ensure that as many species as possible were included in the measurements.

To measure relative bat activity, a fixed transect of 100 m was established per field located in the middle of the cocoa plantation. To avoid influences of edge effects a gap of 20 m was left between the transect line and the edges of the field. The transect was describing straight lines (compass bearing) and 90 degree angles after every 10 m, walking 100 m in total (see fig. 1). Due to the different shapes of the fields, the transect was fitted into each field. The same transect per field was walked (1-1,5 km/h) during before- and after-measurements, using a bat detector (Pettersson D 100, Heterodyne Bat Detector with a frequency 10-250 kHz) to count bat passes (WICKRAMASINGHE et al. 2003, KUNZ & BROCK 1975). Bat passes are defined as 'the continuous string of echolocation calls heard on the bat detector' (with a sequence of >2 calls (THOMAS 1988), as a bat flies over within range (BARLOW 1999) and are correlated to bat abundance (WICKRAMASINGHE et al. 2003).

Bat species composition was assessed continuously by mist netting on the plantation using two mist nets (7 and 14 m) from 18.30 h to 24.00 h. Nets were checked regularly, at least every 15 minutes (KUNZ & BROCK 1975).

Depending on the area characteristics, the nets were set up in a T- (s. fig. 1) (MEDELLIN et al. 2000) or V-configuration. The nets were preferably 'covered' by a canopy of overhanging branches from nearby trees (Kunz & Brock 1975), crossed the flyway or stream completely (Barlow 1999, Flaquer et al. 2007) and were reaching from the ground to the canopy.

After freeing the captured bats from the nets, they were kept in cloth bags a maximum of one hour (Faria & Baumgarten 2007) for family identification using Rosevar (1965).

Occupancy of bat boxes has been checked during the 2nd visit (after-measurements) of each field to see whether there were any signs of bats present in the bat boxes (bats, faeces and insect remains). This has been done by using an infrared flashlight to minimize disturbance of emerging bats (Barlow 1999).

2.4 Insect monitoring

In order to increase the probability of catching as many types of arthropods as possible a combination of two methods has been used to assess the relative abundance of arthropods in the sampling area: Beating trays (net diameter: 50 cm) and sticky strips with non drying insect glue on both sides (Pherobank, 25 x 10 cm, Wageningen UR 2010). Data collection of insect sampling sessions started after each of the bat sampling sessions at 20.00 h, 22.00 h and 24.00 h. Ten trees were chosen along the transect line (within 5-10 m) during each insect sampling session for the beating tray method and three trees were used for setting up the sticky strips (see fig. 1). With the use of beating trays insects were collected along the transect by sweeping (using a palm leaf broom without handle) 10 times along the trunk from the bottom to where the first branch begins and 10 times along branches and leaves of the cocoa trees at a maximum height of 2 m sweeping along the whole length of the branch.

With the use of sticky traps, insects were caught that stepped on, flew into them or were blown against them (Johnson et al. 2008). The sticky strips were used on three trees, each individual tree was touched 10 times with one sticky strip on the tree trunk and on one branch with leaves. After finishing with the touching method, one of the sticky strips was placed on the substrate next to the tree. The other two sticky strips were hung into branches of the two remaining trees (length of rope = 50 cm).

These procedures were repeated for both methods, during every of the three insect sampling sessions per night, with other trees than those that were chosen during the first session. The gathered insects were then poured into a bucket with a lid and counted at the field station the following morning classifying them into three categories (small <0,7 cm, medium >0,7 cm, large >1,0 cm).

3 Analysis

The total number of bat passes was summed up per sampling night. The same was done for the total number of insects collected with both methods. After a log(x+1) transformation all residuals were normally distributed which was checked with a Shapiro-Wilks test (Hill et al. 2007).

The Analysis of Covariates (ANCOVA) for repeated measures was used two times to test the effect of bat boxes on the dependent variables insect abundance, bat activity and bat species composition using field characteristics (ground vegetation density, absence or presence and of a stream) as control variables.

The same was done using General Linear Model univariate (GLM), with rainfall (absence or presence) and bat boxes as fixed factors and field number as random factor.

Additionally, insect abundance was used as a covariate when bat activity was the depending variable and the other way around to test the correlation between insect abundance and bat activity.

For all models the stepwise procedure (Hosmer & Lemeshow 2000) has been used. The Levene's test was used to test for homogeneity of the residuals for each GLM model (Hill et al. 2007).

Outliers were determined using Cook's distance (De Vocht 2008) and consequently two plantations were filtered out of the data (D>4/N, Cook 1979) that contained outliers in insect abundance.

4 Results

Our sampling effort using mist nets (150 hours) resulted in the capture of 234 bats. There was no significant difference in numbers of fruit bats before 38 ($\bar{x}$ 2.53 ± SD 3.4) and after bat box installation 26 ($\bar{x}$ 1.73 ± SD 1.58) and neither for insectivorous bats with 90 ($\bar{x}$ 6 ± SD 6.91) bats during the before- and 80 ($\bar{x}$ 5.33 ± SD 8.67) during the after-measurements. Four families of insectivorous bats were identified (s. table 1). A list of bat species which are proven to occur in this region and are most probably the ones caught can be found in appendix I.

The comparison between bat activity, before and after bat box installation showed no significant difference (ANCOVA: $F_{1,11} = 0.913$ $p = 0.360$). This is supported by the fact that no signs of roosting or emerging bats could be found in the bat boxes after installation.

The GLM model also showed no significant results for insect abundance between before- and after-measurements ($F_{1,8} = 0.226$ $p = 0.647$). There was no significant correlation found for the relation between insect abundance and bat activity (GLM $F_{1,5} = 904$ $p = 0.385$).

As for other influencing factors, numbers of *Hipposideros* were significantly higher when a stream was present (ANCOVA $F_{1,13} = 5.193$ $p = 0.04$). The other field characteristics, namely stream presence and ground vegetation cover had no influence on species composition.

Bat activity was higher on sampling units with a dense ground vegetation cover (GLM: $F_{1,11} = 6.804$ $p = 0.024$) and lower during rainfall in the before measurements (GLM: $F_{1,6} = 11.31$ $p = 0.013$). As can been seen in fig. 3 bat activity decreases with the change in season. This relation is not apparent for insect abundance. Moreover, no significant relations between insect abundance and field characteristics (GLM: $p > 0.05$) could be detected. However, the relation between insect abundance and the presence of a stream was marginally significant (ANCOVA $F_{1,8} = 3.997$ $p = 0.081$).

Table 1. Mist netting effort of insectivorous bats on all sampled cocoa plantations in Buoyem, Ghana

		Before bat box installation		After bat box installation		Average of insectivorous bat species per family caught
Identified insectivorous bat families (N = 170)	**Families**	N	%	N	%	$\bar{x} \pm$ Std
	Hipposideros	60	74	62	77	61 ± 1.41
	Nycteridae	22	25	10	13	16 ± 8,49
	Rhinolophus	1	1	5	6	3 ± 2.83
	Vespertilionidae	0	0	3	4	1,5 ± 2,12
Average of all insectivorous bat species caught	$\bar{x} \pm$ Std	20,75 ± 28,06		20 ± 28,15		

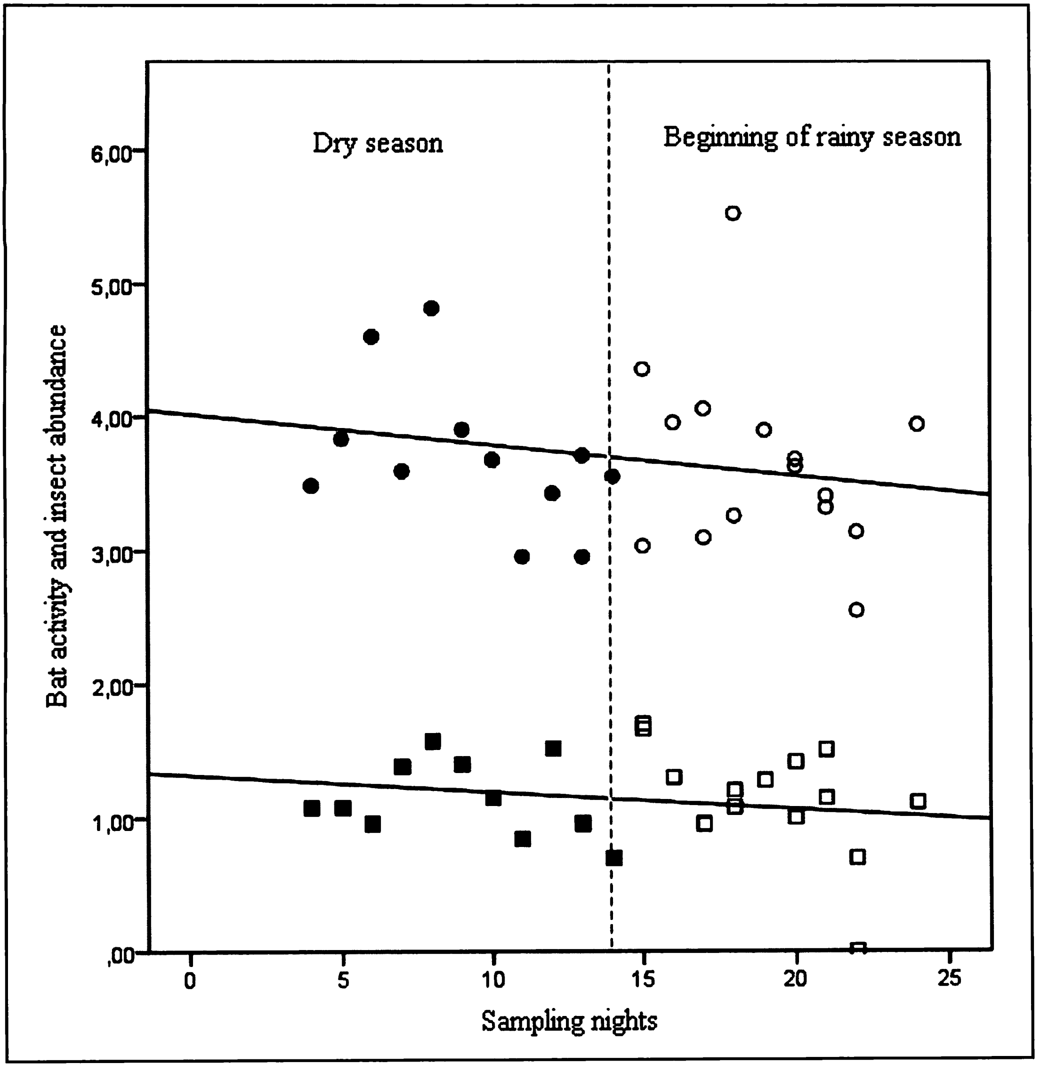

Figure 3. Insect abundance and bat activity (LogX+1 transformed) during all sampling nights.

5 Discussion

Insectivorous bats were present on all of the assessed cocoa plantations, but the bat boxes were not occupied during this research. However, it could still be that over a longer time period bat boxes on the cocoa plantations will be occupied (BRITTINGHAM & WILLIAMS 2000) as also shown in the study of LESIŃSKI et al. (2009). WHITE (2004) showed that the length of time that bat boxes have been installed does not necessarily influence the number of occupancies.

Another reason for why the boxes were not used yet might be the beginning of the rainy season during the research period. According to WEINBEER et al. (2006) and as found in our results bats are less active during rainfall. Since the number of rainy nights was increasing throughout the research period less bats were flying after the bat boxes installed and therefore the chance for them to discover the boxes in this time frame got smaller as well.

Furthermore, bat box occupancy depends on a variety of factors, such as size and shape of the box, humidity levels (KUNZ & BROCK

2003), canopy cover (White 2004, Kalcounis-Ruppell 2005), height of the bat box in the tree (Schober & Grimmberger 1987) and disturbances (Richarz & Limbrunner 1992) such as pesticide contamination (Tuttle 1979). In addition, the presence of multiple roosting sites in or near the sampling area is an important influencing factor on bat box occupancy as suggested by Dillingham et al. (2003) and therefore also influences bat activity.

Although our results didn't show a significant correlation between bat activity and insect abundance, Scanlon & Petit (2008) and Racey & Swift (1985) found that insect abundance influences bat activity in such a way that bat activity increases when insect prey activity increase.

The results showed that the number of insectivorous bats in the field was higher whenever a stream was present presumably due to the bat's use of streams as flyways and because they facilitate foraging. This is also suggested by Seidman & Zabel (2001).

Furthermore, it turned out that density of ground vegetation cover is positively related to bat activity. This might be influenced by a higher insect abundance where there is dense ground vegetation as is also suggested by Haddad et al. (2001) who state that plant biomass has a positive effect on insect abundance although our results showed no significant relation between insect abundance and ground vegetation cover (ANCOVA $F_{1,3} = 1.4628$ $p = 0.121$). As Grindal & Brigham (1999) suggest we also assume that "the spatial complexity of a habitat, in combination with insect availability, influences habitat use by foraging bats" and ground vegetation cover can be counted among the features of spatial complexity.

Recommendations

Since the boxes are installed permanently on the fields it is advisable to conduct a follow-up research in March and April within the following years to assess the effect of these bat boxes.

Figure 4. Rüppell's Pipistrelle (*Pipistrellus rueppelli*). Photo: Sarah Koschnicke

Research on different bat box type preferences by bats, and presence and availability of roosting sites on the different fields should be done to exclude these influencing factors and to further assess the effect of bat box presence.

Appendix I

Leaf-nosed bats (*Hipposideridae*)
Aba Leaf-nosed Bat (*Hipposideros abae*)
Common Africa Leaf-nosed Bat (*Hipposideros ruber*)
Sundevall's Leaf-nosed Bat (*Hipposideros caffer tephrus*)
Giant Roundleaf Bat (*Hipposideros gigas*)

Slit-faced bats (*Nycteridae*)
Egyptian Slit-faced Bat (*Nycteris thebaica* c. f.)

Horseshoe bats (*Rhinolophidae*)
Lander's Horseshoe Bat (*Rhinolophus landeri*)
Halcyon Horseshoe Bat (*Rhinolophus alcyone*)

Vesper bats (*Vespertilionidae*)
Rüppell's Pipistrelle (*Pipistrellus rueppelli*) – fig. 4
Banana bat (*Pipistrellus nanus*)

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Femke van Doormaal, Ferdinand Bolplein 19, NL-5171 ZC Kaatsheuvel, The Netherlands; E-Mail: Femkevandoormaal@gmail.com

Lena Franke, Hauer Heide 14, D-47551 Bedburg-Hau, Germany; E-Mail: l_franke@yahoo.co.uk

Sarah Koschnicke, Oldesloer Straße 53, D-23795 Bad Segeberg; E-Mail: Skoschnicke@gmail.com

Henry Kuipers, Van Hall Larenstein Institute, Agora 1, NL-8934 CJ Leeuwarden, The Netherlands; E-Mail: henry.kuipers@wur.nl

Martijn Weterings, Van Hall Larenstein Institute, Agora 1, NL-8934 CJ Leeuwarden, The Netherlands; E-Mail: martijn2.weterings@wur.nl

Florian Gloza-Rausch, Noctalis – Welt der Fledermäuse, Oberbergstraße 27, D-23795 Bad Segeberg, Germany; E-Mail: gloza-rausch@noctalis.de

Justice Konadu Ameyaw, PO Box 141, Buoyem Senior High School, Buoyem, Brong Ahafo Region, Ghana; E-Mail: justkonadu@yahoo.com