

# **Bat (Chiroptera) activity and community composition in contrasting agricultural landscapes and the adjacent Budongo forest reserve, Uganda**



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## **Abstract.**

Human activities are causing a biodiversity crisis in all biomes of the Earth. As the world's population continues to grow, more land will be converted to agricultural land to meet the growing food demands, especially in the tropics where we find the most species rich habitats in the world. Many of these species and ecosystems provide valuable services to the humans living here. To best protect species richness and the people dependent on rural livelihoods in the tropics, two types of managed agricultural landscapes have been suggested: land sparing and land sharing. Land sparing promotes high yield agriculture in order to have as large an area as possible protected, while land sharing is farming a more extensive area of the landscape, but is able to retain more species and ecosystem services by using agricultural methods such as agroforestry. The potential for conservation and retaining ecosystem services in a land sharing or a land sparing type landscape in Uganda is addressed using data about insectivorous bats recorded with Anabat detectors in habitats from sugarcane, home garden and forest in and around Budongo forest, Uganda. Species richness, diversity, activity and species composition were determined for all habitats and used to give a picture of the conservation value of the different habitat types. As found in other studies both agricultural landscape types have a higher species richness and diversity than the forest habitat. But the higher activity and number of species related to the forest gives the home garden landscape better potential for conservation of microbats. Scattered trees and distance to the forest in the sugarcane landscape type does not add any conservation value compared to the sugarcane habitat. This study helps to demonstrate the value of land sharing type agriculture for conserving species richness and retaining ecosystem services.

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# 1. Introduction

All of Earth's ecosystems are influenced by human actions. Climate change, pollution, invasive species, habitat change and overexploitation are the major drivers of biodiversity loss in all biomes (MEA, 2005). A consequence of these human activities is the extinction of species. The loss of biodiversity seen today is up to one thousand times higher than that recorded by the fossil record (MEA, 2005). Myers et al. (2000) identified 25 hotspots of biodiversity and suggested that these should be focused on for the conservation of biodiversity. Fifteen of these hotspots are found in the tropics: an area in which the future of biodiversity does not look bright (Bradshaw et al., 2009). Tropical forests contain more than 60% of all species, yet they cover only 7% of the earth's surface (Laurance, 1999). In the tropics, habitat change is the most important direct driver for biodiversity loss (MEA, 2005), and as the population continues to grow and demand for fertile land increases, the trends we see today are likely to increase in the future (Bawa and Dayanandan, 1997). Conservation in the tropics is a very complicated issue, as a large number of the people living in these areas and using the protected landscapes, are rural and living below the poverty line (Fisher and Christopher, 2007).

More than half of the land that can potentially be used for agriculture is already covered by cropland or permanent pasture (FAO, 2006) and just 11% of the world's forests are protected by designated conservation areas thus recently, we have seen an increased focus by ecologists on conservation of tropical forest biota in the landscapes that have already been modified by humans (Gardner et al., 2009).

To protect both biodiversity and the people living in the tropics, two possible solutions are being discussed, land sharing and land sparing (Green et al., 2005). The idea behind land sparing is that we maximize yields on land that has already been cultivated, allowing more land to be set aside for conservation or to restoration of wildlife (Balmford et al., 2005). But there are several problems with this approach. Even though protected areas are crucial for maintaining a great deal of the earth's biodiversity, they are also known to fail to preserve the entire diversity of habitats, and therefore many species will not be protected. Local people are also known to dislike these strictly protected areas (Bhagwat and Rutte, 2006). High intensity agriculture is losing a lot of ecosystem services by focusing on short term yields in food production (Foley et al., 2005). The land sparing conservation model would leave us with a fragmented landscape with forest surrounded by a high intensity

agricultural matrix. The matrix is defined as the part of a landscape that has been or is currently undergoing anthropogenic alteration (Perfecto and Vandermeer, 2002). Research has shown that the species living in protected areas are very much affected by the matrix and surrounding landscapes (Ricketts, 2001). How species are influenced by fragmentation varies and depends on the structure of the surrounding matrix. It can provide food resources, corridors between different habitats and even breeding and roosting area (Antongiovanni and Metzger, 2005). The use of the matrix as corridors can prove to be important in the migration of forest dependent species in the case of future climate changes.

The alternative solution, land sharing (Green et al., 2005), recommends using a larger part of the landscape for agriculture, but promotes more wildlife-friendly farming, by retaining greater habitat diversity and minimizing the negative side effects of farming practices in the matrix. Land sharing or wildlife-friendly farming could potentially solve the problem of a possible inhospitable matrix. Agroforestry is one type of wildlife friendly farming that has been suggested as an alternative way to improve the matrix and reduce deforestation by the intentional use of shade trees together with agricultural crops (Ashley et al., 2006). Bhagwat et al. (2008) reviewed studies that compared the species richness and similarity of assemblages for different organisms between primary forest and different agroforestry systems. They found that an average of 60% of the species found in primary forests is also found in agroforestry systems. Although protected areas are important for conservation of biodiversity, the quality of the landscape matrix is thought to contribute significantly to the success of the biota living inside the reserves and parks. Biota in the matrix will also provide ecosystem services such as erosion control, crop pollination and pest limitation. Agroforestry could also enhance rural livelihoods by somewhat increased yields: a study by Soto-Pinto (2000), for example found that shade tree cover up to 40% had a positive effect on coffee production. To try to understand patterns of biodiversity in landscapes that are actively managed is seen by many as the way forward for conservation in tropical regions (Chazdon et al., 2009).

To determine how the diversity and abundance of life forms respond to anthropogenic factors would be time and resource consuming. So the use of indicator species to evaluate how systems respond is widespread. Taxa that are abundant ecologically and taxonomically and are trophically diverse are seen as useful indicator species. As a result, they can be used to evaluate disturbance effects and ecological patterns (Noss, 1990).

Bats (Chiroptera) occupy a variety of trophic levels, they are species rich and abundant in the tropics and are shown to behave in a predictable manner to disturbance and are thus seen as good indicator taxa in the tropics (Medellin et al., 2000). They contain approximately 1001 species worldwide (Hutson et al., 2001) and are the second-largest order of mammals in terms of species richness (Wilson and Reeder, 2005). They are not only a diverse group in terms of their number of species, but also in the variety found in morphology, feeding and roosting behavior (Altringham, 1998). Insectivorous bat diversity and activity are associated with the abundance of insects (Rautenbach et al., 1996). Monoculture cash crops like oil palm, cocoa, rubber and coffee reduce the biodiversity of insects such as moths, on which microbats feed (New, 2004), so bats are expected to follow the same pattern. This has been seen in previous bat studies, which have shown less bat activity in open areas where single-species crops are dominant. For example Estrada et al. (1993) did not capture any bats in 4 sites on the dominant pasture habitats in Mexico, whereas they captured 336 bats, belonging to 22 species in forest sites. There is often an observed increase of insect species in intermediately disturbed habitats or on the edges of habitats. For example, Ricketts et al., (2001) found that moths show small community changes between agricultural habitats, but a significant difference between relative distance from primary forest. Because of the heterogeneity of the disturbed areas, this might make them more attractive to insectivorous bats.

Bats provide important ecosystem services. In the tropics predation by insectivorous bats is more important than birds in reducing the abundance of arthropods and thus herbivory on agricultural plants (Kalka et al., 2008; Williams-Guillen et al., 2008). In a region of south-central Texas, the value of bats as pest control for the cotton industry has been estimated to be \$741 000 per year (Cleveland et al., 2006).

Arnett (2003) recognized bat responses to habitat management as one of the most critical pieces of missing information that is hindering our understanding of how to better conserve bats. Many of the threats to chiropteran communities can be related to an increase in human populations (Mickleburgh et al., 2002). Worldwide, it can be seen that agriculture has had a large impact on many bat species, partly by land degradation and removal of canopy trees (Fenton et al., 1998) or the use of pesticides, to which bats are known to be especially sensitive (Clark, 1981). In Africa some bat species are also consumed by humans, and bats that roost in houses are often exterminated by fumigation (Taylor, 2000).

Microbats use echolocation as a sensory means of orientation. Bat detectors let us eavesdrop, and presents the sound that the human ear is often unable to hear, in visual or acoustic models (Altringham, 1998). The availability of bat detectors has had a strong effect on field studies of bats, making them considerably less time and resource consuming (Altringham, 1998). Acoustic bat studies are also seen as a good way to supplement the more traditional bat sampling methods, like mistnetting and harptraps. Acoustic and trapping methods both have biases for the bat species they are most likely to catch or record. Bat detectors will not sample fruitbats, bats with very low frequency echolocation, and species that fly above the canopy. Mistnetting is not able to capture a lot of the agile or high flying microbat fauna (MacSwiney et al., 2008). In a study in the United States, O'Farrell and Gannon (1999) found that captures sampled 63.5% and acoustic methods 86.9% of the combined species sampled, making acoustic sampling a viable option.

The echolocation calls are species specific, and bat detectors can be used to identify different species (Fenton and Bell, 1981). Bat detectors have been used in field studies all over the world in determining the distribution and habitat use of species. On a general level, some capture data show that some bats have a clear association with specific habitats and habitat disturbance (Fenton et al., 1992), while other data suggest that the opposite is true (Rautenbach et al., 1996). In addition, studies of echolocation have also proven useful for detecting cryptic species, for example, studies of echolocation calls of the species *Pipistrellus pipistrellus* exhibited two call types (Jones and Vanparijs, 1993).

The objective of this study is to determine the conservation value of two tropical agricultural landscape types. Sugarcane represents the habitat sparing strategy, with high intensity monoculture plantations and little structural diversity and only a few trees that are situated far apart. The home garden represents land sharing, a diverse habitat in terms of structure both with a variety of different agriculture practices and a large number of trees growing in and around these agricultural patches. To see if these landscape types differ in their effect on microbat community composition, diversity, species richness and activity, these landscape types are compared to each other and to forest sites, to determine their potential for conservation of microbats and retention of ecosystem services. By sampling sites that are not so intensively managed and have greater habitat diversity inside a high intensity agricultural landscape, I could assess how habitats on a more local scale influence microbats. This will help determine if patches of trees in this landscape type are



more actively used by microbats, as is known from other parts of the world (Lumsden and Bennett, 2005). The data from this landscape are also used as a control for the home garden landscape site, to see if differences here are only because of very small scale differences in structure. I also sampled microbat communities over the whole period of foraging activity, to determine the nightly variation in activity.

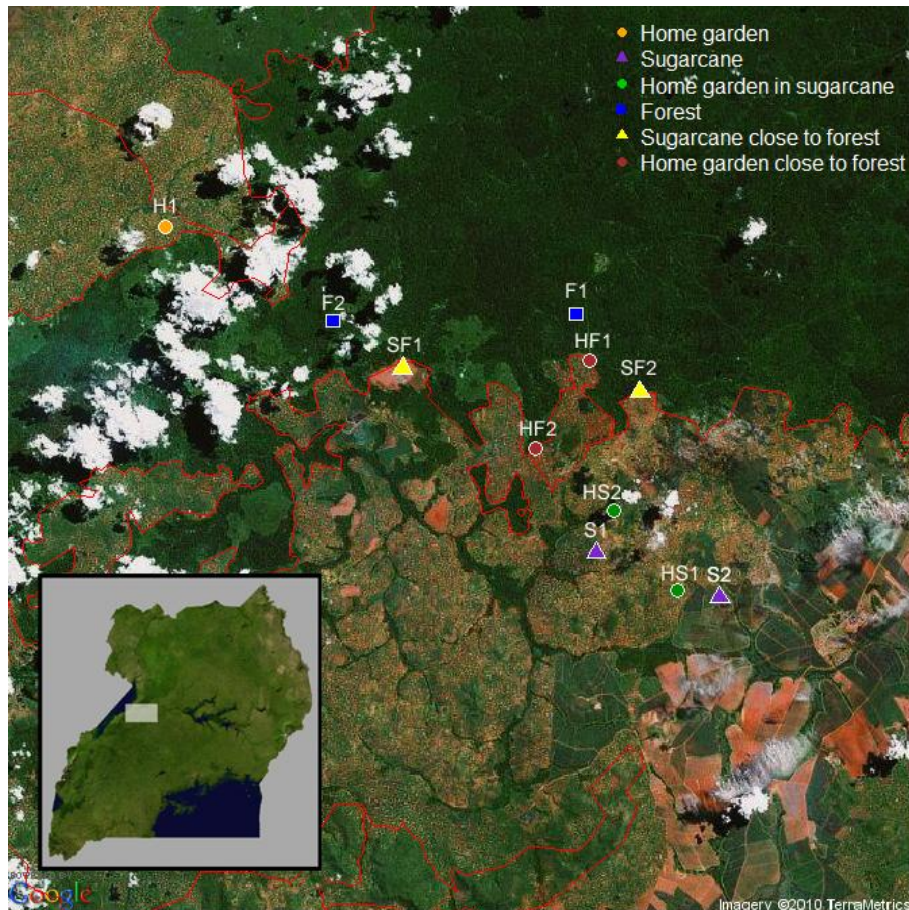
This study was conducted in the North Western part of Uganda. The future of the biodiversity in the tropical forests of the world is very dependent on the management of human impact on the landscape. This is also the case in Uganda, where 26% of the broadleaf forest cover was lost between 1990 and 2005 (FAO, 2009). Even though 14% of the land area in Uganda is protected (Howard et al., 2000), its biodiversity is threatened. The production of charcoal, illegal timber production, agricultural land expansion and forest clearing for sugarcane and oil palm plantations are among many of the reasons for the degradation of Uganda's forests. Uganda's population growth (3.5%) is the second fastest in the world (CIA, 2010). In Uganda, 87% of the population is rural, and 71% of land use change in tropical Africa is directly caused by small- and large scale agriculture (FAO, 2009). So to quantify how agricultural practices are affecting biodiversity in Uganda is crucial for knowing how to conserve the great biodiversity found here. Uganda also has a large microbat fauna, and this makes it a good system for the purpose of studying effects of land use on microbat communities. 77 species of microbats are found in Uganda (Kityo and Kerbis, 1996). This is over 20% of the country's mammalian diversity.

## 2. Materials and methods.

### 2.1 Study area.

The acoustic bat study took place in and around the Budongo Central Forest Reserve (BCFR) of Bunyoro kingdom. It is located in Masindi district, north western part of Uganda (1° 43' 14.452" N, 31° 32' 42.241" E) near the east shore of Lake Albert (Figure 2.1). Budongo has an altitude of 1100 m and is adjacent to other protected areas, for example Murchison Falls National Park, Bugungu Game Reserve and Karuma Game reserve. In the south, BCFR borders sugarcane plantations and several villages inhabited by subsistence farmers (Mwavu and Witkowski, 2008). BCFR is located in the northern part of The Albertine Rift Valley, a region of high conservation value as it is the most species-rich area in Africa for vertebrates (Plumptre et al., 2003), and has been identified as a "Biodiversity Hotspot" by Conservation International (Sheil, 1997; Myers et al., 2000). The precipitation in the area usually ranges from 1200 to 1800 mm each year. Most of the rain falls in two periods; September–November and March–May (Sheil, 1997).

BCFR was gazetted between 1932 and 1939 and covers a total area of 793 km<sup>2</sup>, of which 428 km<sup>2</sup> is forested, making it the largest forest reserve in Uganda. It also has the largest number of forest tree species recorded in Uganda (Howard, 1991). BCFR is a lowland type forest, consisting of three main forest types: pioneer forest, mixed forest and ironwood forest (*Cynometra*). Mixed forest is the successional stage between pioneer forest and ironwood forest. It has a large number of tall trees 20 to 55 m high and it is the richest of the forest types (Paterson, 1991). The canopy consists of three layers. Mixed and ironwood forest covers most of the forested parts of the reserve (Eggeling, 1947). The forest has been a site of commercial exploitation for timber since 1910. During the 1950's and 1960's management operations such as logging and the use of aboricides on selected trees regarded as weed species, were carried out (Plumptre and Reynolds, 1994). In addition to these changes within the forest, human settlements and conversion of forested areas for agriculture has divided the forest into a main block and several riverine forest patches surrounded by an agricultural matrix.



**Figure 2.1** Map of the south side of Budongo forest with location in Uganda shown on the inset map (from maplibrary.com). The forest border from 1998 is drawn in red. The different sites of the acoustic microbat study are marked and named. For GPS of locations see Appendix. The area to the south of the forest is a landscape dominated by large sugarcane plantations, while the area to the north is used for smaller home gardens. The map was extracted and drawn using RgoogleMaps (Markus Loecher and Sense Networks, 2009)

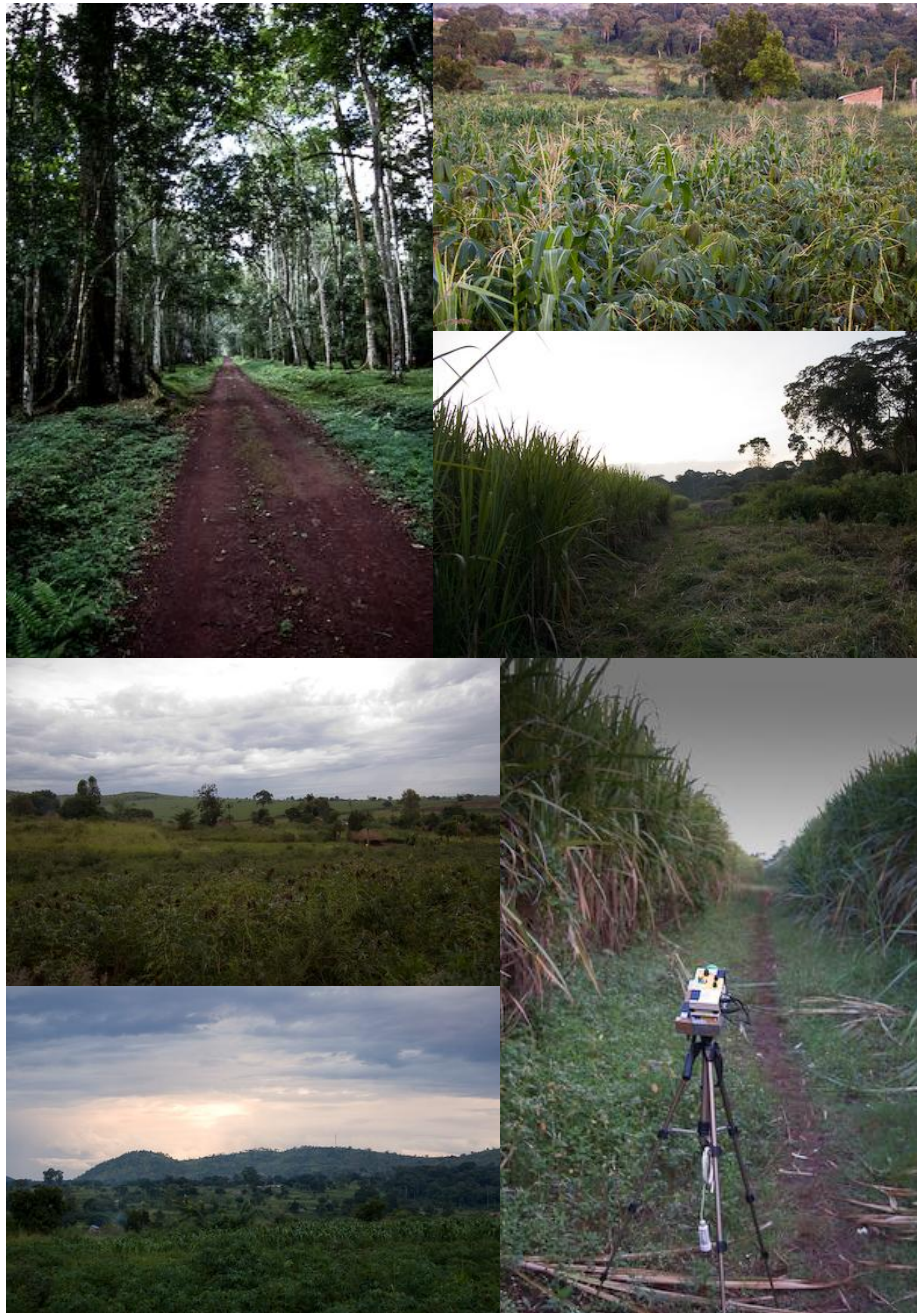
## 2.2 Methods.

### 2.2.1 Land use study.

Eleven study sites were sampled for two nights, using two detectors each night. One AnaBat™ II linked to a CF storage device and an AnaBat™ SD I detector (Titley Scientific, Australia) were used to record the bat activity passively. The detectors were placed on a tripod approximately 1.5 m above the ground at an angle of 45°, positioned to capture as much of, and as many call sequences as possible (Weller and Zabel, 2002). The sensitivity of the recorder was adjusted to get as many calls as possible and minimize background noise. The detectors were placed at least 100 m apart, to ensure that the same individual was not continually sampled at both detectors. Ideally the two detectors should have been



placed in two separate sites per night. Due to logistic constraints both detectors were used to sample the same site the same night.



**Figure 2.2** The six different habitat types used for sites in the acoustic microbat study in North Western Uganda. The pictures show the forest (top left), home garden close to forest (top right) and sugarcane close to forest (middle right), home garden in sugarcane (middle left), home garden landscape (lower left) and sugar cane (lower right).

The sites were selected to establish a land-use gradient based on the variation in the intensity of agricultural use and the occurrence of large trees. Sites encompassed six habitat types (figure 2.2), placed in three different landscape types, sugar cane, home garden and forest. The two different agricultural landscapes are found south and northwest of the forest. In the south sugarcane plantations are dominating, while these are not found northwest of the forest. In the sugarcane landscape type, two habitat types were sampled, at two landscape positions: sugarcane, home garden in sugarcane landscape, sugarcane close to the forest, and home garden in sugarcane landscape close to the forest. Only one home garden landscape type site was sampled, because of logistic constraints. This gives the study eleven sites shown in figure 2.1. Areas close to water sources were excluded, as areas associated with water are known to be important foraging habitat for some bat species (Furlonger et al., 1987; Monadjem and Reside, 2008). Sugarcane and sugarcane close to forest sites were based in large fields of mature sugar cane between two and three meters in height. Home garden, home garden in sugarcane and home garden close to forest sites were sites used for subsistence farming. This landscape is dominated by fields of cassava (*Manihot esculenta*), maize (*Zea mays*) and different species of bean. Mango (*Mangifera indica*), jack fruit (*Artocarpus heterophyllus*), eucalyptus, banana, avocado (*Persea americana*), moringa and acacia are also grown. Both forest sites are situated in parts of the forest classified as mixed forest (Eggeling, 1947): the dominant genera are *Chrysophyllum*, *Cynometra*, *Khaya* and *Trichilia* (Paterson, 1991). The sugarcane plantations are a dense habitat, so small roads inside the fields were used as sample sites (figure 2.2). Roads were also used in the forest to allow a comparison of the activity and species assemblages between the sites. Geographical coordinates were recorded for each site (Garmin eTrex Handheld GPS).

Data were collected between the 10<sup>th</sup> October and 26<sup>th</sup> November 2009. Detectors were turned on at 18:45, about 15 minutes before civil twilight, and continued until 22:00. This way I hoped to catch the species that come out to feed right before sunset and early in the night, and get sufficient data at each site to properly sample the communities. Sampling was avoided on nights when the moon was full. Five nights with a gibbous moon (Time and Date, 2010) were divided equally between the five habitat types to avoid bias. The effect of the moon should therefore be equal in all habitat types, but bats in the forest can change their vertical habitat (Hecker and Brigham, 1999), so the moon cycles effect on activity could be smallest in the forest. To avoid behavior biased results, no sampling was done on nights with heavy rainfall or high winds. The low number of sites in this study is a

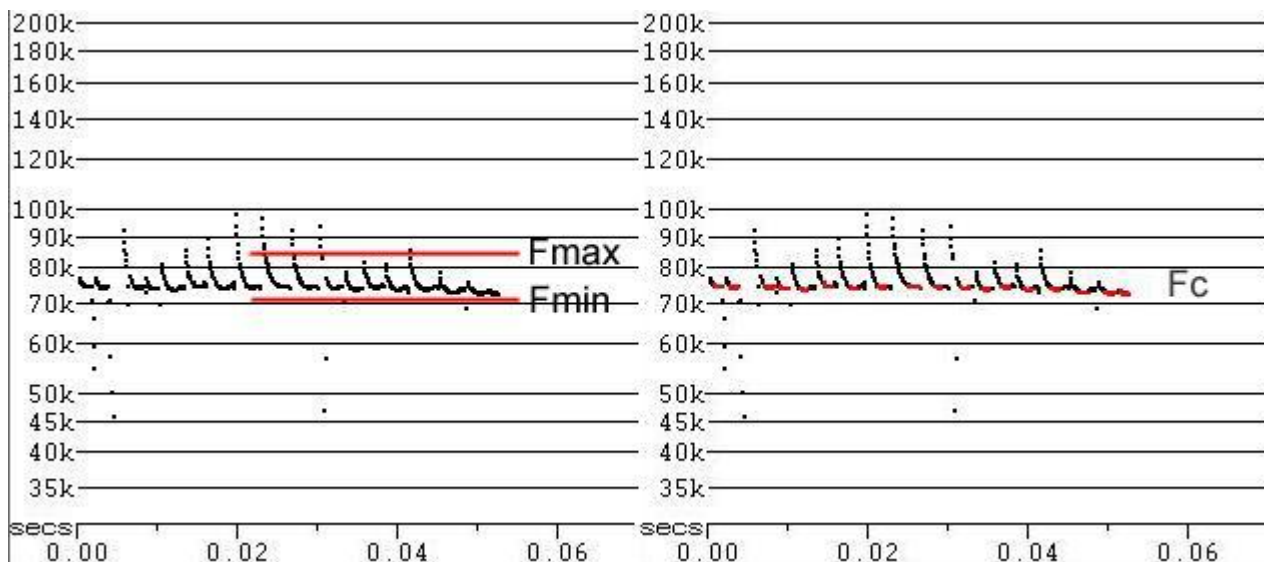
result of such limitations, which were used to get as many unbiased results as possible. Temperature and relative humidity were recorded every ten minutes during each field night with a Hobo Pro v2, Temperature/Relative Humidity data logger (Onset Computer Corporation, USA). The logger was placed with one of the detectors, 50 cm above ground. Wind speed was estimated using the Beaufort Wind Force Scale (Singleton, 2008). The local tree canopy was calculated from the number of large trees and their approximated canopy size. This was estimated inside of a 100x100 m area centered on one of the bat detectors.

### **2.2.2 Whole night study.**

The all night acoustic bat study took place at the Budongo Conservation Field Station (BCFS) (1° 43' 23.376" N, 31° 32' 44.765" E) inside the Budongo Forest Reserve (BFR), between the 19<sup>th</sup> September and the 28<sup>th</sup> November 2009. Two Anabat™ detectors were used on the 6<sup>th</sup> October and the 28<sup>th</sup> November. The two detectors were placed approximately 100 m apart, one facing south east (A), the other west (B). On three other nights (19<sup>th</sup>, 20<sup>th</sup> and 21<sup>st</sup> September) only the Anabat™ SD I detector was used. The detectors were recording passively from a window facing out into an open area at a 45° angle, making sure that there was nothing that obstructed the detectors. This kept the equipment under shelter in case of rainfall. Recording started 15 minutes before dark at 18:45, and ended 07:30. The detectors were not moved during the nights. To avoid the recordings being biased by rainfall during the night, I placed a small container outside, and if it held water in the morning, the data were discarded. Batteries were fully charged or new before the whole night study.

### 2.2.3 Species identification.

Species identification of the calls was done with the help of Dr. Robert Kityo at Department Of Zoology, Makerere University, using his earlier recordings (Kityo, 2008). Identification calls with less than three distinct pulses were discarded (Johnson et al., 2002). The identification was done using AnalookW™ (Corben, 2006). Each call has a distinct duration measured in milliseconds from beginning to the end of a pulse, a shape and a frequency range (figure 2.3). Some of the calls that were recorded could not be identified to species with the information currently available. These calls are nonetheless distinct, and were categorized and assigned a letter from A to I. It can be assumed that these calls are either distinct species or that they are an unknown variation in the call traits of a species already known.



**Figure 2.3** The echolocation call of *Neoromicia nanus*, with three call parameters marked. The x-axis is time in seconds, and the y-axis frequency in kilohertz. In this call the characteristic frequency ( $F_c$ ) is 74 kHz, the maximum frequency of the call ( $F_{max}$ ) is 83 kHz and the minimum frequency of the call ( $F_{min}$ ) is 72 kHz.  $F_c$  is the frequency on the right, flat portion of the call, and the most important parameter for distinguishing species.  $F_c$  is often close to  $F_{min}$ , but some calls have a down swipe at the end.

## **2.3 Statistics.**

All statistical analysis were done using the statistical program R 2.11.0 (R Development Core Team, 2010).

### **2.3.1 Data manipulation.**

The bat call data for the land-use study was pooled from individual detectors and nights, into sites. The temperature and relative humidity varied little during the night, so an average for each night was calculated, and used to calculate the average for each site. If it had been raining on the same day as sampling, the site was given a value of one, or two, if it had rained on both sampling days. Wind was summed for the two sample nights into one value for the site.

### **2.3.2 Call parameters.**

Breiman's random forest algorithm (Breiman, 2001) was used to test if there was potential for automatic species identification. The algorithm makes many classification trees on a bootstrap sample of the data. Then each classification tree votes on the test samples. The classification with the most votes is chosen as the best. Random forest also gives values for importance of the individual parameters. Maximum, minimum and characteristic frequency, duration, time between calls and characteristic slope were used as parameters.

### **2.3.3 Activity, diversity and species richness.**

Estimations of the species richness in the microbat communities were done by drawing species accumulation curves (Colwell and Coddington, 1994). The non-parametric Chao1 estimation method was also used. It is known to give good estimates of the potential richness in species poor communities (Colwell and Coddington, 1994). Rarefied species richness was estimated to see how many species would be expected at the lowest activity detected for any of the sites (n=81) (Hurlbert, 1971). The Simpson-index D diversity was calculated for each site. Because the detectors are not able to tell the difference between individuals, an index of bat activity is used instead of abundance. To test if there is a significant relationship between the activity and the different habitat types a Kruskal-Wallis



test was used. Non-parametric tests were used because my data violates the assumptions of parametric tests. A generalised linear model regression analysis was done to test the significance of the different parameters against distance to forest and local tree cover percentage.

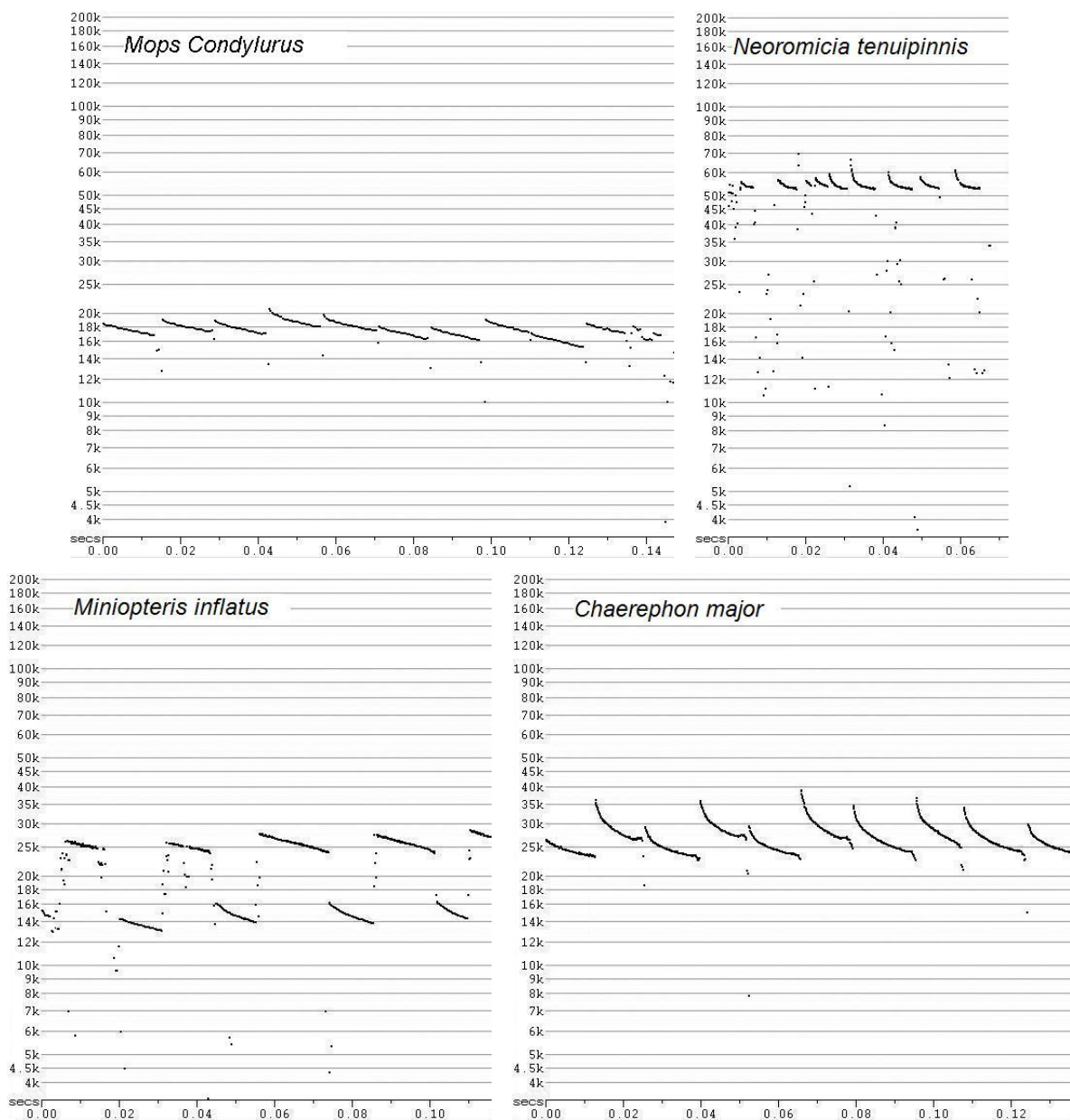
#### **2.3.4 Community structure.**

Detrended Correspondence Analysis (DCA) (Hill and Gauch, 1980) was used to determine if the species composition had a linear or unimodal response to the underlying environmental gradient. The length of the first axis (3.5SD) indicates a unimodal relationship. Correspondence Analysis (CA) (Legendre and Legendre, 1998) was then used to better visualize the species composition as DCA rescales the axis. CA can be sensitive to rare species, so *Species g* was removed from the analysis because only one call of this species was recorded. A Constrained Correspondence Analysis (CCA) (Legendre and Legendre, 1998) was used with the environmental variables (distance from forest, rain during the day, wind strength, tree cover, temperature, relative humidity and lunar illumination). Forward selection was used to find the environmental variables that were most important in describing the variance in species composition. The Jaccard index is used in the study by Bhagwat et al. (2008) and will be used to supplement the CCA (Legendre and Legendre, 1998) and for comparisons with the previous studies. The Jaccard index does not use abundance, but presence-absence data (Chao et al., 2005). And gives results from 0 to, 1 where 0 is identical composition.

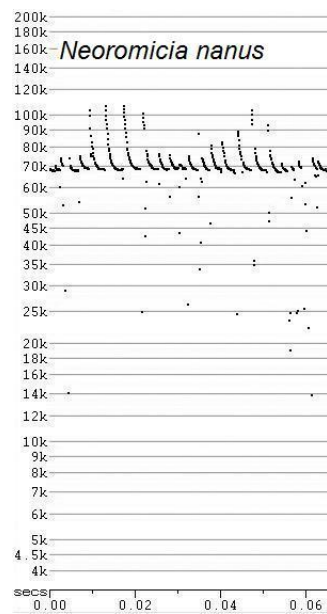
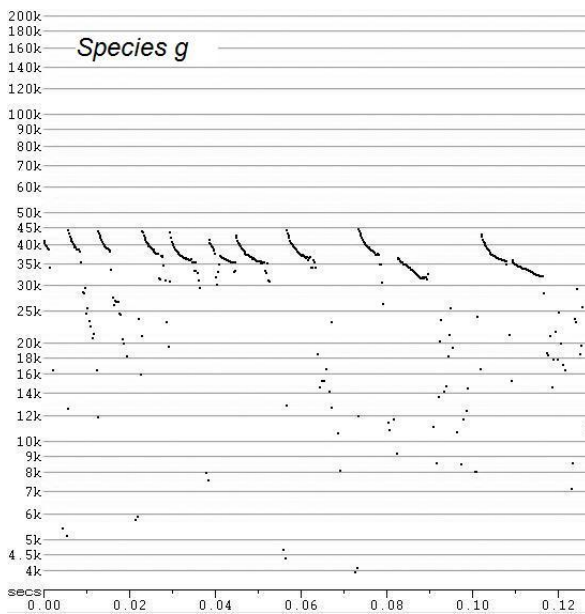
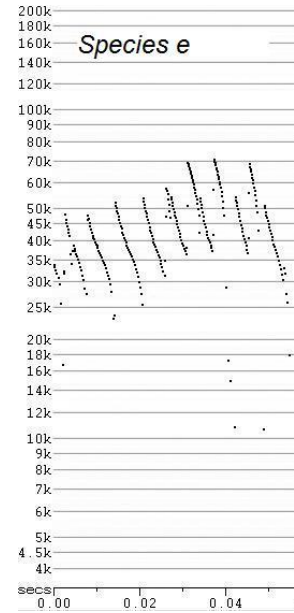
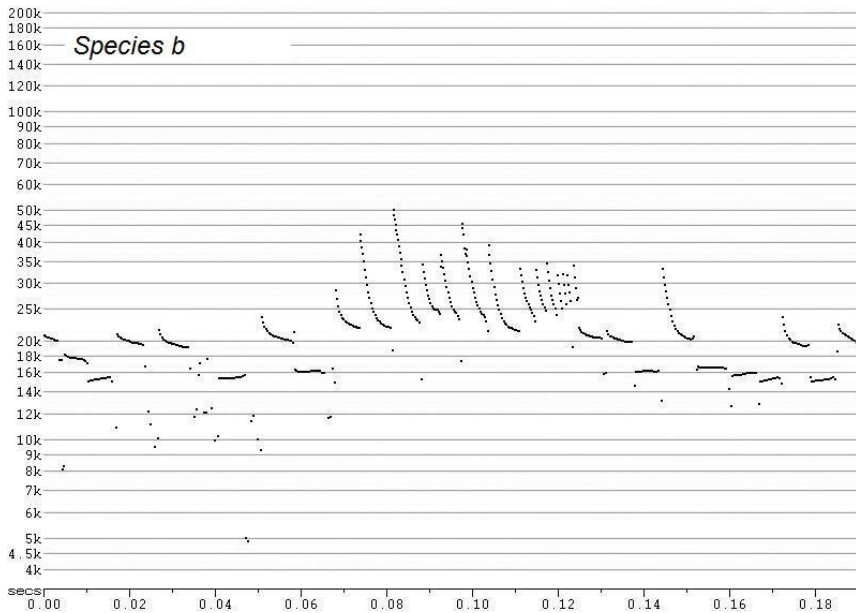
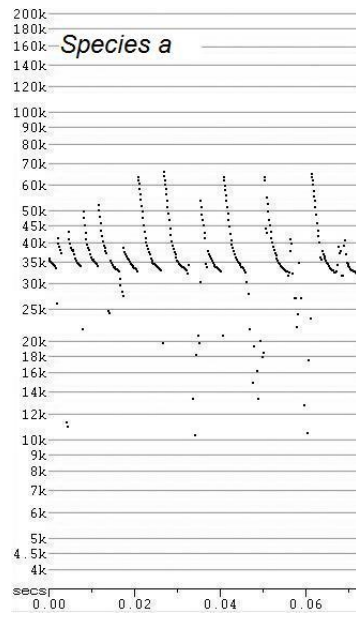
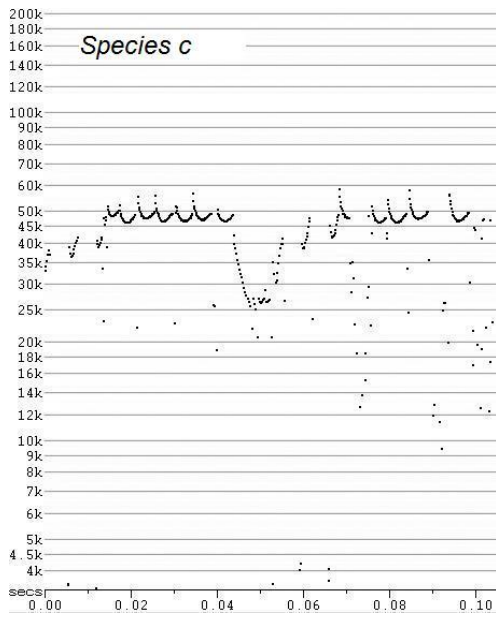
### 3. Results.

#### 3.1 Call parameters.

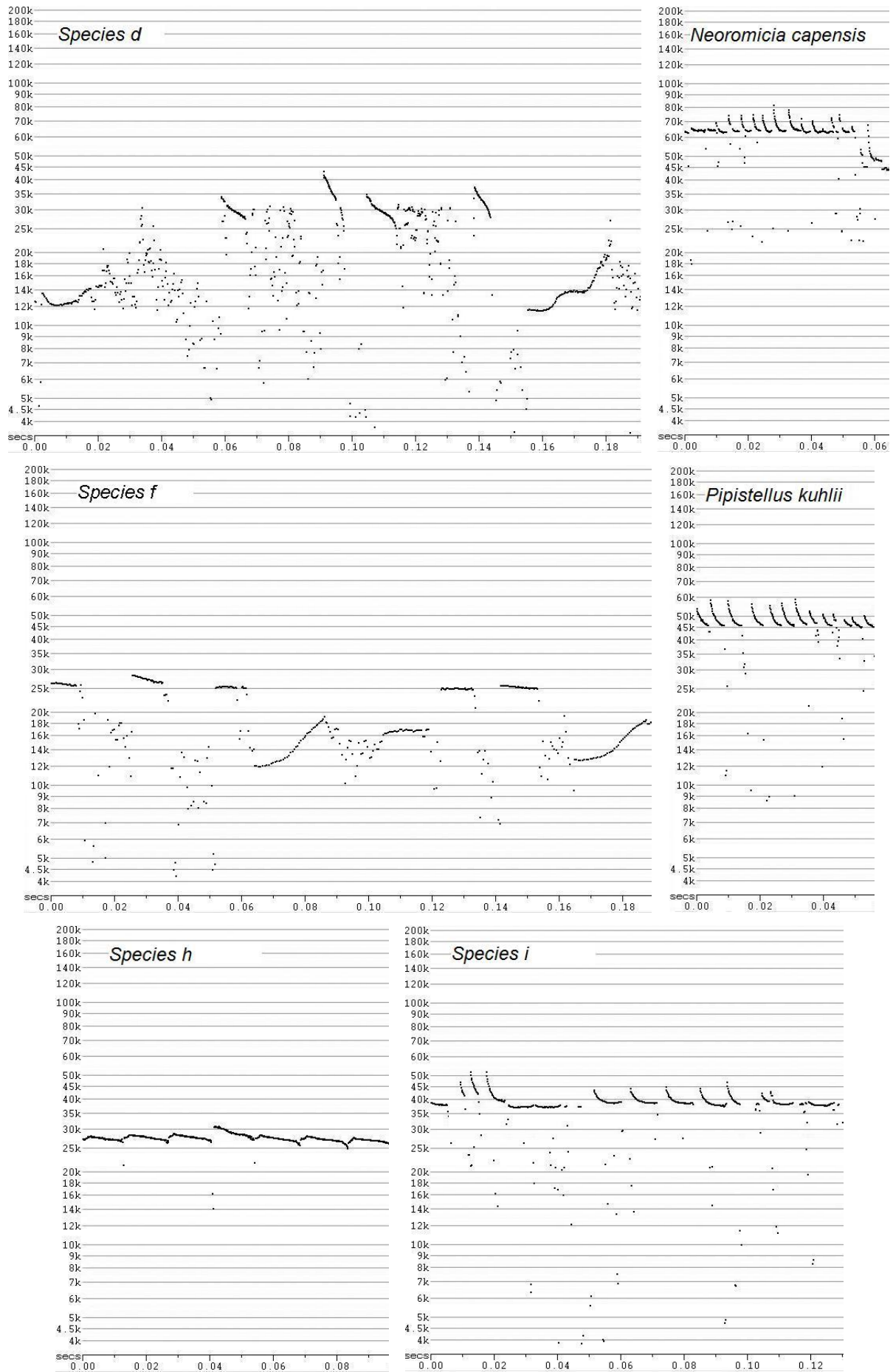
The echolocation calls of the 17 microbat species recorded in this study can be seen below in figure 3.1. These example calls can be used to identify microbat species from the same area, and habitats.



# Results



## Results



**Figure 3.1** The sonograms of the microbat calls recorded in and around Budongo forest reserve in Western Uganda. The calls are distinct in their shape and different frequency measures.

## Results

In 71% of the cases the random forest classification of the call parameters (table 3.1), placed calls in the same taxa as the qualitative species identification. Because the call characteristics of some of species have large variations (see figure 3.1) a confusion matrix was made for the known species (table 3.2). Here only 7 % of the calls were misclassified.

In both cases the characteristic frequency is the most important parameter for identifying species. The minimum frequency is more important than the maximum frequency. This might be because the weaker maximum frequency can vary according to the distance to the microbat. The slope is seen as less important than frequencies. The time between calls is the least important parameter. The mean frequency and duration were not used because AnalookW™ gave wrong readings for these parameters. *Pipistrellus khulii* (96%), *Neoromicia nanus* (100%), and *Species d* (81%) are the species with the largest percentage of correct classification.

## Results

**Table 3.1** Confusion matrix showing the classification of bat calls based on call properties from many classification trees. The calls of each true species are classified as a predicted species based on parameters. The parameters which were used are: max, min and characteristic frequency, duration, time between calls and characteristic slope.

True species	Mc	Mi	Cm	Nc	Pk	Nn	Nt	Sp a	Sp b	Sp c	Sp g	Sp f	Sp d
<b>Predicted species</b>													
Mc	7	0	9	0	0	0	0	0	0	0	0	2	8
Mi	0	3	0	0	0	0	0	1	4	0	0	3	4
Cm	7	0	29	0	0	0	0	1	0	0	0	3	1
Nc	0	0	0	0	0	2	0	0	0	0	0	0	0
Pk	0	0	1	0	162	0	3	0	0	3	0	0	0
Nn	0	0	0	0	0	27	0	0	0	0	0	0	0
Nt	0	0	0	0	3	0	27	0	0	0	0	0	0
Sp a	0	0	1	0	1	0	0	1	0	0	0	0	0
Sp b	0	0	0	0	0	0	0	0	22	0	0	5	8
Sp c	0	0	0	0	27	0	0	0	0	9	0	0	0
Sp g	0	0	1	0	1	0	0	0	0	0	0	0	0
Sp f	4	0	3	0	0	0	0	0	3	0	0	14	29
Sp d	3	0	2	0	0	0	0	0	4	0	0	17	109

*Pipistrellus kuhlii* (Pk), *Neoromicia capensis* (Nc), *Neoromicia nanus* (Nn), *Neoromicia tenuipinnis* (Nt), *Mops condylurus* (Mc), *Chaerephon major* (Cm), *Miniopterus inflatus* (Mi).

**Table 3.2** Confusion matrix based on call properties from the known microbat species. For further explanation see Table 3.1

	Pk	Nn	Nt	Mc	Cm
Pk	165	0	4	0	0
Nn	0	26	0	0	0
Nt	3	0	27	0	0
Mc	0	0	0	18	7
Cm	0	0	0	7	30

*Pipistrellus kuhlii* (Pk), *Neoromicia nanus* (Nn), *Neoromicia tenuipinnis* (Nt), *Mops condylurus* (Mc), *Chaerephon major* (Cm).

### 3.2 Land use study.

From a total of 132 hours of bat detecting, 2980 bat calls representing 16 species were recorded. The seven species that I was able to positively identify belong to two families, Mollosidae (Free-tailed bats) and Vespertilionidae (Plain-faced bats). Thirty three percent of all the recorded calls belonged to *Neoromicia khulii*, while 12% were *Chaerophon major*, 9% *Mops condylurus* and 8% *Species b*.

#### 3.2.1 Environmental data.

Amongst the 12 sites, the longest distance from the forest (table 3.3) was from site S2, which was 4368 m from the forest. Sugarcane and home garden in sugarcane sites are all approximately 2 km from the forest edge. Local percentage of tree cover ranges from 98% (F1) to 0% (S1). There is a clear gradient in the percentage of cover going from the sugarcane sites to the forest. On the different nights of sampling, the temperature varies from 18°C in HS2 (17.Oct) to 21°C in SF1 (21.Nov) (table 3.4). The variation in humidity is small, only one night SF1 (21.Nov) is under 90%, and the majority around 96%. The illumination of the moon varies from 0.5% (HS2) to 75% (HS2). The illumination is evenly dispersed among the sites. The greatest effect from the moon would be expected in HS2 (28.10) when the moon is close to full and sets at 22:12. During sampling there was very little wind, a light breeze (16.Oct HS1) is the highest wind speed recorded.

**Table 3.3** Distance from forest and tree cover percentage in the 11 sites used to sample microbat activity in and around Budongo forest, Uganda

	S1	S2	SF1	SF2	HS1	HS2	HF1	HF2	H1	F1	F2
<b>Distance from forest (m)</b>	1814	4368	5	24	4156	1943	16	10	730	0	0
<b>Tree cover (%)</b>	0	4	48	43	24	11	55	53	18	98	95

*Sugarcane (S), Sugarcane close to forest (SF), home garden in sugarcane landscape type (HS), home garden close to forest in sugarcane landscape type (HF), home garden landscape type (H) and forest (F).*

## Results

**Table 3.4** Environmental variables for each acoustic microbat sampling night at the land use sites, in and around Budongo. The moonrise and moonset is not shown on nights when the moon is not up during the time of the acoustic sampling.

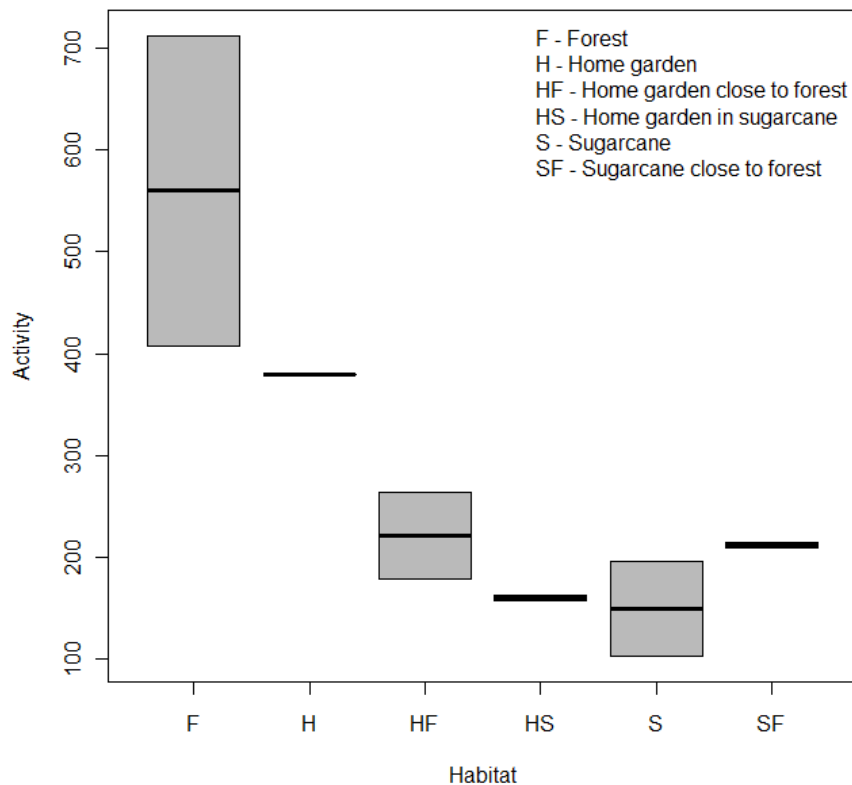
Site	Date	Moonrise	Moonset	Lunar phase (%)	Wind (Beaufort scale)	Temp (C°)	Humidity (%)	Rain
S1	11.10	-	-	52.7	0	-	-	No
	22.11	11:02	23:23	29.0	0	18.49	97.46	No
S2	19.10	07:15	19:38	1.9	0	19.11	96.21	Yes
	25.11	13:09	00:47	57.5	0	18.67	96.93	Yes
SF1	15.10	-	-	10.8	0	18.97	96.13	No
	21.11	10:16	22:38	20.6	0	21.55	86.15	No
SF2	24.10	11:36	23:58	36.9	0	19.25	96.23	Yes
	23.11	-	-	38.1	0	19.01	93.98	No
HS1	16.10	-	-	4.7	2	-	-	Yes
	24.11	12:28	00:06	47.7	0	18.97	96.03	Yes
HS2	28.10	14:34	22:12	74.7	1	19.92	94.30	No
	17.11	06:49	19:14	0.5	0	18.15	97.27	Yes
H1	26.10	13:09	00:45	56.2	0	18.43	96.37	Yes
	20.11	09:27	21:50	13.2	1	19.53	93.97	Yes
HF1	14.10	-	-	19.3	0	20.83	93.91	No
	16.11	-	-	0.4	0	19.56	96.69	Yes
HF2	27.10	13:52	01:29	65.7	1	20.26	93.63	Yes
	19.11	08:36	21:00	7.2	0	19.59	96.27	No
F1	13.10	-	-	29.5	0	-	-	No
	18.11	07:43	20:07	2.9	0	20.19	91.17	No
F2	21.10	09:00	21:25	11.8	0	19.31	95.85	No
	26.11	13:50	01:28	67.3	0	19.75	96.04	No

*Sugarcane (S), Sugarcane close to forest (SF), home garden in sugarcane landscape type (HS), home garden close to forest in sugarcane landscape type (HF), home garden landscape type (H) and forest (F).*



### 3.2.2 Activity.

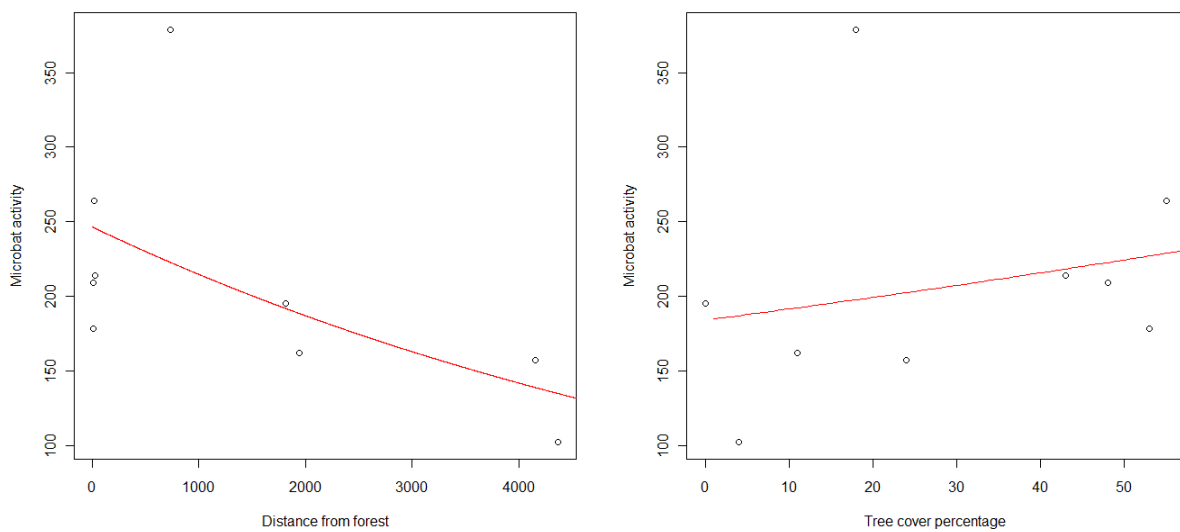
The microbat activity varies from  $148 \pm 65.8$  bat passes per site in sugarcane, to  $560 \pm 216.4$  in the forest sites (figure 3.2). We can see a pattern where forest and home garden landscape type sites have relatively high microbat activity. A weaker trend can be seen in the sugarcane and home garden sites in sugarcane landscape type, where sites located close to the forest tend to have higher activity than sites that are located further away. These difference in activity is not significant over habitats (Kruskal-Wallis chi-squared=8.4091, df=5, p-value=0.1351).



**Figure 3.2** Microbat activity recorded using Anabat detectors in the different habitats in and around Budongo forest, Uganda. The black lines are the mean activity and the gray boxes the range. Home garden landscape type (H) only has one site, while the variation in home garden in sugarcane landscape type (HS) and sugarcane close to forest is so small it does not show on the figure.

## Results

Regression of the microbat activity against tree cover and distance gradient were not significant ( $P=0.569$  and  $P=0.099$ , respectively). Figure 3.3 shows the regression lines. Microbat activity along a distance gradient shows that there is a little bit more activity the closer to the forest the sites are situated. This pattern is reflected by the local tree cover percentage. This is because the 4 sites with 40% cover or more are the sites that are situated on the forest edge. Home garden landscape type is an outlier in both of these plots, it has higher activity than the sites situated closer to the forest and more than the sites with more tree cover percentage.



**Figure 3.3** Regression analysis of the microbat activity around Budongo forest in Uganda. Activity was sampled over a distance from forest and tree cover percentage gradient.

### 3.2.3 Species richness and diversity.

Species richness and diversity varies between the sites, but also between the two nights sampled at each site. A high Simpson diversity index value (table 3.5) indicates high diversity. Home garden in a sugarcane landscape type close to forest sites (Simpson index  $0.84\pm 0.00$ ) are the most diverse habitat and forest sites (Simpson index  $0.54\pm 0.17$ ) the least diverse. No other pattern is seen either in differences in habitat or distance from forest. There is no significant correlation between the diversity and habitat types (Kruskal-Wallis chi-squared=6.9545,  $d=5$ ,  $p$ -value=0.2240).

## Results

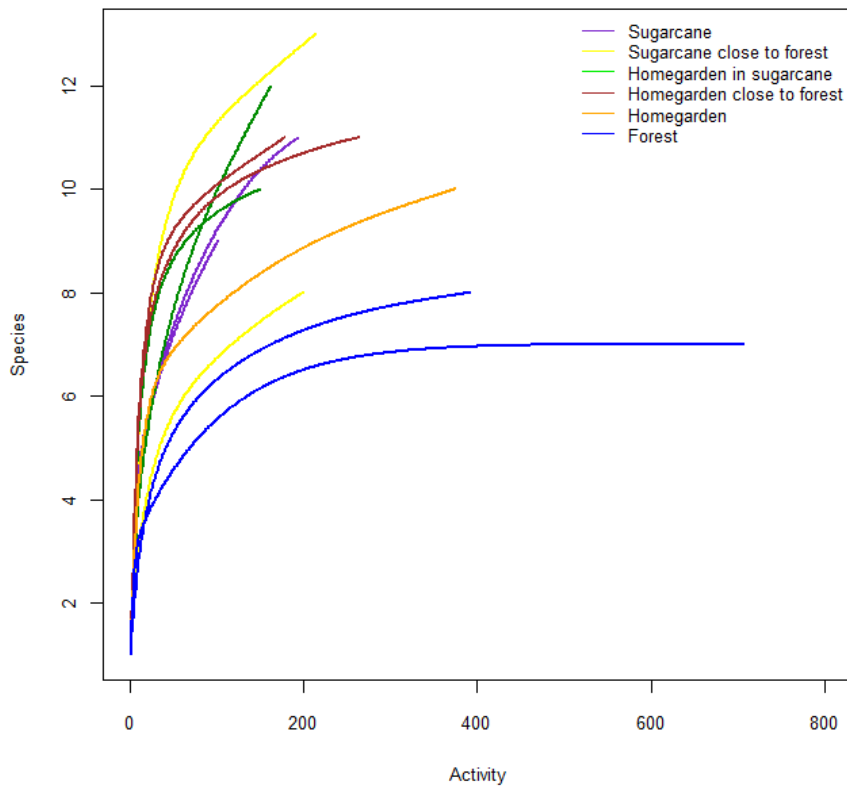
**Table 3.5** Mean and standard deviation of microbat activity, observed richness, rarefied richness and Chao1 estimated richness in the different land use habitats.

	Activity		Observed richness		Rarefied (n=81)		Chao1 estimated		Simpson Diversity	
	Mean	s.d	Mean	s.d	Mean	s.d	Mean	s.d	Mean	s.d
<b>Sugarcane</b>	148.5	65.8	10	1.4	8.5	0.2	10.9	0.5	0.75	0.04
<b>Sugarcane close to forest</b>	211.5	3.5	10.5	3.5	8.6	3.2	12.3	5.3	0.64	0.23
<b>Home garden in sugarcane landscape</b>	159.5	3.5	11	1.4	9.3	0.1	16	8.5	0.75	0.2
<b>Home garden close to forest</b>	221	60.8	11	0	9.7	0.2	11.5	0.7	0.84	0.0
<b>Home garden</b>	379	NA	10	NA	7.5	NA	11	NA	0.69	NA
<b>Forest</b>	560	216.4	7.5	0.7	5.6	0.6	7.5	0.7	0.54	0.17

Rarefied and Chao1 estimated species richness per site were calculated to supplement the observed species richness data (table 3.5). Rarefied species richness per site is highest in home garden in sugarcane ( $9.3\pm 0.1$ ) and home garden close to forest ( $9.7\pm 0.2$ ). Lowest rarefied richness is found in the forest sites ( $5.6\pm 0.6$ ). The forest sites also have the lowest Chao1 estimated species richness per site, while the home garden in sugarcane site ( $16\pm 8.5$ ) has the highest. The habitats with the highest richness indices all have high standard deviations, because one site is much higher than the other. In conclusion the lowest richness is found in the forest sites, while the species observed, rarefied and Chao1 richness in the other sites show no clear pattern.

Many of the sites have reached or are close to reaching an asymptote in the rarefaction curve (Figure 3.4), indicating that the sampling is sufficient as few species are expected to be added with further sampling. Both of the sugarcane and one of the sugarcane close to forest sites (SF1) have especially steep curves. More species would be expected to be found here if the sampling intensity was higher. The curve for the home garden site and forest site (F2) is leveling out, but additional species are expected at these sites as well. The same can also be said, to a lesser degree, about the home garden close to forest and sugarcane close to forest sites.

## Results



**Figure 3.4** Rarefaction curve of the microbat data, the number of new species added as the sampled microbat activity increases.

The Chao1 extrapolated species richness in table 3.6 gives an estimation of the number of species at each site. The Chao1 extrapolated species richness adds fewer species to the communities than the rarefaction curve, as seen especially in F2, H1, HF1, HS1 and S1. Both indices show that the sampling in most of the sites came close to getting a complete sample of the communities. However HS2 seems to be under sampled, probably as a result of the large number of species that has been detected once or only a few times, while others like *Species i* and *C. major* are very dominant.

**Table 3.6** Observed and extrapolated number of microbat species in the eleven sites sampled in the land use study in Budongo.

	S1	S2	SF1	SF2	HS1	HS2	HF1	HF2	H1	F1	F2
Observed	11	9	13	8	10	12	11	11	10	7	8
Chao1	11.3	10.5	16	8.5	10	22	11	12	11	7	8
Se Chao1	1.3	7.2	NA	3.7	1.3	NA	1.3	NA	NA	NA	NA

*Sugarcane (S), Sugarcane close to forest (SF), home garden in sugarcane landscape type (HS), home garden close to forest in sugarcane landscape type (HF), home garden landscape type (H) and forest (F).*

### 3.2.4 Species composition.

Table 3.7 shows the activity of the species recorded over the different sites. *Species b* and *Species c* are only found in the forest sites, with quite high activity. *Species f* seems to be very active in HS2. This site has 95 % of all the recorded calls of this species. Both species of molossid bats are found in all habitats outside of the forest, but only 3 calls were recorded inside the forest. *P.khulii* seems to be dependent on forest or edges. It is the most active of all species in the forest with 55% of all recorded calls. *Species d* is dominant in the home garden (51% of all calls), and 65% of all the *Species d* from the home garden landscape site. *Miniopterus inflatus* seems to prefer habitats outside of the forest but which are associated with trees or hedges. *Neoromicia nanus* is the only species that is more active in the sugarcane (51%) than in any of the other sites.

**Table 3.7** Activity of the different microbat species recorded using Anabat detectors in and around Budongo forest, Uganda. Species activity is divided into the habitat they were recorded in.

	S1	S2	SF1	SF2	HS1	HS2	HF1	HF2	H1	F1	F2
<b>Family Molossidae</b>											
<i>Mops condylurus</i>	33	15	20	10	19	23	34	50	39	4	0
<i>Chaerephon major</i>	43	20	50	6	47	37	71	21	42	0	0
<b>Family Vespertilionidae</b>											
<i>Miniopterus inflatus</i>	1	0	15	2	2	0	30	12	27	7	3
<i>Neoromicia capensis</i>	2	1	8	0	1	1	2	4	3	0	8
<i>Neoromicia nanus</i>	62	46	6	1	29	3	5	14	47	0	1
<i>Neoromicia tenuipinnis</i>	3	11	11	9	9	1	8	12	1	10	45
<i>Pipistrellus kuhlii</i>	38	4	72	140	19	5	31	19	21	312	295
<b>Unknown species</b>											
<i>Species a</i>	0	1	1	0	6	3	1	9	3	0	15
<i>Species b</i>	0	0	0	0	0	0	0	0	0	236	3
<i>Species c</i>	0	0	0	0	0	0	0	0	0	131	22
<i>Species d</i>	7	1	17	0	13	1	30	35	190	0	0
<i>Species e</i>	1	0	1	0	0	1	0	1	1	7	0
<i>Species f</i>	0	0	4	0	0	79	0	0	0	0	0
<i>Species g</i>	2	2	7	1	5	7	8	1	0	0	0
<i>Species h</i>	0	0	0	0	0	1	0	0	0	0	0
<i>Species i</i>	2	0	1	30	0	0	44	0	0	0	0

Sugarcane (S), Sugarcane close to forest (SF), home garden in sugarcane landscape type (HS), home garden close to forest in sugarcane landscape type (HF), home garden landscape type (H) and forest (F).

## Results

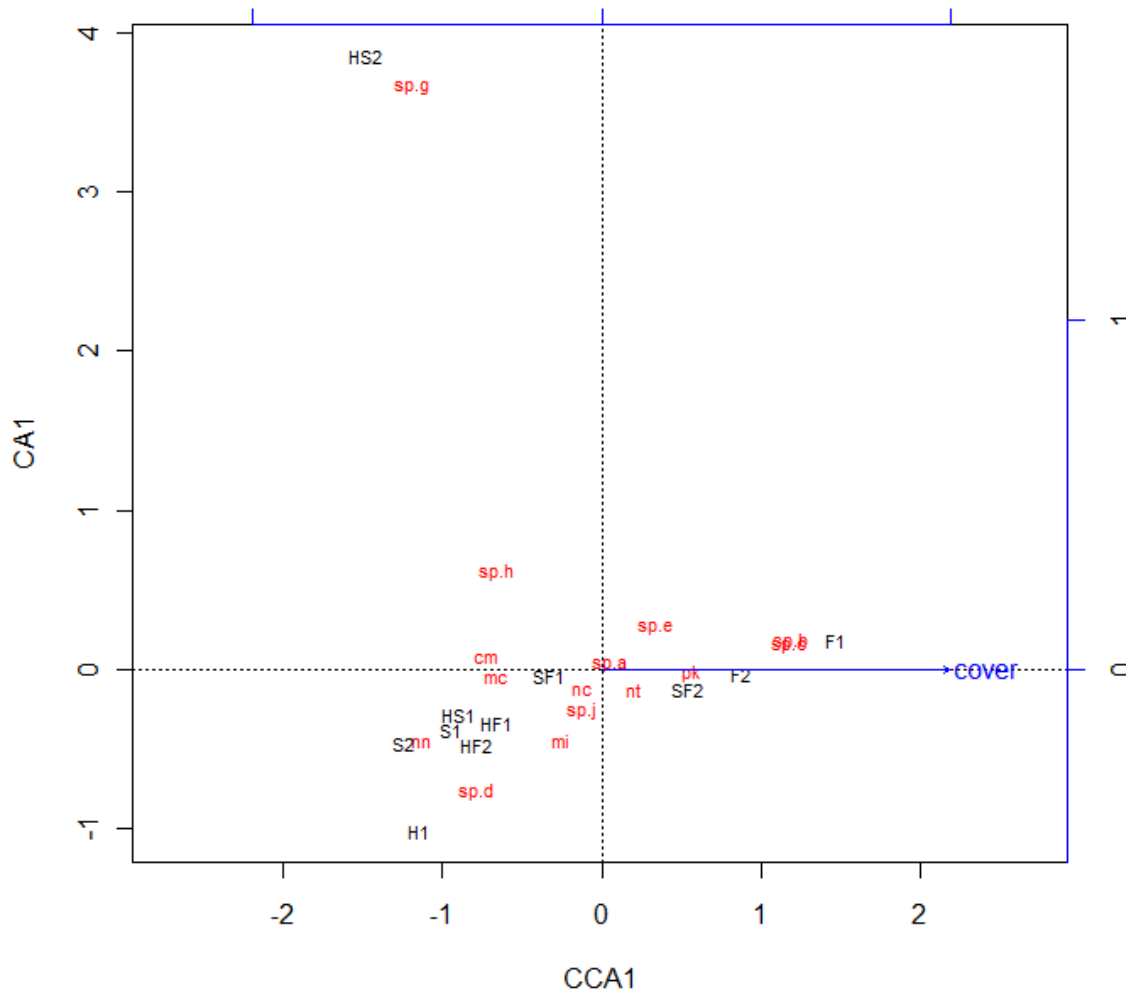
**Table 3.8** The mean values and standard deviation of pair wise Jaccard indices, using presence-absents microbat data.

	Jaccard similarity index				
	S	SF	HS	HF	H
SF	0.3±0.12				
HS	0.21±0.1	0.32±0.17			
HF	0.17±0.01	0.25±0.12	0.16±0.1		
H	0.26±0.02	0.37±0.19	0.34±0.05	0.17±0.11	
F	0.65±0.08	0.64±0.03	0.64±0.1	0.6±0.08	0.54±0.06

*Sugarcane (S), Sugarcane close to forest (SF), home garden in sugarcane landscape type (HS), home garden close to forest in sugarcane landscape type (HF), home garden landscape type (H) and forest (F).*

The Jaccard similarity index for presence-absence data (table 3.8) show that all habitats are quite similar to forest, ranging from 0.65±0.08 in sugarcane to 0.54±0.06 in home garden landscape. And home garden landscape habitats are most similar to forest habitats (0.54±0.06). Cover is the only variable to significantly explain the variation in the micro bat composition (CCA with forward selection, P=0.005). Percentage of canopy cover explains 31% of the total variance in the microbat species composition. Since only one variable is significant the species and site scores (figure 3.5) indicate how they are situated along this variable, which is local tree cover percentage. Sugarcane landscape type and home garden landscape type sites are quite similar. And home garden close to forest and home garden in sugarcane landscape sites are also situated close to these two. HS2 and H1 are outliers on the second axis. Distance is not significant in explaining any of the variance (P= 0.31). Wind (P=0.07667) was close to being significant.

## Results



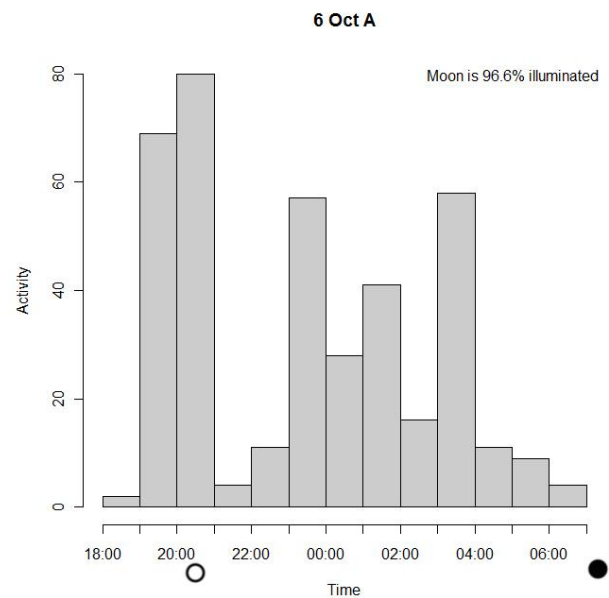
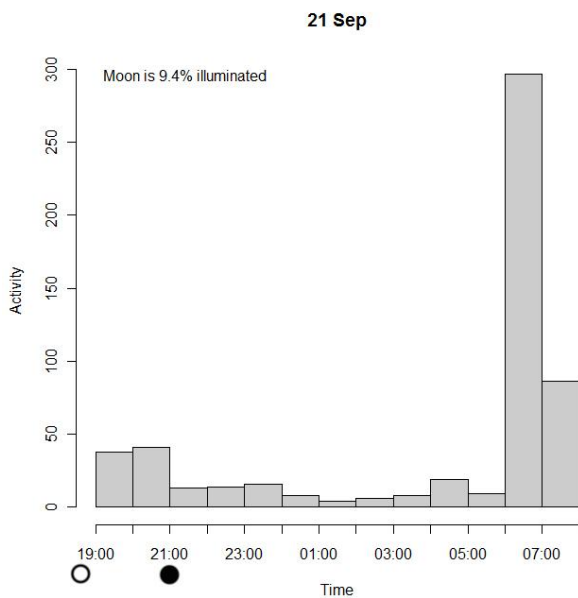
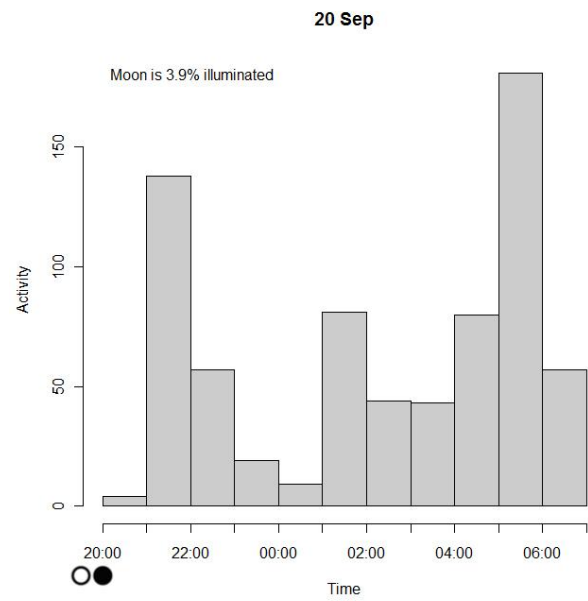
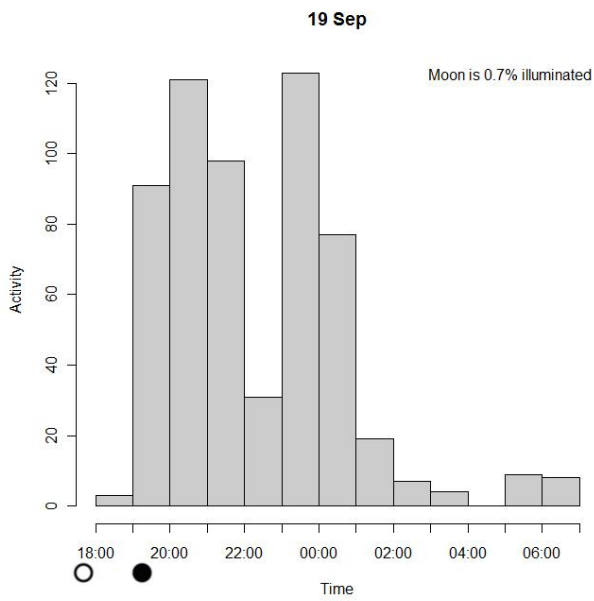
**Figure 3.5** CCA of the variation in microbat species composition in the different sites, with canopy cover as a constrained variable. Species are marked in red and sites in black. Sugarcane (S), Sugarcane close to forest (SF), home garden in sugarcane landscape type (HS), home garden close to forest in sugarcane landscape type (HF), home garden landscape type (H) and forest (F).

### 3.3 Whole night sampling.

Microbat activity varied considerably both within and between nights (figure 3.6). Total activity varied from 465 bat passes (6<sup>th</sup> October) to 1018 bat passes (28<sup>th</sup> November). The distribution of the activity also varied through the nights, from relatively constant activity to patterns with one or more distinct peaks. In the nights when the moon's illumination is close to 0%, the microbat activity seems to follow a pattern of more activity early in the night, and a second period of activity early in the morning before the sun comes up (figure 3.6). On the 21<sup>st</sup> September the moon had more illumination (9.4%) and set at 20:59, and

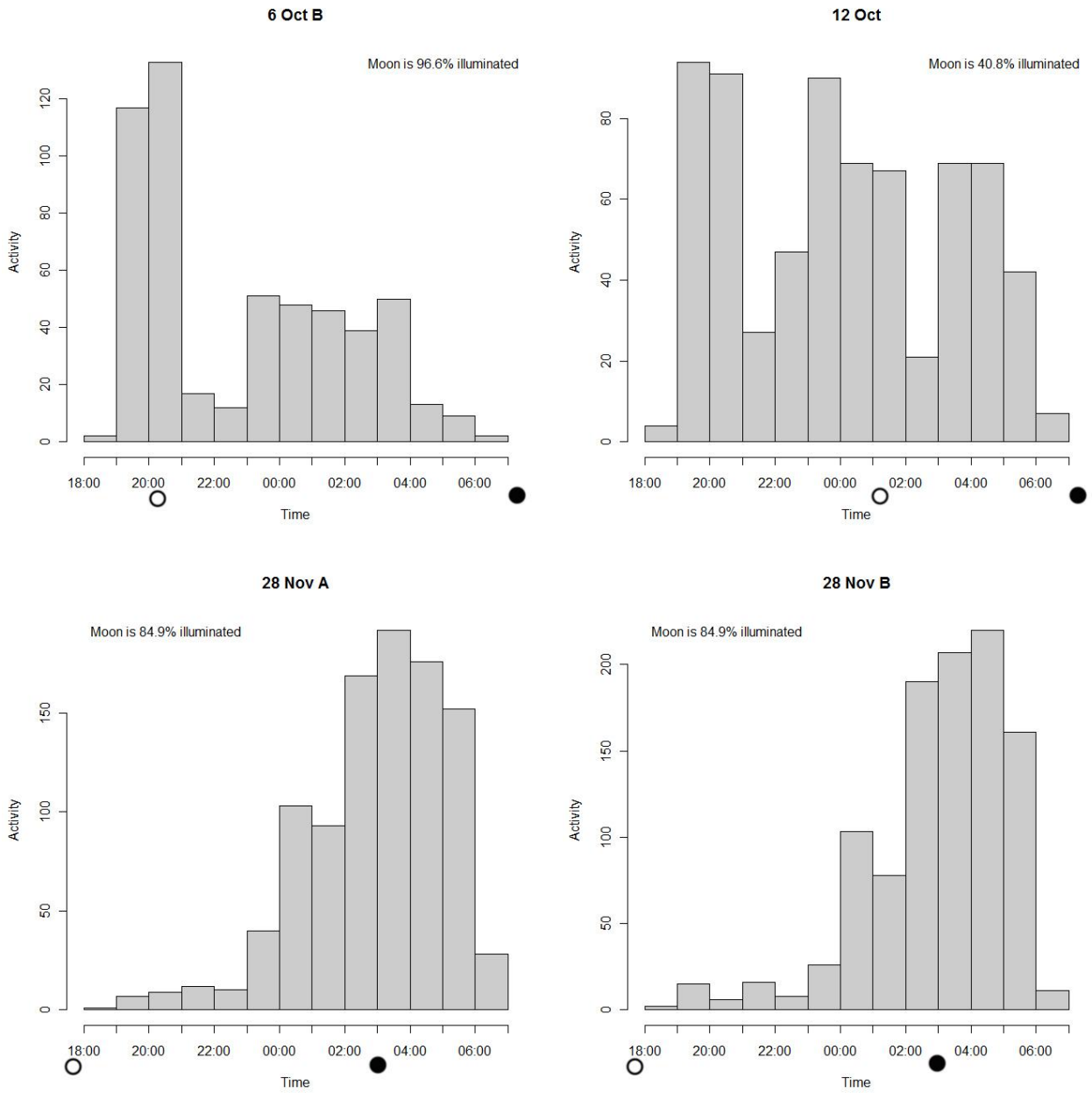
## Results

only a period of early morning activity was recorded. On the 6<sup>th</sup> October the moon was almost full and out from 20:27 and throughout the night. A period of activity in the hours before moonrise can be seen. In the last two histograms the moon sets at 02:54, and there is almost no activity before 02:00, and no distinct period of activity in the hours after sunset. The microbat activity follows the moons illumination. And on nights when the moon is close to being full, the bat activity changes to either the hours before moonrise or after the moon has set.





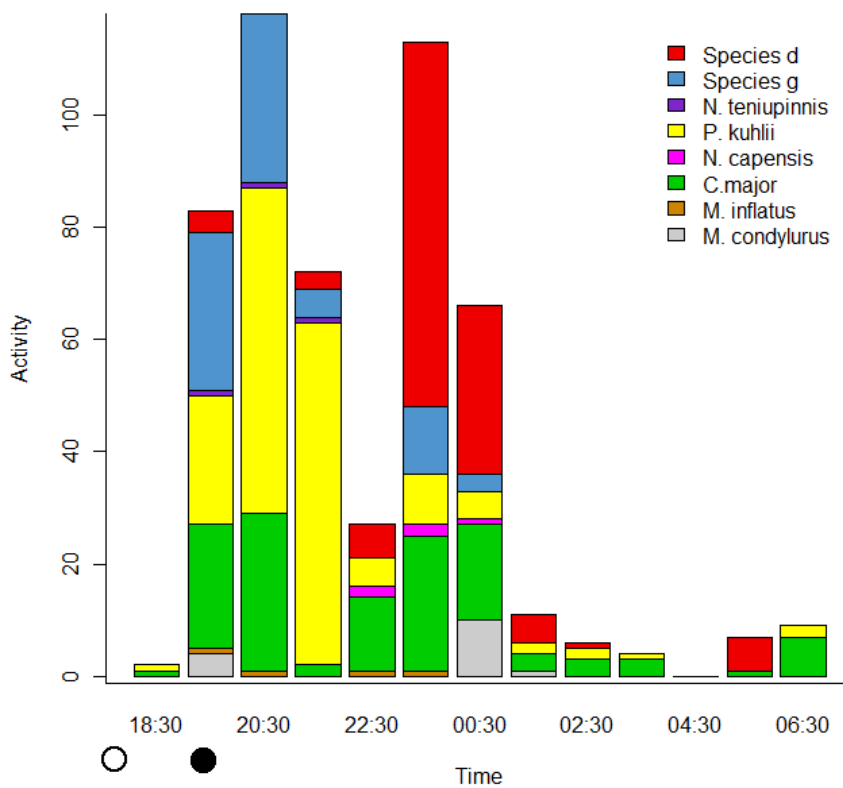
## Results



**Figure 3.6** Bat activity sampled over a whole night on six nights with different moonsets, moonrises and illumination. The moonrise is symbolized by the white circle and the moonset by the black. If the moon rises or sets before or after the time interval of the sampling, the symbol is placed on the end of the time axis. The moon is visible between the white and the black circles.

## Results

Figure 3.7 shows when the different species are active throughout the night of 19<sup>th</sup> September. The different species clearly show different patterns in their nightly activity. *Pipistrellus khulii* dominates the activity before 22:00. *Species g* also seems to be more dominant early in the night and *N. tenuipinnis* also disappears after 22:00. After 23:00 a new species, *Species d* takes over as the dominant species. *C. major* and *M. inflatus* are both quite constant until 01:00, when their activity drops. *M. condylurus* is out during the first hour of the night and also the two hours after midnight. The moon set early in the night so it should have little effect on variation in species composition.



**Figure 3.7** The activity of different microbat species sampled over the duration of a whole night, Budongo field station. The moon is 0.7% illuminated.

## 4. Discussion.

### 4.1 Land use study

The 16 species sampled in this study compares well to other studies done on bats in Africa. In Western African rainforests 20-22 species are typically reported (Monadjem and Fahr, 2007). Published ANABAT recordings of African bats are limited. But some work has been done in recent years on different species and locations, for example the identification of echolocation calls of a number of rhinolophids and hipposiderids in Swaziland (Monadjem et al., 2007), and also a number of species in Western Uganda (Monadjem et al., Unpublished). The bat calls in this study compares well with the few that have previously reported. *N. nanus* has a  $F_c$  around 74 kHz, as reported by Taylor (2000) but is a lower frequency than the 79 kHz found at other sites in Western Uganda (Monadjem et al., Unpublished). To be able to do more effective studies of the habitat preferences in Africa using bat detectors, it is quite clear that more work has to be done to construct a comprehensive echolocation call library.

In this study the home garden sites, a landscape with a large number of trees and a heterogeneous habitat, represents a landscape that would become increasingly common under a land sharing scenario. In contrast, the sugarcane sites - homogenous, high intensity monoculture plantations - represent a landscape that would become increasingly common under a land sparing scenario. The microbat data shows that both habitats are very similar in species richness and they are higher than in the forest habitat sites. This parallels the bat studies used in Bhagwat et al. (2008). Where Faria et al., (2006) and Harvey and Villalobos (2007) reported a higher percentage of species richness (139%) in the agroforestry systems than in the forest. Species richness was calculated as percentage of the species found in agroforestry to species found in forest. Using the same formulae the richness for sugarcane landscape type around Budongo is 120% while it is 100% for home garden landscape type. In terms of species richness a more heterogeneous landscape does not conserve microbats better than a plantain monoculture. So a future land sharing system will not be able to conserve more species rich assemblages of insectivorous bats than a land sparing system.

The largest difference between the three main habitats (sugarcane landscape type, homegarden landscape type and forest.) in this study is the activity. Forest and home

garden landscape type habitats have higher activity than sugarcane landscape type habitat. Both bat studies used in Bhagwat et al. (2008) are mistnetting studies, so they use abundance instead of activity, and their results differ in respect to abundance in forest compared to agriculture habitats. Faria et al. (2006) captured 4 times more bats in their Cabruca (agroforestry habitat) sites than in the forest, while Harvey and Villalobos (2007) found that abundance did not vary significantly between habitats. The same pattern can also be seen in an acoustic study in the rainforest of Madagascar where the activity was highest in human-modified areas outside of the forest (Randrianandrianina et al., 2006). This can indicate that my forest sites might be biased because of their location on roads going through the forest. Bats are known to use roads, trails and parts of the rainforest understory with little clutter (Law and Chidel, 2002), so a “tunneling” effect might explain the high activity of microbats in the forest sites of my study. Also the differences between mistnetting and acoustic surveying can reflect variation in the way fruitbats and microbats use an agroforestry landscape.

Bats are very mobile, and are able to use a diverse range of habitats. So for an agricultural landscape to be effective in conserving the biodiversity that is threatened by human activities it should be able to retain the species that are dependent on a forested landscape. The composition of the home garden landscape type sites and sugarcane landscape type sites are similar, but are different from the communities found in the forest. The mean similarity for bat communities between forest and agroforestry sites in the review by Bhagwat et al. (2008) is 61%, while in this study the similarity of sugarcane and forest is 65% and home garden and forest is 54%. So the potential for conserving microbats is a little better in land sparing landscapes than land sharing landscapes according to this index.

The microbat species that use forest edges are dependent on a forested habitat. *Miniopterus inflatus* and *Species d* are more active on the forest edge habitats than in the same habitat further from the forest. They also have high activity in the home garden landscape site. *Species d* is the third most recorded species and 65% of this activity is in the home garden landscape site. A more diverse agricultural landscape with a greater number of trees is more suited for *M. inflatus* and *Species d* in this study. Many species of microbats are known to forage along edges (Grindal and Brigham, 1999) and the land sharing landscape in this study better supports these forest edge species.

The microbats around Budongo do not use the home garden sites inside the sugarcane landscape more actively than the surrounding sugarcane plantations. There are no significant differences in the activity, species richness and diversity of the sugarcane and the home garden in sugarcane sites. This is in contrast to what has been reported by other studies. Lumsden and Bennett (2005) found significantly higher microbat activity in treed patches than the open paddocks devoid of trees inside active farming areas in Australia. These trees are valuable roosting habitats for bats in different parts of the world (Lumsden et al., 2002). Both the sugarcane and the home gardens in sugarcane sites have low levels of microbat activity. These home gardens are not more used by bats than the surrounding sugarcane, but they might improve the overall sugarcane landscape as microbat habitat.

Forest bat communities are often categorized into different classes according to their different foraging behavior, morphology and echolocation calls (Aldridge and Rautenbach, 1987; Crome and Richards, 1988). The low species richness in the forest can be explained as a sampling bias. The forest is a much more complex habitat than home gardens or monoculture cash crops. Bats are known to forage at specific heights, with different species showing a constant order of use in the vertical stratification (Bernard, 2001). A strong allocation of food resources is found in tropical bat communities (McNab, 1971). As the sampling in the forest sites was done on roads, it will be the species that are more adapted to open habitats that are sampled, and many of the different foraging classes found in the forest will not have been sampled. For example some species are found above the canopy and the detectors would not be able to sample these individuals, and similarly for species that are clutter foragers, that would be found deeper into the forest. When using mistnets in the same forest sites as this study, Kityo (2008) caught 13 species of microbats, of these only two were recorded in this acoustic study. Of the six known species recorded in my study only two were caught in Kityo's study, and it should be noted that four species sampled in my study are unknown. Most notably, 43% of all his captures were *Rhinolophus alcyone*, a forest clutter species that was not recorded in the forest sites of this study, although two individuals were recorded inside the strict nature reserve on the 7<sup>th</sup> October. The reason for this variation might be that Kityo (2008) sampled farther into the forest, or down by the Sonso river, where the communities would be expected to be different. Or the two sample methods are so different that to get a complete picture of the bat communities of a forest both acoustic and capture techniques have to be used.

## 4.2 Whole night sampling.

In two of the whole nights sampled without influence from the moon we can see a period of about two hours with great activity after sundown and a drop in activity can be seen after about 22:00. Likewise a second time of activity is seen just before sunrise on some of the nights. Many studies have documented two peaks of insect activity during the night (Rautenbach et al., 1988; Rydell et al., 1996; Meyer et al., 2004). The time microbats become active appears to be a trade-off between the availability of prey and predation risk (Jones and Rydell, 1994). In the tropics, lunar phobia is thought to be widespread, especially in fruitbats (Fleming and Heithaus, 1986). It has also been suggested for insectivorous species in Africa (Fenton et al., 1977; Meyer et al., 2004), in contrast to temperate regions where there are no examples of lunar phobia in microbats (Hayes, 1997; Karlsson et al., 2002). The lunar phobic activity of tropical bat species is thought to be a consequence of pressure from aerial predators that are not found in higher latitudes (Fenton et al., 1977; Rydell et al., 1996). If this is the case, then a landscape that has greater tree cover and more structural diversity could have greater conservation value than an open landscape. But we must remember that a forest sparing landscape also consists of an intact block of forest, which at least will provide cover for the forest species.

Different species have developed individual foraging times, with the result that interspecific competition is minimized. Additionally, some species can be using the area around the site as roosting sites but forage in other habitats, consequently higher activity is recorded when the bats fly from their roost after sundown and when they come back to their roosts before sunrise. When looking at how the moon affects bat activity, activity is lower on nights with higher luminosity, and on one night microbat activity was delayed until after the moon had set at 03:00.

Variation in foraging times will make some species overrepresented with the sampling methods used in this study. Unless one is able to sample during the whole duration of microbat activity, it is as good to sample the first three hours after dark as any other time during the night. The whole nights sampled show a high amount of variability, the source of this variation is unknown, although temporal variation is known to affect microbat activity (Hayes, 1997). So to get a proper estimation of the richness, diversity, composition and activity of a site many sampling nights must be used, unless this variation can be accounted for.

### **4.3 Call parameters.**

When identifying microbat species by their echolocation calls, one must be aware that there can be intra species variation (Obrist, 1995). The traits of bat calls are known to vary between different places (Barclay et al., 1999), with flight situation (Berger-Tal et al., 2008) and with habitat structure (Kalko and Schnitzler, 1993). Much of this variation is small, and using calls from different location makes accurate identifications possible (Murray et al., 2001).

For my study, I had a library of sixteen microbat echolocation calls collected by Robert Kityo from different forests in Uganda, but Budongo was not included in his study. I was only able to positively identify seven microbat species and nine distinct bats calls had to be categorised and given a letter from A to I. The random forest correctly identified species in at least 70% of the calls or above 90% with unknown species excluded. This is the same as previous qualitative studies in other parts of the world (Berger-Tal et al., 2008; Kofoky et al., 2009), and automatic identification of the microbat fauna in and around Budongo forest would be possible.

## 5. Conclusions.

The species richness data suggest that, outside of the forest a land sparing landscape is able to retain the same amount of microbat species as a land sharing landscape, but the activity suggests that the latter habitat is more used by the microbats. The main ecosystem service provided by microbats is consumption of insects that provide a threat to crops (Cleveland et al., 2006) or humans. A habitat that supports larger microbat activity will limit more crop pests and might also help limit malaria carrying mosquitos, if these are consumed by microbats in the area. So a land sharing type heterogeneous landscape is able to better maintain and improve ecosystem services than a land sparing landscape. The microbats in this study exhibit lunar phobia. If this is a consequence of predator pressure, more open habitats could make bats more vulnerable to predation, and a land sharing landscape with a greater number of trees will provide bats with more cover, thus could have larger conservation value than an open plantation monoculture landscape. The species richness and diversity found in agricultural landscapes seems to indicate that microbats are less affected by habitat conversion than other fauna, but a land sharing landscape outside of the forest shows greater conservation value for microbats than a land sparing landscape around Budongo forest.



## References:

- Aldridge, H. and I. L. Rautenbach (1987). Morphology, echolocation and resource partitioning in insectivorous bats. *Journal of Animal Ecology* **56**, 763-778.
- Altringham, J. D. (1998). Bats: biology and behaviour. Oxford, Oxford University Press.
- Antongiovanni, M. and J. P. Metzger (2005). Influence of matrix habitats on the occurrence of insectivorous bird species in Amazonian forest fragments. *Biological Conservation* **122**, 441-451.
- Arnett, E. B. (2003). Advancing science and partnerships for the conservation of bats and their habitats. *Wildlife Society Bulletin* **31**, 2-5.
- Ashley, R., D. Russell and B. Swallow (2006). The policy terrain in protected area landscapes: Challenges for agroforestry in integrated landscape conservation. *Biodiversity and Conservation* **15**, 663-689.
- Balmford, A., R. E. Green and J. P. W. Scharlemann (2005). Sparing land for nature: Exploring the potential impact of changes in agricultural yield on the area needed for crop production. *Global Change Biology* **11**, 1594-1605.
- Barclay, R. M. R., J. H. Fullard and D. S. Jacobs (1999). Variation in the echolocation calls of the hoary bat (*Lasiurus cinereus*): influence of body size, habitat structure, and geographic location. *Canadian Journal of Zoology-Revue Canadienne De Zoologie* **77**, 530-534.
- Bawa, K. S. and S. Dayanandan (1997). Socioeconomic factors and tropical deforestation. *Nature* **386**, 562-563.
- Berger-Tal, O., R. Berger-Tal, C. Korine, M. W. Holderied and M. B. Fenton (2008). Echolocation calls produced by Kuhl's pipistrelles in different flight situations. *Journal of Zoology* **274**, 59-64.
- Bernard, E. (2001). Vertical stratification of bat communities in primary forests of Central Amazon, Brazil. *Journal of Tropical Ecology* **17**, 115-126.
- Bhagwat, S. A. and C. Rutte (2006). Sacred groves: Potential for biodiversity management. *Frontiers in Ecology and the Environment* **4**, 519-524.
- Bhagwat, S. A., K. J. Willis, H. J. B. Birks and R. J. Whittaker (2008). Agroforestry: A refuge for tropical biodiversity? *Trends in Ecology & Evolution* **23**, 261-267.
- Bradshaw, C. J. A., N. S. Sodhi and B. W. Brook (2009). Tropical turmoil: A biodiversity tragedy in progress. *Frontiers in Ecology and the Environment* **7**, 79-87.
- Breiman, L. (2001). Random forests. *Machine Learning* **45**, 5-32.
- Chao, A., R. L. Chazdon, R. K. Colwell and T. J. Shen (2005). A new statistical approach for assessing similarity of species composition with incidence and abundance data. *Ecology Letters* **8**, 148-159.

- Chazdon, R. L., C. A. Harvey, O. Komar, D. M. Griffith, B. G. Ferguson, M. Martinez-Ramos, H. Morales, R. Nigh, L. Soto-Pinto, M. van Breugel and S. M. Philpott (2009). Beyond reserves: A research agenda for conserving biodiversity in human-modified tropical landscapes. *Biotropica* **41**, 142-153.
- CIA. (2010). "The World Factbook." Retrieved 23. May, 2010, from <https://www.cia.gov/library/publications/the-world-factbook/geos/ug.html>.
- Clark, D. R. (1981). Death in bats from DDE, DDT or dieldrin - diagnosis via residues in carcass fat. *Bulletin of Environmental Contamination and Toxicology* **26**, 367-374.
- Cleveland, C. J., M. Betke, P. Federico, J. D. Frank, T. G. Hallam, J. Horn, J. D. López, G. F. McCracken, R. A. Medellín, A. Moreno-Valdez, C. G. Sansone, J. K. Westbrook and T. H. Kunz (2006). Economic value of the pest control service provided by Brazilian free-tailed bats in south-central Texas. *Frontiers in Ecology and the Environment* **4**, 238-243.
- Colwell, R. K. and J. A. Coddington (1994). Estimating terrestrial biodiversity through extrapolation. *Philosophical Transactions: Biological Sciences* **345**, 101-118.
- Corben, C. (2006). AnalookW. 3.3q. from [http://users.lmi.net/corben/WinAnalook.htm#AnaLookW\\_Content](http://users.lmi.net/corben/WinAnalook.htm#AnaLookW_Content).
- Crome, F. H. J. and G. C. Richards (1988). Bats and gaps - microchiropteran community structure in a Queensland rain-forest. *Ecology* **69**, 1960-1969.
- Eggeling, W. J. (1947). Observations on the ecology of the Budongo rain forest, Uganda. *Journal of Ecology* **34**, 20-&.
- Estrada, A., R. Coatesestrada and D. Meritt (1993). Bat species richness and abundance in tropical rain-forest fragments and in agricultural habitats at Los-Tuxtlas, Mexico. *Ecography* **16**, 309-318.
- FAO (2006). Global forest resources assessment 2005. Rome, Food and Agriculture Organization of the United Nations.
- FAO (2009). State of the World's Forests. Rome, Food and Agriculture Organization of the United Nations.
- Faria, D., R. R. Laps, J. Baumgarten and M. Cetra (2006). Bat and bird assemblages from forests and shade cacao plantations in two contrasting landscapes in the Atlantic Forest of southern Bahia, Brazil. *Biodiversity and Conservation* **15**, 587-612.
- Fenton, B. M., D. H. M. Cumming, I. L. Rautenbach, G. S. Cumming, M. S. Cumming, G. Ford, R. D. Taylor, J. Dunlop, M. D. Hovorka, D. S. Johnston, C. V. Portfors, M. C. Kalcounis and Z. Mahlanga (1998). Bats and the loss of tree canopy in African woodlands. *Conservation Biology* **12**, 399-407.
- Fenton, M. B., L. Acharya, D. Audet, M. B. C. Hickey, C. Merriman, M. K. Obrist, D. M. Syme and B. Adkins (1992). Phyllostomid bats (Chiroptera-Phyllostomidae) as indicators of habitat disruption in the neotropics. *Biotropica* **24**, 440-446.
- Fenton, M. B. and G. P. Bell (1981). Recognition of species of insectivorous bats by their echolocation calls. *Journal of Mammalogy* **62**, 233-243.

- Fenton, M. B., D. H. M. Cumming and D. J. Oxley (1977). Prey of bat hawks and availability of bats. *Condor* **79**, 495-497.
- Fisher, B. and T. Christopher (2007). Poverty and biodiversity: Measuring the overlap of human poverty and the biodiversity hotspots. *Ecological Economics* **62**, 93-101.
- Fleming, T. H. and E. R. Heithaus (1986). Seasonal foraging behavior of the frugivorous bat *Carollia perspicillata*. *Journal of Mammalogy* **67**, 660-671.
- Foley, J. A., R. DeFries, G. P. Asner, C. Barford, G. Bonan, S. R. Carpenter, F. S. Chapin, M. T. Coe, G. C. Daily, H. K. Gibbs, J. H. Helkowski, T. Holloway, E. A. Howard, C. J. Kucharik, C. Monfreda, J. A. Patz, I. C. Prentice, N. Ramankutty and P. K. Snyder (2005). Global consequences of land use. *Science* **309**, 570-574.
- Furlonger, C. L., H. J. Dewar and M. B. Fenton (1987). Habitat use by foraging insectivorous bats. *Canadian Journal of Zoology-Revue Canadienne De Zoologie* **65**, 284-288.
- Gardner, T. A., J. Barlow, R. Chazdon, R. M. Ewers, C. A. Harvey, C. A. Peres and N. S. Sodhi (2009). Prospects for tropical forest biodiversity in a human-modified world. *Ecology Letters* **12**, 561-582.
- Green, R. E., S. J. Cornell, J. P. W. Scharlemann and A. Balmford (2005). Farming and the fate of wild nature. *Science* **307**, 550-555.
- Grindal, S. D. and R. M. Brigham (1999). Impacts of forest harvesting on habitat use by foraging insectivorous bats at different spatial scales. *Ecoscience* **6**, 25-34.
- Harvey, C. A. and J. A. G. Villalobos (2007). Agroforestry systems conserve species-rich but modified assemblages of tropical birds and bats. *Biodiversity and Conservation* **16**, 2257-2292.
- Hayes, J. P. (1997). Temporal variation in activity of bats and the design of echolocation-monitoring studies. *Journal of Mammalogy* **78**, 514-524.
- Hecker, K. R. and R. M. Brigham (1999). Does moonlight change vertical stratification of activity by forest-dwelling insectivorous bats? *Journal of Mammalogy* **80**, 1196-1201.
- Hill, M. O. and H. G. Gauch (1980). Detrended Correspondence-Analysis - an improved ordination technique. *Vegetatio* **42**, 47-58.
- Howard, P. C. (1991). Nature conservation in Uganda's tropical reserves. Gland, Switzerland, IUCN.
- Howard, P. C., T. R. B. Davenport, F. W. Kigenyi, P. Viskanic, M. C. Baltzer, C. J. Dickinson, J. Lwanga, R. A. Matthews and E. Mupada (2000). Protected area planning in the tropics: Uganda's national system of forest nature reserves. *Conservation Biology* **14**, 858-875.
- Hurlbert, S. H. (1971). The nonconcept of species diversity: A critique and alternative parameters. *Ecology* **52**, 577-586.
- Hutson, A. M., S. P. Mickleburgh and P. A. Racey (2001). Microchiropteran bats: Global status survey and conservation action plan., IUCN, Gland, Switzerland and Cambridge, UK.
- Johnson, J. B., M. A. Menzel, J. W. Edwards and W. M. Ford (2002). A comparison of 2 acoustical bat survey techniques. *Wildlife Society Bulletin* **30**, 931-936.

## References

- Jones, G. and J. Rydell (1994). Foraging strategy and predation risk as factors influencing emergence time in echolocating bats. *Philosophical Transactions of the Royal Society B-Biological Sciences* **346**, 445-455.
- Jones, G. and S. M. Vanparijs (1993). Bimodal echolocation in Pipistelle bats - are cryptic species present. *Proceedings of the Royal Society of London Series B-Biological Sciences* **251**, 119-125.
- Kalka, M. B., A. R. Smith and E. K. V. Kalko (2008). Bats limit arthropods and herbivory in a tropical forest. *Science* **320**, 71-71.
- Kalko, E. K. V. and H. U. Schnitzler (1993). Plasticity in echolocation signals of European Pipistelle bats in search flight - implication for habitat use and prey detection. *Behavioral Ecology and Sociobiology* **33**, 415-428.
- Karlsson, B. L., J. Eklof and J. Rydell (2002). No lunar phobia in swarming insectivorous bats (family Vespertilionidae). *Journal of Zoology* **256**, 473-477.
- Kityo, R. (2008). Bat communities in some disjunct areas of Central and Western Uganda: Implications for their conservation. *Zoology*. Kampala, Makerere. **Ph.D.**
- Kityo, R. and J. C. Kerbis (1996). Observations on the distribution and ecology of bats in Uganda. *Journal of East African Natural History* **85**, 49-63.
- Kofoky, A. F., F. Randrianandrianina, J. Russ, I. Raharinantenaina, S. G. Cardiff, R. K. B. Jenkins and P. A. Racey (2009). Forest bats of Madagascar: Results of acoustic surveys. *Acta Chiropterologica* **11**, 375-392.
- Laurance, W. F. (1999). Reflections on the tropical deforestation crisis. *Biological Conservation* **91**, 109-117.
- Law, B. and M. Chidel (2002). Tracks and riparian zones facilitate the use of Australian regrowth forest by insectivorous bats. *Journal of Applied Ecology* **39**, 605-617.
- Legendre, P. and L. Legendre (1998). Numerical ecology. Amsterdam, Elsevier.
- Lumsden, L. F. and A. F. Bennett (2005). Scattered trees in rural landscapes: Foraging habitat for insectivorous bats in south-eastern Australia. *Biological Conservation* **122**, 205-222.
- Lumsden, L. F., A. F. Bennett and J. E. Silins (2002). Location of roosts of the lesser long-eared bat *Nyctophilus geoffroyi* and Gould's wattled bat *Chalinolobus gouldii* in a fragmented landscape in south-eastern Australia. *Biological Conservation* **106**, 237-249.
- MacSwiney, M. C., F. M. Clarke and P. A. Racey (2008). What you see is not what you get: The role of ultrasonic detectors in increasing inventory completeness in Neotropical bat assemblages. *Journal of Applied Ecology* **45**, 1364-1371.
- Markus Loecher and Sense Networks. (2009). RgoogleMaps: Overlays on google map tiles in R. R package version 1.1.8. from <http://cran.r-project.org/web/packages/RgoogleMaps/index.html>.
- McNab, B. K. (1971). Structure of tropical bat faunas. *Ecology* **52**, 352-&.
- MEA (2005). Ecosystems and human well-being: Biodiversity synthesis. Millenium Ecosystem Assessment. Washington DC, World Resources Institute.

- Medellin, R. A., M. Equihua and M. A. Amin (2000). Bat diversity and abundance as indicators of disturbance in neotropical rainforests. *Conservation Biology* **14**, 1666-1675.
- Meyer, C. F. J., C. J. Schwarz and J. Fahr (2004). Activity patterns and habitat preferences of insectivorous bats in a West African forest-savanna mosaic. *Journal of Tropical Ecology* **20**, 397-407.
- Mickleburgh, S. P., A. M. Hutson and P. A. Racey (2002). A review of the global conservation status of bats. *Oryx* **36**, 18-34.
- Monadjem, A. and J. Fahr (2007). Rapid survey of bats of North Lorma, Gola and Grebo National Forests, with notes on shrews and rodents. A Rapid Biological Assessment of North Lorma, Gola and Grebo National Forests, Liberia, Conservation International.
- Monadjem, A., M. Rasmussen and D. C. Van Der Made (Unpublished). Echolocation calls and wing morphology of selected bats in Western Uganda.
- Monadjem, A. and A. Reside (2008). The influence of riparian vegetation on the distribution and abundance of bats in an African savanna. *Acta Chiropterologica* **10**, 339-348.
- Monadjem, A., A. Reside and L. Lumsden (2007). Echolocation calls of rhinolophid and hipposiderid bats in Swaziland. *South African Journal of Wildlife Research* **37**, 9-15.
- Murray, K. L., E. R. Britzke and L. W. Robbins (2001). Variation in search-phase calls of bats. *Journal of Mammalogy* **82**, 728-737.
- Mwavu, E. N. and E. T. F. Witkowski (2008). Land-use and cover changes (1988-2002) around Budongo Forest Reserve, NW Uganda: Implications for forest and woodland sustainability. *Land Degradation & Development* **19**, 606-622.
- Myers, N., R. A. Mittermeier, C. G. Mittermeier, G. A. B. da Fonseca and J. Kent (2000). Biodiversity hotspots for conservation priorities. *Nature* **403**, 853-858.
- New, T. R. (2004). Moths (Insecta: Lepidoptera) and conservation: Background and perspective. *Journal of Insect Conservation* **8**, 79-94.
- Noss, R. F. (1990). Indicators for monitoring biodiversity - a hierarchical approach. *Conservation Biology* **4**, 355-364.
- O'Farrell, M. J. and W. L. Gannon (1999). A comparison of acoustic versus capture techniques for the inventory of bats. *Journal of Mammalogy* **80**, 24-30.
- Obrist, M. K. (1995). Flexible bat echolocation - The influence of individual, habitat and conspecifics on sonar signal-design. *Behavioral Ecology and Sociobiology* **36**, 207-219.
- Paterson, J. D. (1991). The ecology and history of Uganda's Budongo forest. *Forest & Conservation History* **35**, 179-187.
- Perfecto, I. and J. Vandermeer (2002). Quality of agroecological matrix in a tropical montane landscape: Ants in coffee plantations in Southern Mexico. *Conservation Biology* **16**, 174-182.
- Plumptre, A. J., M. Behangana, E. Ndomba, T. Davenport, C. Kahindo, R. Kityo, P. Ssegawa, G. Eilu, D. Nkuutu and I. Owionji (2003). The Biodiversity of the Albertine Rift. *Albertine Rift Technical Report Series* **3**.

- Plumptre, A. J. and V. Reynolds (1994). The effect of selective logging on the primate population in the Budongo forest reserve, Uganda. *Journal of Applied Ecology* **31**, 631-641.
- R Development Core Team (2010). R: A language and environment for statistical computing, R Foundation for Statistical Computing.
- Randrianandrianina, F., D. Andriafidison, A. F. Kofoky, O. Ramilijaona, F. Ratriomomanarivo, P. A. Racey and R. K. B. Jenkins (2006). Habitat use and conservation of bats in rainforest and adjacent human-modified habitats in eastern Madagascar. *Acta Chiropterologica* **8**, 429-437.
- Rautenbach, I. L., M. B. Fenton and M. J. Whiting (1996). Bats in riverine forests and woodlands: A latitudinal transect in southern Africa. *Canadian Journal of Zoology-Revue Canadienne De Zoologie* **74**, 312-322.
- Rautenbach, I. L., A. C. Kemp and C. H. Scholtz (1988). Fluctuations in availability of arthropods correlated with microchiropteran and avian predator activities. *Koedoe* **31**, 77-90.
- Ricketts, T. H. (2001). The matrix matters: Effective isolation in fragmented landscapes. *The American Naturalist* **158**, 87-99.
- Ricketts, T. H., G. C. Daily, P. R. Ehrlich and J. P. Fay (2001). Countryside biogeography of moths in a fragmented landscape: Biodiversity in native and agricultural habitats. *Conservation Biology* **15**, 378-388.
- Rydell, J., A. Entwistle and P. A. Racey (1996). Timing of foraging flights of three species of bats in relation to insect activity and predation risk. *Oikos* **76**, 243-252.
- Sheil, D. (1997). Long-term growth and rainfall in a Ugandan moist forest: Seasonal rhythms and flexing stems. *Commonwealth Forestry Review* **76**, 121-127.
- Singleton, F. (2008). The Beaufort scale of winds - its relevance, and its use by sailors. *Weather* **63**, 37-41.
- Soto-Pinto, L., I. Perfecto, J. Castillo-Hernandez and J. Caballero-Nieto (2000). Shade effect on coffee production at the northern Tzeltal zone of the state of Chiapas, Mexico. *Agriculture Ecosystems & Environment* **80**, 61-69.
- Taylor, P. J. (2000). Bats of Southern Africa. Scottsville, University of Natal Press.
- Time and Date. (2010). "Moonrise, Moonset and Moonphase for Uganda." Retrieved 24. May, 2010, from <http://www.timeanddate.com/worldclock/astronomy.html?obj=moon&n=115>.
- Weller, T. J. and C. J. Zabel (2002). Variation in bat detections due to detector orientation in a forest. *Wildlife Society Bulletin* **30**, 922-930.
- Williams-Guillen, K., I. Perfecto and J. Vandermeer (2008). Bats limit insects in a neotropical agroforestry system. *Science* **320**, 70-70.
- Wilson, D. E. D. and D. M. Reeder (2005). Mammal species of the world : A taxonomic and geographic reference Baltimore, Johns Hopkins University Press.

## Appendix I

The tables give the activity of each microbat species for each of the nights of sampling. The activity per night and per bat species is also totaled. The table has been divided up in two parts: the first part is the first 11 sampling nights, while the second part is the last 11.

	11.10	13.10	14.10	15.10	16.10	19.10	21.10	24.10	26.10	27.10	28.10	Total
<b>Family Molossidae</b>												
<i>Mops condylurus</i>	10	0	23	7	9	15	0	2	26	16	9	117
<i>Chaerephon major</i>	13	0	29	26	28	17	1	1	17	5	0	137
<b>Family Vespertilionidae</b>												0
<i>Miniopterus inflatus</i>	1	2	19	7	2	0	1	1	31	5	0	69
<i>Neoromicia capensis</i>	0	0	1	0	0	0	7	0	1	3	1	13
<i>Neoromicia nanus</i>	15	0	2	0	18	14	1	0	29	13	1	93
<i>Neoromicia tenuipinnis</i>	1	1	1	5	7	6	49	5	0	11	0	86
<i>Pipistrellus kuhlii</i>	7	89	17	28	6	2	138	71	9	9	0	376
<b>Unknown species</b>												0
<i>Species a</i>	0	0	1	1	4	1	12	0	3	7	1	30
<i>Species b</i>	0	136	0	0	0	0	1	0	0	0	0	137
<i>Species c</i>	0	37	0	0	0	0	22	0	0	0	0	59
<i>Species d</i>	4	0	16	16	12	1	0	0	11	7	0	67
<i>Species e</i>	1	2	0	1	0	0	0	0	1	0	0	5
<i>Species f</i>	0	0	0	0	1	0	0	0	0	0	0	1
<i>Species g</i>	0	0	6	4	2	2	0	1	0	0	5	20
<i>Species h</i>	0	0	0	0	0	0	0	0	0	0	1	1
<i>Species i</i>	2	0	44	0	0	0	0	9	0	0	0	55
<b>Total</b>	54	267	159	95	89	58	232	90	128	76	18	1266

## Appendix I continued.

	16.11	17.11	18.11	19.11	20.11	21.11	22.11	23.11	24.11	25.11	26.11	Total
<b>Family Molossidae</b>												
<i>Mops condylurus</i>	11	14	4	34	13	13	23	8	10	0	0	130
<i>Chaerephon major</i>	42	16	0	18	11	24	30	3	14	3	0	161
<b>Family Vespertilionidae</b>												0
<i>Miniopterus inflatus</i>	11	0	5	7	10	8	0	1	0	0	2	44
<i>Neoromicia capensis</i>	1	0	0	1	2	8	2	0	1	1	1	17
<i>Neoromicia nanus</i>	3	2	0	1	18	6	47	1	11	32	1	122
<i>Neoromicia tenuipinnis</i>	7	1	15	1	1	6	2	4	2	5	0	44
<i>Pipistrellus kuhlii</i>	14	5	223	10	12	44	31	69	13	2	157	580
<b>Unknown species</b>												0
<i>Species a</i>	0	2	0	2	0	0	0	0	5	0	13	22
<i>Species b</i>	0	0	100	0	0	0	0	0	0	0	0	100
<i>Species c</i>	0	0	94	0	0	0	0	0	0	0	0	94
<i>Species d</i>	14	1	0	28	179	1	3	0	1	0	0	227
<i>Species e</i>	0	1	5	1	0	0	0	0	0	0	0	7
<i>Species f</i>	0	6	6	0	0	0	0	0	0	0	0	12
<i>Species g</i>	2	2	0	1	0	3	2	0	3	0	0	13
<i>Species h</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Species i</i>	0	0	0	0	0	1	0	21	0	0	0	22
<b>Total</b>	105	50	452	104	246	114	140	107	60	43	174	1595



## Appendix II

The geographical coordinates of the eleven sites used for the acoustic bat study in the agricultural areas around Budongo, and inside the forest.

Site	UTM zone 36	
	Easting	Northing
Homegarden	326529	191523
Sugarcane I	338129	182835
Sugarcane II	341447	181631
Homegarden in sugarcane I	340291	181808
Homegarden in sugarcane II	338600	183965
Forest I	337588	189209
Forest II	331041	189025
Sugarcane close to forest I	332917	187763
Sugarcane close to forest II	339299	187128
Homegarden close to forest I	337935	187950
Homegarden close to forest II	336495	185614