MSc PROJECT ASSESSMENT FORM

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IS THERE A CORRELATION BETWEEN TENT OCCUPANCY AND ABUNDANCE OF TENT-ROOSTING BATS AND ENVIRONMENTAL FACTORS IN THE AREA OF CAÑO PALMA BIOLOGICAL STATION, LIMÓN, COSTA RICA?

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Abstract

This study aimed to investigate potential climatic effects on the behaviour of tent-roosting Phyllostomidae in lowland rainforest in the area of Tortuguero, Limón, Costa Rica. The rationale behind this project was to test whether any tent-roosting bat species found in the study area could possibly qualify as combined climate change and biodiversity indicators for this particular life zone. Since tent-roosting bats are instrumental for rainforest health, as they are major seed distributors, using them as potential early warning systems could have wider implications on rainforest survival. The study area consisted of a 20-metre wide corridor along an existing 1,050 m long mammal transect on the grounds of the Biological Station Caño Palma. In total, 86 tents were under investigation and tent occupancy varied from 3.51% to 19.05%. The focus lay in particular on tent occupancy of these frugivorous bats in relation to daily precipitation and temperature variation. It was to be seen whether there was any linkage between these two climatic indicators and bat ecology. To test this, linear correlations were computed that compared tent occupancy and tent abundance with recent precipitation and temperature variation. This offered no conclusive results of altered bat behaviour in relation to weather changes in the short-term. However, this does not mean that tent-roosting bats are not influenced by long-term climate changes and the results obtained could be used for long-term meta-analyses on the topic. In addition to weather data, the distance to the nearest waterway was compared against two rainforest types and with reference to tent height preference. The study area is situated on a flood plain and therefore prone to being partially under water. While one part is slightly more elevated and only occasionally flooded, the second part is a swamp forest regularly under water. Climate change models for the tropics predict that temperatures will rise and more extreme weather conditions will occur. Therefore considering a certain roosting distance from the canal taking into account height preference of occupied tents and forest

type, would cover the aspect of adaptation to extreme flooding. A two-way ANOVA of roosting distance to the canal according to tent height and forest type differences was calculated. The results showed that neither influencing factor (p=0.29 for tent height and p=0.33 for forest type respectively) was solely responsible for roost differentiation but in combination (p=0.02) showed clear preference for transitional forest and a tent height variation of 180-220 cm as combined roosting criteria. In essence, even though precipitation and temperature could not be shown to influence roosting behaviour, a clearer picture of roosting preference could be drawn from all the data collected. In hindsight, additional research is needed to truly prove the potential of tent-roosting bats as good bioindicators.

1. Introduction

1.1. Climate structure in Costa Rica and the study site

Costa Rica, situated well within the tropical belt, displays 12 different lifezones within the country, namely: Tropical Dry Forest, Tropical Wet Forest, Tropical Moist Forest, Premontane Moist Forest, Premontane Wet Forest, Premontane Rain Forest, Lower Montane Moist Forest, Lower Montane Wet Forest, Lower Montane Rain Forest, Montane Wet Forest, Montane Rain Forest and Subalpine Rain Paramo (Kohlmann, *et al.* 2010). The northern part of the Atlantic coast, in particular the area around Tortuguero, Limón, is characterised by a wet climate without distinguishable wet and dry seasons (Lewis *et al.* 2010). This is in line with Köppen-Geiger´s categorisation of wet rainforests, where precipitation never drops below 60 millimetres per month (Peel *et al.* 2007). While precipitation peaks twice in a year around the months of July and November/December, average monthly temperatures vary only by a few degrees. In the case of the Limón region, average minimum temperatures fluctuate between 21-23°C and average maximum temperatures between 29-31°C (taken from IMN 2013). Tortuguero National Park and Barra del Colorado Wildlife Refuge, both tropical wet forest sites near the Caribbean coast, comprise primary and secondary rainforest and are located close to fresh water streams (Lewis *et al.* 2010 and Hulatt, unpublished report). Wildlife thrives within the two nature conservation establishments and offers good grounds for research opportunities that could link biodiversity with climate change.

Climate changes across the globe are becoming a more and more serious concern for ecosystems due to the implications they bring. Some examples for the tropics include habitat loss due to sea level rise, increased exposure to tropical storms, migration shifts due to higher temperatures, as well as habitat isolation and fragmentation leading to local species extinction (McNamara 2010; Jones *et al.* 2009; Kappelle *et al.* 1999; Jenkins *et al.* 1992). For instance, climate change studies for Costa Rica have shown an upwards trend in temperature and an increase in rainfall extremes over the past 40 years (Aguilar *et al.* 2005; Vargas and Trejos 1994). It is therefore interesting to see whether biological indicators can be found that act as early warning systems of climate change for the country.

1.2. Forest cover over time

Forests play a key role in controlling the climate on Earth due to their capacity to trap carbon dioxide and ground water as well as their cooling properties (Soares-Filho *et al.* 2010). On top of that, rainforests, in particular, offer refuge to a wealth of species, making them indispensable for the conservation of biodiversity (McNamara 2010). Figure 1, p.5 provided by UNEP/Grid-Arendal (2008) shows the change in Costa Rica's forest cover over 65 years (1940-2005). It clearly demonstrates a negative trend in forested surface area until the 1990s. While forests still comprised 72% of the country's surface in the 1950s, they were reduced to a mere 26% in 1994 (Cole 1994). Bergoeing (1998) produced even more drastic results from 80% to 20% in 50 years. However, this tendency is reversing as indicated on the map of 2005. It reflects on Costa Rica's effort to improve its environmental status and these measures are a requirement to halt negative climate and biodiversity trends. Long-term studies will show whether these efforts will actually reflect positively on the ecological health of the country, potentially acting as role models for other nations.

Figure 1: Change in Forest Cover for Costa Rica over the course of 65 years: a clear negative trend in forest cover can be seen until 1997, followed by the recovery stage in 2005. Source UNEP/GRID-ARENDAL; http://www.grida.no/graphicslib/detail/change-forest-cover-costa-rica_11db

1.3. Environmental Performance Index of Costa Rica

The Environmental Performance Index (EPI) is a measure to compare countries according to ecosystem vitality and environmental public health covering the categories Environmental Burden of Disease, Water, Water Resources, Air Pollution, Biodiversity and Habitat, Forestry, Fisheries, Agriculture, and Climate Change. The EPI 2012 ranks Costa Rica at fifth place in the world compared to the third place in 2010 categorising it still among the strongest EPI performers globally. However, both the EPI trend and Costa Rica´s ecosystem vitality are decreasing. This is largely due to poor marine protection. In fact, in terms of forest cover Costa Rica ranks number one in the world and its forestry policy can be seen as a prime model for other countries (YCELP 2012). Once again, bioindicators could play a key role in detecting both positive and negative changes in ecosystem vitality.

1.4. Bats form an integral part of Costa Rica´s Biodiversity

Costa Rica, a bottleneck site for migratory animals due to its tropical location along a funnelling migration corridor between North and South America, harbours a wealth of resident and vagrant species making it a hotspot for biodiversity. More than five per cent of all species in the world can be found in an area that covers 0.03% of the planet's surface (INBio – Costa Rica 2013). Among this diversity the largest group of mammals in Costa Rica can be found – bats. They make 110 of the 210 native mammal species and have a very versatile ecology (Rodriguez-Herrera *et al.* 2011). As an example of their ability to adapt to their environment, bats use a variety of roosts from caves, abandoned buildings to tree hollows, branches and even constructed leaf tents.

1.5. Tent-roosting bats

The ability to build tents out of large leaves to form a shelter co-evolved in two parts of the world. While the Paleotropics only hold few species, the majority of tent-making bats[1] is distributed between Mexico and Argentina in the Neotropics (17 out of 21 spp. worldwide).

Costa Rica is an ideal study area for tent-roosting bats as 10 out of 17 of these neotropical specialists can be found widely distributed in the country[2] and much research has already been conducted there (Rodriguez-Herrera *et al.* 2006). All of these ten species belong to the

[1]The term "tent-making" has been replaced by "tent-roosting" in this thesis, since it is not absolutely clear whether all bat species found under these tents actually always construct them themselves (Rodriguez-Herrera *et al.* 2007).

[2]Jamaican Fruit-eating Bat (*Artibeus jamaicensis*), Least concern (LC); Thomas' Fruit-eating Bat (*Artibeus watsoni*), LC; Pygmy Fruit-eating Bat (*A. phaeotis*), LC; Toltec Fruit-eating Bat (*A. toltecus*) (but prob not in Tortuguero as highland sp.), LC; Honduran White Bat (*Ectophylla alba*), Near Threatened; Heller's Broad-nosed Bat (*Platyrrhinus helleri),* LC; *Tent-making Bat* (*Uroderma bilobatum*), LC; MacConnell´s Bat (*Mesophylla macconnelli*), LC; Northern Little Yellow-eared Bat (*Vampyressa thyone*), LC; Striped Yellow-eared Bat (*Vampyressa nymphaea*), LC (Rodriguez-Herrera *et al.* 2007, IUCN 2013).

leaf-nose (Phyllostomidae) family and their diet consists mainly of fruit (Rodriguez-Herrera *et al.* 2007).

Apart from the species-specific echolocation, tent-roosting bats are usually identified by their teeth/mouth, nose/ear shape and colour as well as body length and colouration (including striping) (Eisenberg 1989). However, much can also be said about the bat species by the characteristics of the roosts. Such characteristics include altitudinal location, forest type and at which stratum level they can be found, the type of tent constructed, the leave shape, size and sturdiness and the plant species used (Rodriguez-Herrera *et al.* 2007 and Kunz and Fenton 2005). All these factors aid in identifying the often very physically similar bat species. This study focuses on leaf tents of the lower strata.

1.6. Tent ecology

1.6.1. Why leaf tents?

In terms of longevity, tents are the least stable housings and a lot of time and energy are invested to keep building them. However, the cost of tent construction must pay off. The energy expenditure of roost-building is costly, but bats can afford constructing tents probably because the tropics offer stable warm temperatures and so much food, i.e. energy that the bats can optimise their roost even at a greater price. The advantage of roosting in tents is that they offer protection against predation, ectoparasites, sun, rain and winds, plus they help regulate body temperature especially in juveniles (Stoner 2000; Stuckey 2009). More importantly, they offer flexibility due to abundance of plant sites, and the ease at which they can be built wherever needed in the forest. Traditional roosting sites, such as caves are moreover rarer to find in the tropics (Kunz 1994). This means these roosting sites are much easier to establish and the roosting range can be more adjusted to the needs of the animals.

1.6.2. Limitations and roost specificity

The architecture is limited to certain plant species with large leaves and follows currently eight tent structures according to Rodriguez-Herrera *et al*. (2007). So far, in the Neotropics more than 80 different plant species have been identified that have leaves modified into tents (Kunz 1994). The main plant families are listed in Table 1, p.9. The Costa Rican bat species that roost in tents construct all of the defined tent types, namely apical, bifid, boat/apical, boat, conical, paradox, pinnate and umbrella[3] (Rodriguez-Herrera *et al*. 2007). Height, age and angle of the leaf are also important factors for the roost selection (Nawrocki 2012; Stoner 2000).

1.6.3. Species specificity

Since every species varies in the tent types they can build or camp in, determining the tent type can aid in narrowing down the identification of the bat that created the tent even in its absence (see Table 1, p.9). For example, while *Ectophylla alba,* an absolute specialist in every sense, mainly modifies *Heliconia* leaves into boat tents relatively low to the ground, *Uroderma bilobatum* is found at the opposite side of the roosting scale. This species uses seven out of eight tent structures and a myriad of plant species at different strata to roost under. Moreover, Nawrocki (2012) discovered that *V. nymphaea* showed the most selective preference for plants that were farther away from all surrounding trees and for plants that were of greater height, while *A. watsoni* displayed a preference for fewer trees in the surrounding area and taller plants. It is suggested that the animals use different tents during the night when they forage to the ones they occupy during the day when they sleep. This is likely a strategy to hide the day roosting sites where they are more vulnerable to predation (Boinski and Timm 1985).

[3] For more detailed structural information on these tents, Rodriguez-Herrera *et al*. 2007 should be consulted.

Table 1: Roost specificity of tent-roosting bats of Costa Rica. For each Costa Rican tent-roosting bat, the table shows the name and number of tent types they construct, at which stratum level they are built, the number of plant species modified and which main plant families they belong to. Tent codes: Ap = Apical, Bi = Bifid, Bo = Boat, B/A = Boat/Apical, Co = Conical, Pa= Paradox, Pi = Pinnate, Um = Umbrella. Extracted from Rodriguez-Herrera, *et al.* (2007).

Bat sp./ roost specificity	no. tent types	tent type	stratum level	no. plant spp.	main plant families
Artibeus jamaicensis	4	Ap, B/A, Um, Pi	lower canopy	5	Araceae; Arecaceae
Artibeus watsoni	5	Ap,Bo,A/B, Bi, Um	understorey, lower canopy	42	Araceae; Arecaceae; Cyclanthaceae; Heliconiaceae; Marantaceae; Melastomataceae; Moraceae; Musaceae; Piperaceae; Rubiaceae; Urticaceae
A. phaeotis	3	Ap, Bo, Bi	understorey	4	Araceae; Arecaceae; Heliconiaceae
A. toltecus	1	Ap	understorey/ lower canopy	1	Araceae
Ectophylla alba	1	Bo	understorey	8	Heliconiaceae; Marantaceae
Platyrrhinus helleri	1	Co	lower canopy	1	Asteraceae
Uroderma bilobatum	7	Co, Um, Pi, Bi, Ap, Pa, Bo	understorey, lower canopy	18	Araceae; Arecaceae; Cyclanthaceae; Gentianiaceae; Heliconiaceae
Mesophylla macconnelli	3	Bi, Pa, Ap	understorey	6	Araceae; Arecaceae; Cyclanthaceae
Vampyressa thyone	1	Ap	understorey/ lower canopy	4	Araceae; Polygonaceae
Vampyressa nymphaea	1	Um	lower canopy	2	Araceae

1.6.4. Organisational structure of tent-roosting bats

Bats create these refuges by biting through different parts of plant leaves as described by Rodriguez-Herrera *et al.* (2007). The construction is linked to harem building, as usually one male is found with several females under the tent (Kunz and McCracken 1996). The current hypothesis is that females choose males according to the roost suitability of the tents. One to several individuals can be found hanging under these tents and group sizes and composition depend on the species, the strength of the leaf as well as the productive cycle of the bats. Harem sizes are larger during gestation and lactation and reduce in size between the bimodal reproductive rhythm of this bat group (Kunz and Fenton 2005).

1.6.5. Roost fidelity and home range

Home range and roost fidelity are species specific and even though roost fidelity of individual tents is not very high with this kind of roost (in comparison to more stable ones such as caves), bats tend to be more committed to certain roost areas (Kunz and Fenten 2005). In fact, foliage roosting species are more likely to show low roost fidelity than other tree roosting species. It is worth noting that measurements across the season may thus be impractical (Lewis, 1995). Home range differs not only amongst different species, sex and age but also according to the availability of food sources and host plant variety (Chaverri *et al.* 2007b; Lewis 1995). The species *Artibeus watsoni*, for example, was found to cover an area of 3.6 hectare, which is the smallest home range among all recorded bat species in Costa Rica (Chaverri *et al.* 2007b). Moreover, bats that camp in tents use alternative types of roosts as well. These include caves, mines, tunnels, culverts, hollow trees and foliage such as unmodified banana leaves (Rodriguez-Herrera *et al.* 2007). Future research projects could investigate under which conditions are sought and what kind of individuals (e.g. sub-adults, females, males) deviate from these alternate roosts the most.

1.7. Threats and the response to them

Increasing threats to neotropical ecosystems in Costa Rica include mainly habitat destruction, deforestation and de-fragmentation (Rodriguez-Herrera *et al.* 2007), but in addition direct persecution, introduced species, pesticides and pollution, including water deterioration, climate change, increasing natural disasters, wind turbines, and disease (Kunz and Fenton 2005; Jones *et al.* 2009). In fact, as previously mentioned, Bergoeing (1998) documented that forest cover was drastically reduced within a 50-year time frame from 80% initially to 20% in the late 1990s. Long-term studies on climate change, where temperature and precipitation were measured over a 30-year time period, showed a significantly negative trend in precipitation for 75% of Costa Rica according to Vargas and Trejos (1994). It means that the country has become drier already.

In the fight for survival, bats have two options to adjust to such disruption. They either move elsewhere or they adapt to the newly found living conditions. Thus, three scenarios are expected to occur. First, in case of translocation, species compositions of tent-roosting bats would shift away from the threat, i.e. a reduction in local bat diversity (LaVal 2004). Of course, this corresponds to encountering these species in new habitats, as demonstrated by LaVal (2004). Second, in terms of adaptation, bat species that managed to adjust to the newly found conditions, are encountered in greater abundance. And finally, a combination of both: fewer species inhabit the disturbed site but the ones that do have conquered the area. Several studies (Gorresen, and Willig 2004; Fenton *et al*. 1992; Jones *et al.* 2009; Willig *et al.* 2007; Pedersen *et al.* 2009; Adams 2010; Kappelle *et al.* 1999; Frick *et al.* 2012; Medellin *et al.* 2000) already prove this behaviour.

Jones *et al.* (2009) suggested the following responses to occur in bat species affected by climate change in the Western Hemisphere: different hibernation behaviour due to temperature rises; higher mortality in relation to extreme drought, heat, cold and rainfall; population declines caused by a rise in tropical storms and; altered roost behaviour and loss of habitat in response to sea level change. If this report proves that climatic factors influence the roost behaviour of tent-roosting bats, it could aid in population predictions for this group of mammals in future.

1.8. Environmental indicators

According to Holt and Miller (2011), biological indicators are defined as "... biological processes, species, or communities ... used to assess the quality of the environment and how it changes over time." However, there is a difference between biodiversity, ecological and environmental indicators. Environmental indicators respond in predictable ways to specific environmental disturbances. The choice of bioindicator depends on the area that needs to be monitored (Jones *et al.* 2009).

Certain criteria determine whether biological processes, species or communities are suitable as bioindicators. They need to possess good indicator abilities, meaning they respond measurably in a graded response and proportionately to negative changes in their environment and these responses must reflect the general shift in the community they belong to. Using a graded response system portrays more clearly the severity of a threat (Jones *et al.* 2009). Secondly, the indicators must be common and abundant and easy to be sampled in order to retrieve statistically viable results that are economically produced (Jones *et al.* 2009). Thirdly, they need to be previously well studied so taxonomy and general species characteristics are well known and can be distinguished from oddities due to environmental changes (Holt and Miller 2011; Jones *et al.* 2009). Moreover, the bioindicators must act as surrogates for other species by corresponding in the same or similar way as also these species would (Jones *et al.* 2009). And finally, they ought to be economically important in order to prove the value of conserving the habitat they live in (Holt and Miller 2011).

1.8.1. Are tent-roosting bats suitable biological indicators?

Following the above mentioned criteria, it can be demonstrated that bats are potentially suitable to make prediction on environmental changes. First of all, the Costa Rican tent-roosting bats of the Phyllostomidae family play a crucial role in seed dispersal in the tropics of the Americas, as they are all *frugivores* (Melo *et al.* 2009). This means they have a high economic value for the country. Phyllostomidae are often food specialists occupying particular niches in the neotropics (Jones *et al.* 2009). This makes this bat family a suitable study group, as much can be said by the composition and abundance of the individual species.

In addition, bats are the most diverse mammal group in Costa Rica and they can be found in abundance throughout the different ecosystems. While some tent-roosting bats are still poorly understood, others like *A. watsoni* and *A. jamaicensis* are well studied. For instance, Pedersen *et al.* (2009) give an example of the response of *A. jamaicensis* to Hurricane Hugo in 1989, comparing the roost behaviour before and after the storm. In this case, the dominating frugivore *A. jamaicensis* only recovered poorly from the devastation and thus had to let *Brachyphylla cavernarum* that came around quicker take over the terrain. This means that changes from their normal behaviour could be easily identified. In terms of measurable responses, the example above of Pedersen *et al.* (2009) demonstrates how changes in roosting behaviour can be linked to altered abundance of other species.

It is also noteworthy to mention their taxonomic stability, which will deliver coherent results over a longer time span, as each species can be clearly identified. One more plus point is that bat data can effortlessly be collected for different structural levels, e.g. for populations, social groups or individuals. Rapid population drops from stressors due to a slow reproductive rate and thus poor recovery can easily be identified. This reproductive trait further reduces any statistical noise (Jones *et al.* 2009).

Moreover, as vectors of many diseases, bats might contain higher levels of antigen loads due to stress, which can easily be measured in the laboratory. However, this stress is not necessarily caused only by climate change but only a generic sign of distress (Jones *et al.* 2009).

1.8.2. Biodiversity Indicators

Disturbance of the roosting sites of tent-roosting fruit bats reflects negatively on plant abundance dispersed by these bats in the proximity of the feeding area (Melo *et al.* 2009). Chaverri *et al.* (2007a) discovered that roost fidelity in *Artibeus watsoni* was not very high in areas with plant species abundance but increased where plant availability was reduced. Therefore, tent occupancy might be a good indicator of forest health and monitoring bat prevalence could be an easy measure to understand their ecology and consequently assess the need for conservation action.

1.8.3. Link to climate change

Effects due to climate change occur slowly and can interact with other stressors making a clean analysis difficult (Kappelle *et al.* 1999). A study in Great Britain (Menendez *et al.* 2006) discovered that changes in species richness and composition of butterflies followed changes in climate but only with a much delayed response. In that research project, it became apparent that generalists took over, as they adapted the quickest to the altered environment. Another study by Jiang *et al.* (2010) demonstrated that bats in China reacted sensitively to changes in humidity and thus climate alterations.

Enquist (2002) developed climate change models for the tropics that predict that the tropics are less sensitive to climate change than temperate zones, since the temperature is less likely to rise. However, if it does, coupled with changes in precipitation, the two climate factors will have a more drastic effect on tropical ecosystems.

LaVal (2004) already verified adjustments in habitat selection of tent-roosting bats due to rising temperatures in the Monteverde Cloud Forest of Costa Rica over the course of 27 years. Species, that were previously more common in lower altitudes, were increasingly captured in this area, which showed a rise in temperature from 14.6°C in 1989 to 16.9°C in 2002. This could be linked to altitudinal habitat adaptation due to climate change. Ecotones and transitional areas of lifezones, for instance, are ideal locations to study climate change indications (Kappelle *et al.* 1999). But further research is needed to better understand the normal responses and preferences of tent-roosting bats in terms of weather. With regard to the evidence that tent-roosting bats deem to be good environmental indicators, one more reason to pursue this monitoring approach has to be considered. Many bat populations are declining, threatening the existence of their species, and thus require increased attention in order to understand and mitigate the threats they face (Jones *et al.* 2009).

If it can be proven that tent-roosting bats are in fact affected by the factors investigated in this study and for the area, they could also serve as climate change indicators for wet tropical lowland forest in the future.

1.9. Vegetation structure of the site

The study area is situated on the grounds of the Biological Station Caño Palma owned by the Canadian Organization for Tropical Education and Rainforest Conservation (COTERC). Found in the North East of the country, 250 metres from the Caribbean coast (Myers 1981), it consists of relatively undisturbed secondary forest with the largest part being Troolie Palm (*Manicaria saccifera*) dominated swamp forest (67.8%). The remaining two forest types are Edge (3.6%) and Transitional Forest (28.6%) (Lewis *et al.* 2010). The grounds are bordered by the Caño Palma canal to the East and secondary forest of the Barra del Colorado Wildlife Refuge to the North and West of the station grounds and to the South by the National Park of Tortuguero (Lewis *et al.* 2010, Hulatt unpublished report)

The station forest has in the past been cleared, which means that the secondary vegetation is still in transition (Lewis *et al.* 2010). The co-founder of the Biological Station, Marilyn Cole (1994), reported that the land was previously owned by squatters that cleared the area for logging and allowed poaching on the lands. These activities ceased after the acquisition and monitoring by COTERC in 1991, giving an account how young the secondary forest is. In fact, Hulatt (unpublished report) reported that most trees were less than 60 years old. Since the foundation of the biological station, only scientific research was conducted on the grounds and occasionally timber was taken from already fallen trees to use at the station (Cole 1994, personal communication).

Smit (2012) concluded that presence of bat tents is higher in primary forest but that secondary forest also plays a role in habitat refuge of these bats. Species such as *Artibeus watsoni* act as pioneers in swamp forests and take advantage of the difficulty of their peers in adapting to this habitat. This study focuses on secondary forest, which forms a large part of tropical rainforest in Costa Rica at present (Brooke 1990; Kohlmann *et al.* 2010). Apart from the meteorological data comparison, it will give further insight in habitat tendencies of tent-roosting bat species.

2. Objectives/ Hypotheses

To compare distribution of tents and occupancy of tent-roosting bats in relation to precipitation, temperature, forest type and distance to the canal at Caño Palma Biological Station, Limón, Costa Rica over the course of 51 days in the second quarter of 2013. This aimed to determine whether tent-roosting bats were suitable bioindicators for climate change.

2.1. Null Hypotheses:

1. Tent abundance during the months of April and May is not significantly influenced by any of the following factors
    a. temperature
    b. precipitation
2. Tent occupancy during the months of April and May is not significantly influenced by any of the following factors
    a. temperature
    b. precipitation
3. The distance at which bats build tents away from the canal during the time of the study is not significantly influenced by tent height and/or forest type.

2.2. Aim of the study

This study aimed to bring further insight into the ecology of tent-roosting bats. In particular, it meant to reveal whether there was a significant difference in roost occupancy and distribution patterns at times with varied degrees of daily precipitation and temperature. It was interesting to see whether roosts and their location showed a different pattern throughout the year. In particular, whether there was a significant difference between tent type abundance, percentage of tent occupancy and relative distance to the canal. The focus lay hereby in the more relevant and fine-tuned day-by-day changes rather than monthly nuances to investigate further behavioural patterns of tent-making bats according to daily weather changes.

This insight could possibly aid in qualifying certain bat species as biological indicators, and thus, potentially increase the value of this specialist group (Medellin *et al.* 2000). Consequently, identifying early warning mechanisms will benefit not only the monitoring of tent-roosting bats but also the habitats they frequent and a myriad of organisms that share the same living space.

3. Methods and Materials

3.1. Initial method rationale

Before arriving in Costa Rica, a different project was proposed according to the information provided by the research station. The idea was to study the bat ecology of the two rainforest transect sites of the biological station, one affected by a human settlement nearby and the other one less disturbed on the station grounds. It was planned to compare the two sites according to bat abundance, occupancy and species composition, and then make conclusions in relation to human disturbance. However, once the two sites were inspected it became apparent that they differed in several factors that would cloud the actual research (see information provided under Section 3.2.1. below). Moreover, it was difficult to find a method to quantify the human disturbance and therefore an *ad hoc* alternative had to be found.

The research site was surrounded by protected areas and was meant to be conserved and given the opportunity to recover from the deforestation the country suffered over the past few decades (see Figure 1, p.5). Hence, focussing on a topic such as finding bioindicators for climate change and biodiversity aimed to create a strong case for future conservation rationale. Tent-roosting bats and their roosts were chosen as test objects because they were abundant and easy to spot. The information on bats as bioindicators, provided in the introduction, should clearly demonstrate why they were suitable for this project.

3.2. Site selection

On arrival in the study area, the two available mammal transects were inspected, which were based on either side of the Caño Palma canal (see Figure 3, p.23) that flows from North to South into the Rio Penitencia (Cole 1994; Hulatt, unpublished report).

3.2.1. The first potential study site

The first transect (Cerro) was situated near the village of San Francisco de Tortuguero and consisted of mainly primary forest growth. The transect circumvented an inactive volcano, hence it was slightly elevated with a slope on one side. The increased elevation made it drier and less likely flooded than the second study site (CPBS), level with the station grounds. Also, the vegetation of the Cerro transect was more diverse and denser then the CPBS transect, probably partially due to the volcanic soil and forest type.

The CPBS study area is described in detail in the introduction (see Section 1.9. Vegetation structure of the site).

3.2.2. Comparison of the two transects for research suitability

Surveying both transects several times prior to the actual thesis work, provided an interesting insight – there were far fewer bat tents detected in this primary forest than in the secondary forest across the canal (see Raw Data in Appendix A2, p.58). This might have been partly influenced by the lower visibility through the denser vegetation. This observation was reinforced by the data from the mammal survey of the biological station recorded for the past eleven months (see Figure 2 p.21) with a much greater abundance of bat tents at the CPBS transect (Hulatt, unpublished data). Higher elevation, a very different terrain relief due to the surrounding mount, the vicinity of a small village as well as the shape of the transect could have played a role in the changes of tent abundance. While the CPBS transect followed a relatively parallel path along the canal, the Cerro transect formed a horseshoe shape leading away from the canal; again introducing another factor that would have needed to be considered if this transect had been selected.

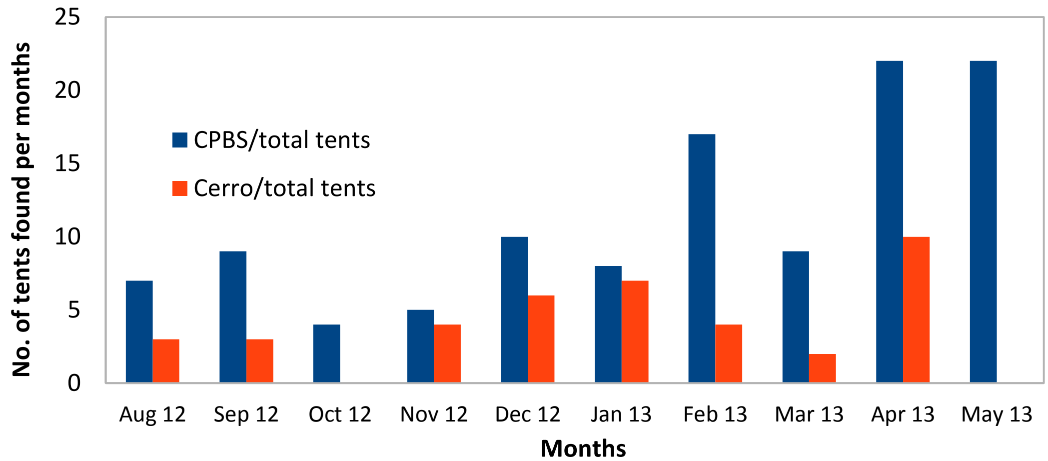

Figure 2: Preliminary site selection: suitability according to tent availability across ten months. The blue bars show tents at the transect Caño Palma Biological Station (CPBS), the red bars show those of the Cerro transect.

3.3. Initial data collection

After this preliminary site selection process, tents were counted and their location was recorded along the existing CPBS transect, 1,050 metres in length. At the same time, weather data was taken at the biological station, measuring among other data, daily temperature and precipitation. The transect led through a secondary lowland rainforest on a relatively flat plain west of the canal Caño Palma. This area is situated in Barra del Colorado Wildlife Refuge near the Caribbean coast of Costa Rica. Eight out of the ten Costa Rican tent-roosting bat species have previously been sighted on the grounds of Caño Palma Biological Station with the two missing species being *Vampyressa thyone* and *Mesophylla macconnelli* (COTERC 2010).

3.4. Main survey

3.4.1. Background on sampling rationale

Tent-roosting bats like nearly all other bats are primarily nocturnal but they use the tents both during the day and the night. Mulcahy (1993) discovered that diurnal resting roosts differ from the feeding roosts at night. This is likely to be a strategy to deter potential predators that spot the food or faeces droppings underneath the nocturnal tents from the diurnal tents when bats rest in a stupor and therefore more vulnerable. Despite their general inactivity during the day, tent-roosting bats occasionally move during daylight, but the least in the early mornings (personal conversation with the research staff of the biological station; Mulcahy 1993). This means collecting data at different times of the day provided a more evenly distributed overview of tent occupancy.

3.4.2. Survey protocol

During the day, a twenty-metre wide corridor along the transect was searched three times a week for tents at different vegetation levels excluding the canopy. Temporal gaps of a few days between visits aimed to reduce the disturbance of the tents and the bias of fleeing animals. In addition, the surveys took place at different times of the day (early morning, late morning and afternoon) in order to minimise biased sampling.

The coordinates together with the accuracy were recorded on a GPS map to mark the location of the tent and to show distribution patterns (see Figure 3, p.23). In addition, tents were marked with a red tape to improve visibility and checked regularly for occupancy[4]. This ensured consistency in data collection and guaranteed, together with the GPS coordinates and the tent height, the correct identification of the tent. During the individual survey runs, a maximum of five percent sampling error was allowed in order to cater for tents that could not be found. The height at which the tent was found was recorded up to 2.20 metres and marked as > 2.20 m when it exceeded this height. In addition, the type of tent (conical, bifid, boat, pinnate, umbrella, apical, paradox, boat/apical) was determined according to the field guide by Rodriguez-Herrera, *et al.* (2007). Tent type and occupancy, plant species, numbers of individual animals per tent and the bat species (as closely as possible without handling the animal) was noted on a recording sheet. When a tent showed weathering signs, e.g. torn or disintegrated leaves, it was declared dead/ or inactive and not

[4] When bats were encountered under a tent, taping the stem was postponed in order to not disturb the animals.

recorded thereafter.

In addition, weather conditions at the time of the survey were recorded on a scale from one to four (1 = sunny, 2 = overcast but no rain, 3 = light to moderate rain, 4 = heavy rain, harsh weather). The observation lasted 51 days, canvassing the site three times a week in order to record roost changes over time.

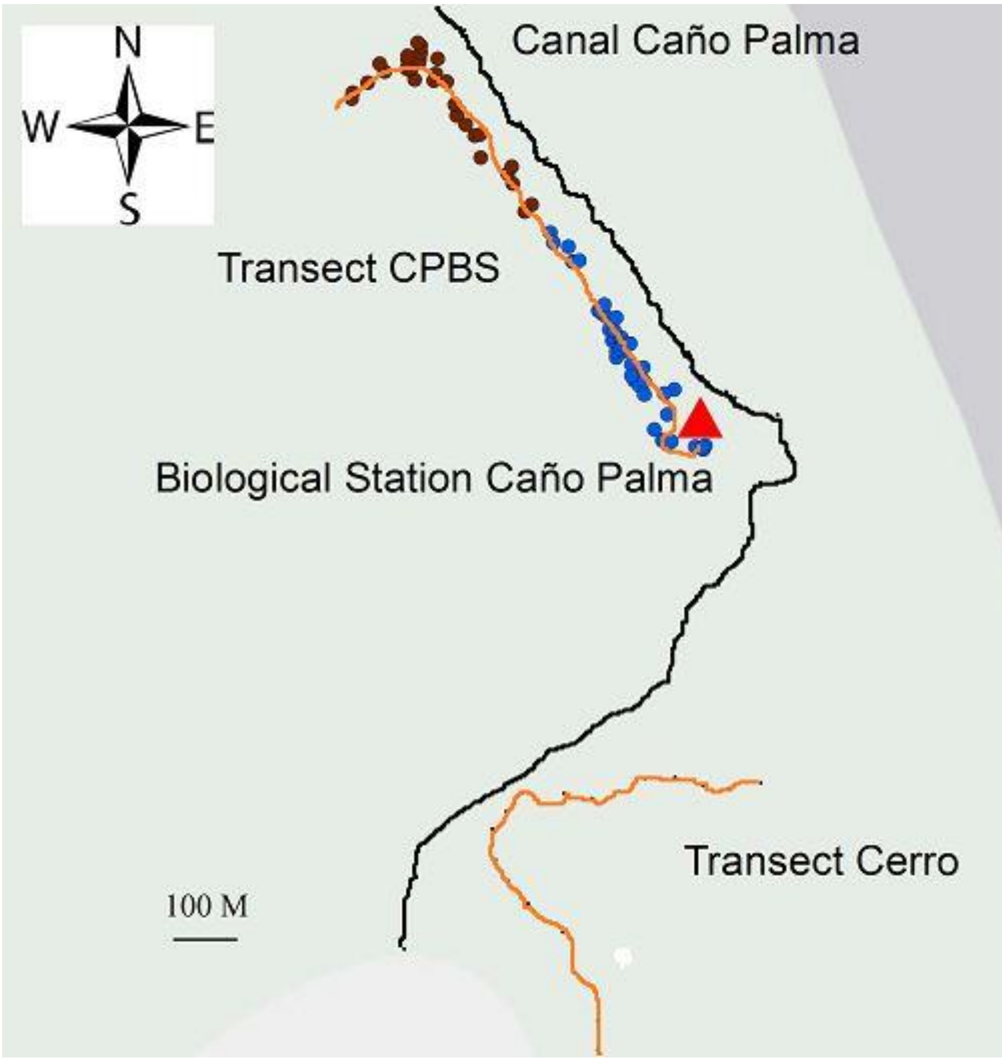

Figure 3: Distribution of the surveyed bat tents. Tents in blue were located in the first half of the transect, which led through transitional mixed forest, tents in brown were found in the Troolie Palm (*Manicaria saccifera*) dominated swamp forest as described by Lewis *et al.* (2010). The orange lines show the Cerro and CPBS transects, the black line the canal, which flows into the Rio Penitencia and the red triangle the location of the biological station.

3.5. Additional research data of the biological station

Further to my own fieldwork, a temporal comparison of occupancy of tent-roosting bat species of the transect was carried out using the data of the COTERC Mammal Survey of the previous nine months covering the period from June 2012 to March 2013. All evidence of mammal activity was recorded and categorised as visual, vocalisation, tracks, trail, scat, foraging, burrow or leaf tent. Other information recorded included the species, number of individuals (adult and juvenile), the transect marker and GPS location, the direction the animal was moving if relevant and the age of the tracks (COTERC, unpublished data). This ought to provide a more coherent trend in roost selection over time. Figure 2, p.21 depicts the Mammal Survey as described above. Hereby only the presence of leaf tents was translated into graphical data.

The study protocol followed the guidelines of occupancy collection by MacKenzie and Royle (2005) ensuring a standardised and methodological approach.

Further to biological monitoring, the biological station kept a meteorological 12-hour log. Caño Palma was equipped with a thermometer that recorded actual, minimum and maximum temperatures within the half-day time frame. In addition, a barometer measured daily extremes and precipitation was read using a rain gauge. This data, together with further weather-related observations irrelevant for this study, were being collected at 5 a.m. and 5 p.m. every day all year round.

3.6. Statistical analysis

In order to test the Null hypotheses, a stepwise multiple linear regression analysis was carried out using the Durbin-Watson statistic comparing

1. Precipitation against tent abundance;
2. Temperature against tent abundance;
3. Tent occupancy against precipitation; and
4. Tent occupancy against temperature.

This aimed to reveal whether a dependence of tent-roosting behaviour on short-term weather conditions exists.

To be more precise, precipitation data measured on a 12-hour basis at the station, were compared according to the rainfall of the last 12 hours, 24 hours and 48 hours. Since the reaction of the bats to weather factors could be delayed, it was worth comparing these three time frames.

Temperature was also split into four categories. First they were differentiated into daily deviations from the maximum and the minimum average temperature per month. Then, the day of the survey and the day prior to it were compared with tent occupancy and abundance.

Table 2: Defining the between-subject factors of the two-way ANOVA of roosting distance to the canal according to tent height and forest type. Transect part 1: Transitional forest, transect part 2: Troolie palm (*Manicaria saccifera*) swamp forest. N indicates how many tents were found under each category.

Inter-subject factors	Cat.no.	Value label	N
Height Categories	1	>220 cm	44
	2	180-220 cm	19
	3	140-179 cm	7
	4	<140 cm	2
Transect part	1	0-550 m	42
	2	550-1050 m	30

Additionally, distance of tents to the canal of 72 tents (where all data was available) was compared against tent height and forest type using a two-way ANOVA. This analysis was conducted in order to see whether there was any significant difference in the means of distances to the canal in relation to these two inter-subject factors (see Table 2). It was to be investigated whether bats make a selection of the location, then adjust the height of their roost taking into account the chance of flooding due to closer proximity to the canal. Hereby four height categories were selected, for which the number of tents found and their location in relation to the canal were calculated. The data was then separated into the transitional forest with some elevated islands (1m) and occasional flooding (0-550 m of the transect) and the Troolie Palm forest with little understory and the least diverse, with permanent mud pools (550-1050m of the transect)[5] according to the mapping of the terrain by Lewis *et al.* (2010) (see Figure 3, p.23). This was done in order to investigate whether the different vegetation types influenced the choice of roost selection. Apart from the distance the tents had to the canal considering height tent as well painted a three dimensional picture of roost preference. Furthermore, a possible pairwise connection of forest type and tent height category in relation to distance to the canal was investigated by conducting a Tukey test in order to see whether there was some kind of inter-relation (see Figure 10, p.36).

3.7. Weather data

The Tortuguero area, situated on the Caribbean coast of Costa Rica, lies 10°30' North of the equator. It follows climate zone "Af" of Köppen-Geiger's classification of climate systems, which separates zones according to certain temperature and precipitation criteria. Whereas "A" refers to the average minimum temperature lying above 18°C all year round, "f" signifies that none of the monthly precipitation per year falls below 60mm, which marks the cut-off point for dry months (Peel *et al.* 2007).

[5]N.B. Earlier it was mentioned that the station grounds were composed of 67.8% Troolie Palm swamp forest, 28.6% transitional and 3.6% edge forest and splitting the transect in half seems ill-fitted. However, the reference refers to the surface area of the search corridor. Since the transitional forest runs close to the biological station itself and the majority of Troolie swamp forest covers the more distant part of the grounds, the line the transect follows splits it nearly equally into these two forest types. A map of the composition of Caño Palma Biological Station grounds in terms of habitat type is presented in the paper by Lewis *et al.* 2010).

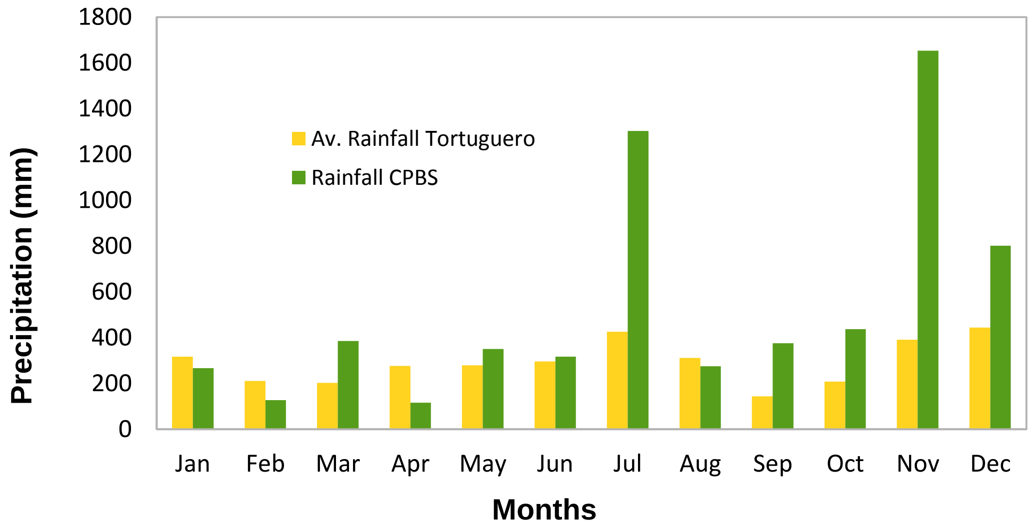

Figure 4: Overview of precipitation patterns for the region of Tortuguero, Limón, Costa Rica. The yellow bar shows precipitation for 2011 and the green bar that of the biological station from June 2012 until May 2013. Seasonal peaks appeared in July and November/December. Data for Tortuguero taken from Instituto Meteológico Nacional de Costa Rica 2013; http://cglobal.imn.ac.cr/

None of the months fell below 60mm of precipitation in the analysis. Instead, two maximum peaks occurred during July 2012 and November/December 2012 with precipitation well above 600 mm and the troughs in February and April 2013 where rainfall barely exceeded 100 mm (see Raw Data in Appendix A3, p.59). Even though the maxima at the station were significantly higher than the average annual rainfall (November 2012 even had quadruple the value of the mean precipitation for this month), the data collected was in line with average precipitation data for the region and the biological station (see Figure 4, taken from IMN 2013). The field studies covered two relatively dry months but with May having more than double as much rainfall as April.

3.8. Materials and costs

Binoculars, GPS device (Garmin S62), torch, camera, watch, recording sheet, geographical map of the research area, measuring tape, bat and tent field guide (Rodriguez-Herrera *et al.* 2007), plant id book, marking tape, ArcGIS (ArcMap 10.1) and IBM SPSS 20 statistics software.

The main proportion of the costs involved was linked to participation fees of the training programme at the Biological Station. This included all tuition, food and lodging and was set at US$ 200 per week at the time of the research. The research station provided nearly all the necessary equipment for this survey.

4. Results

4.1. Overall findings

4.1.1. Tent types, bat and plant species encountered

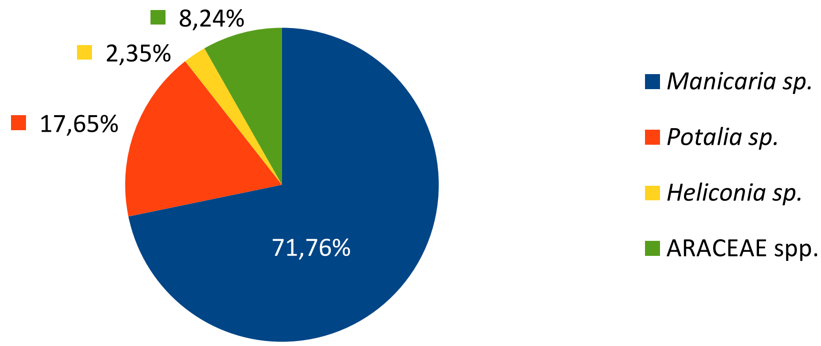

Figure 5: Abundance of modified plant species in the study area. The pie chart depicts the dominance of *Manicaria saccifera* in the understory of the station grounds.

An overall of 86 tents (see Raw Data in Appendix A1, p.57) were marked for observation during the study made out of mainly four plant species plus one plant family (see Figure 5, *Manicaria saccifera, Potalia turbinata, Heliconia sp*. and epiphytic plants from the Araceae family). Since young Troolie Palms dominated the understorey landscape, most of the tents encountered were altered Troolie Palm leaves (72%).

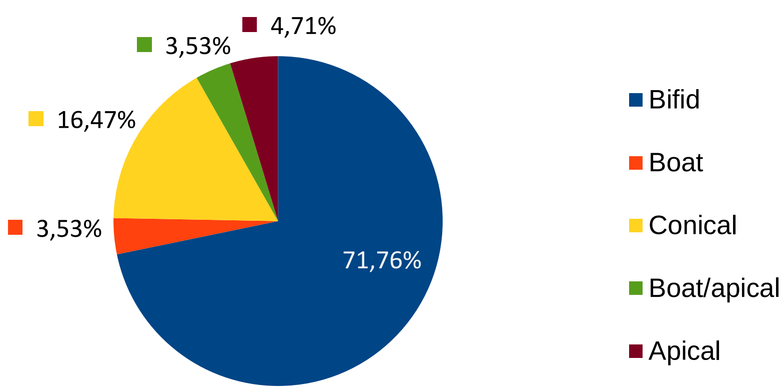

Figure 6: Proportion of tent types found on the transect. It shows that the nearly three quarters of tents were bifid constructions, followed by roughly one sixth of conical tents. The percentage of the other tent types was relatively evenly distributed among the remainder tents. All bifid tents were constructions of Troolie Palm leaves (compare with Figure 5 above).

This corresponds exactly with the bifid tents recorded (see Figure 6, p.29). While apical and boat/apical tents were all constructed out of the leaves of epiphytic aroid plants, *Potalia turbinata* was the basis of all conical tents but, in addition, of one boat tent. The rest of the boat tents were modified

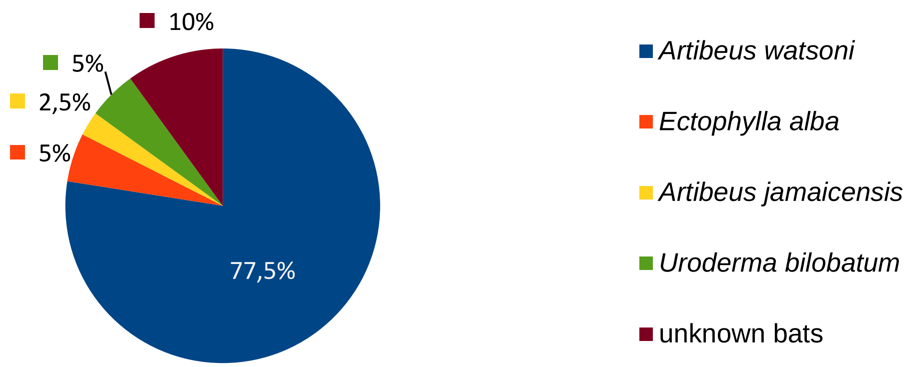

Figure 7: Percentage of bat species found under tents. Once again, *A. watsoni* closely corresponds to the data of the other pie charts above. Note: the species *A. watsoni* cannot be distinguished by sight from *A. phaeotis.*

During this field work, five different tent types (bifid, boat, apical, boat/apical and conical) on the understorey stratum and at least four species of tent-roosting bats (see Figure 7 *Artibeus jamaicensis, A. watsoni, Ectophylla alba* and *Uroderma bilobatum*) occupying the tents were observed. It is noteworthy that the species *A.watsoni* could not be differentiated from its close relative *A. phaeotis* without handling the bat, as the teeth or molecular analysis are key to identifying the near identical and closely-related species (Redondo *et al.* 2008, Solari *et al.* 2009; Timm 1985; Chaverri and Kunz 2006). For the sake of simplicity and in line with previous findings on the station grounds (O´Toole 1993; Mulcahy 1993; Hulatt, unpublished report) that the dominant species in the area has been recorded as *A. watsoni, A. phaeotis* was included under *A. watsoni* when referred to in the findings of this study. However, according to research on habitat specificity and bat ecology (Smit, 2012; Rodriguez-Herrera *et al.* 2007; O'Toole 1993), *A. watsoni* is a generalist among tent-roosting bats and well adapted to swamp and secondary forests. This led to believe that at least the majority of bats encountered under that species name were indeed of the species *A.watsoni*.

The majority of structures were bifid tents made out of *Manicaria saccifera* leaves (see Figure 6: Proportion of tent types found on transect, p.29) and were inhabited by *A. watsoni* (see Figure 7, p.30). On several occasions newly born juveniles could be seen clinging onto their mothers (see cover photo) giving evidence to the expected gestation/lactation period of the bat species.

Individuals of *E. alba were found* roosting only in boat tents typically made of *Heliconia sp.* leaves relatively low to the ground, which all goes hand in hand with the literature (Brooke, 1990; Rodriguez-Herrera *et al.* 2007). But interestingly, they were also seen roosting under a modified young *Potalia turbinata* tree, which has not been documented before. The two groups observed showed remarkable affinity to the two specific tents they were encountered in on nearly every visit. During the course of the research, a juvenile was born and nurtured. Despite the close proximity of researchers looking under the tent that was 101 cm off the ground, they never attempted to flee. Thus, they displayed the strongest roost fidelity among the observed species.

On the opposite end, both *Uroderma bilobatum* and *A. jamaicensis* were only spotted a few times during the survey period. However, the researcher strongly suspected that the conical tents, which were found mostly abandoned, to be constructions of *U. bilobatum*, since the only other bat species *Platyrrhinus helleri* known to build this type of tent was not detected. Plus, on the few occasions of bat encounters under these tents, it was indeed *U. bilobatum*. During the course of the study, further tent development of a few of the conical tents that were under construction could be observed, hence indirectly bat presence and activity could be confirmed. Out of the tent types discovered in this area, the conical tent is one of the hardest to make, taking the longest time until completion. However, the sturdiness of the petioles that are being bent, which can only be mended by the strong teeth of selected species (Rodriguez-Herrera *et al.* 2011), also permits these tents to stay intact the longest.

The unknown bats, accounted for in the pie chart of Figure 7, p.30, were either composed of bats that flew away prior to identifying them or where fresh foraging was found under the tent in the absence of any bats. It is very likely that the majority was also of the species *A. watsoni* since they were nearly all linked to bifid tents and the seeds were the same as under tents where this type of bat was seen.

4.1.2. Some general statistics and further observations

From the time period 8 April until 28 May 2013, 254 bats were spotted on 97 occasions (between 1 and 7 bats) with an average of 2.62 bats per tent. Tent occupancy varied from survey to survey from 3.51% to 19.05% (see Raw Data in Appendix A4, p.60) and was on average 8.71% (see Appendix A4: Raw Data). During the course of the investigation, juveniles were born and therefore confirmed that these two months fell in the gestation and lactation period of at least some of the bat species (*Artibeus watsoni, Ectophylla alba*) (Rodriguez-Herrera *et al.* 2007). This means that intra-group patterns were probably adjusted to these conditions and differed from non-mating roosting behaviour (Chaverri *et al.* 2007a, b and c, Rodriguez-Herrera *et al.* 2007). Chaverri *et al.* (2007a) discovered, for example, that the foraging range of lactating females was the largest, while heavily pregnant females had the smallest foraging range. Moreover, she and her colleagues discovered that daytime social interaction was far more important than night time interactions (Chaverri *et al.* 2007c). Hence, observations during the day should not be underestimated.

On a different note, many of the marked tents seemed to appear in clusters. It was likely that these tent groups all belong to particular bat harems. This was in accordance with O'Toole´s findings (1993), that is that *A. watsoni* created tents in close proximity to each other, which could be used interchangeably. O'Toole's observation could be confirmed in this study. In addition to this observation, the hypothesis by Mulcahy (1993) that tent-roosting bats chose different day roosts when they rested, and overnight roosts when they foraged, was reinforced. In general, either foraging evidence in the form of remains of eaten fruit underneath a tent could be observed or bats hanging under the leaves but usually not both at the same time.

Table 3: Results of Pearson´s correlation to test whether tent abundance or tent occupancy were significantly influenced by any climate factors. Climatic factors tested were precipitation within 12 hours, 24 hours and 48 hours prior to the survey, as well as temperature deviations from the extreme values on the day and the day before the survey.

	Test variables	**Tent Abundance**	**Percent Occupancy**
Pearson´s Correlation	Tent Abundance	1	-0.107
	TEMPMINDEV	0.003	0.015
	TEMPMAXDEV	0.328	-0.356
	TEMPMINDEVDAYminus1	-0.11	-0.233
	TEMPMAXDEVDAY-minus1	0.321	-0.139
	Rain12	0.266	0.092
	Rain24	0.358	0.042
	Rain48	0.321	0.212
	Percent Occupancy	-0.107	1
One-sided Significance	Tent Abundance	.	0.332
	TEMPMINDEV	0.496	0.475
	TEMPMAXDEV	0.085	0.067
	TEMPMINDEVDAYminus1	0.327	0.168
	TEMPMAXDEVDAY-minus1	0.09	0.285
	Rain12	0.136	0.355
	Rain24	0.066	0.433
	Rain48	0.09	0.192
	Percent Occupancy	0.332	.
N		19	19

4.2. Precipitation against tent abundance

Before any analysis on the tent roosting behaviour of the study group could be drawn, it had to be assured that other parameters were stable. First of all, it needed to be established that tent abundance was not significantly influenced by rainfall. Conducting a correlation analysis between these two parameters showed no significant influence of precipitation on the number of counted tents per survey, as none of the values were within the 95% confidence level. There was a slight tendency (with a significance of 6.6%) towards a correlation of 36 % between tent abundance and precipitation that fell within the last 24 hours. But since this covariance was relatively low and the confidence was below the 95%, this tendency was statistically insignificant (see Table 3, p.33).

4.3. Temperature against tent abundance

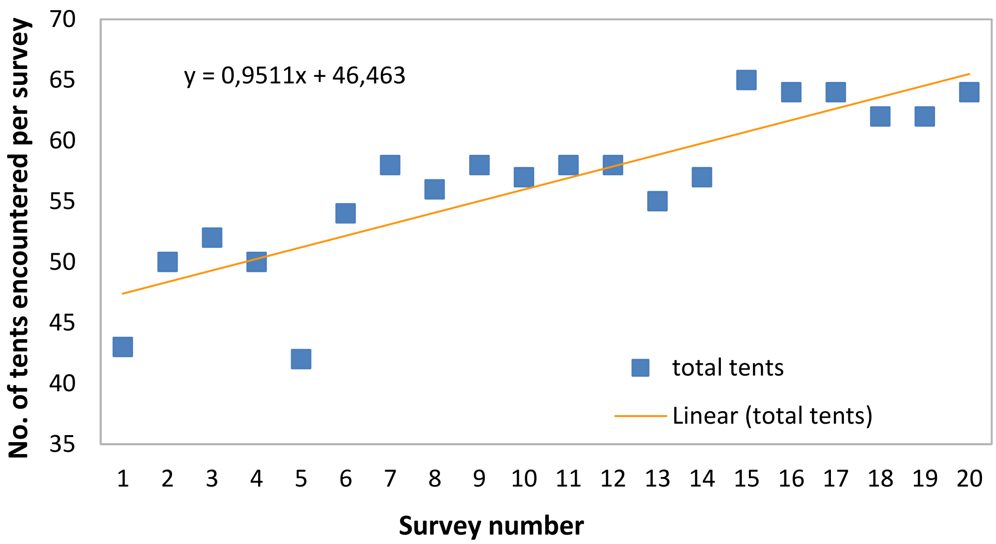

Figure 8: Trend in tent abundance across survey. There was an upward tendency of tent counts due to the fact that it took longer for tents to disintegrate than for them to be built. The slope in the equation of the trend line roughly points toward the discovery of one new tent per survey run.

Further to rainfall as a potentially influencing factor on tent abundance, also the daily temperature deviation was offset against possible variation in tent abundance. Once again, the results were even more conclusive: no significant covariance could be proven, as neither sufficient correlation nor significance were computed (see Table 3 p.33). In fact, tent abundance was stable throughout the survey period with only a small rise due to new tents being discovered while the degradation of old ones that could be declared as inactive was much slower. (shown in Figure 8).

4.4. The correlation of tent occupancy to precipitation and temperature

As demonstrated by the results of the Pearson´s correlation coefficient in Table 3, p.33, there was no covariance significant enough to be considered an influencing factor of occupancy for tent-roosting bats. This was reflected in the low percentages of covariance (the highest covariance was 35.6% for maximum temperature deviation in relation to occupancy) and the lack of data reaching the 95% confidence level. Figure 9 shows a more detailed overview of the patterns of both the tent occupancy and the rainfall during the entire duration of the survey. While there were some troughs of occupancy after heavy rainfall, other cases showed just the opposite and hence no clear roost strategy of tent-roosting bats in relation to precipitation.

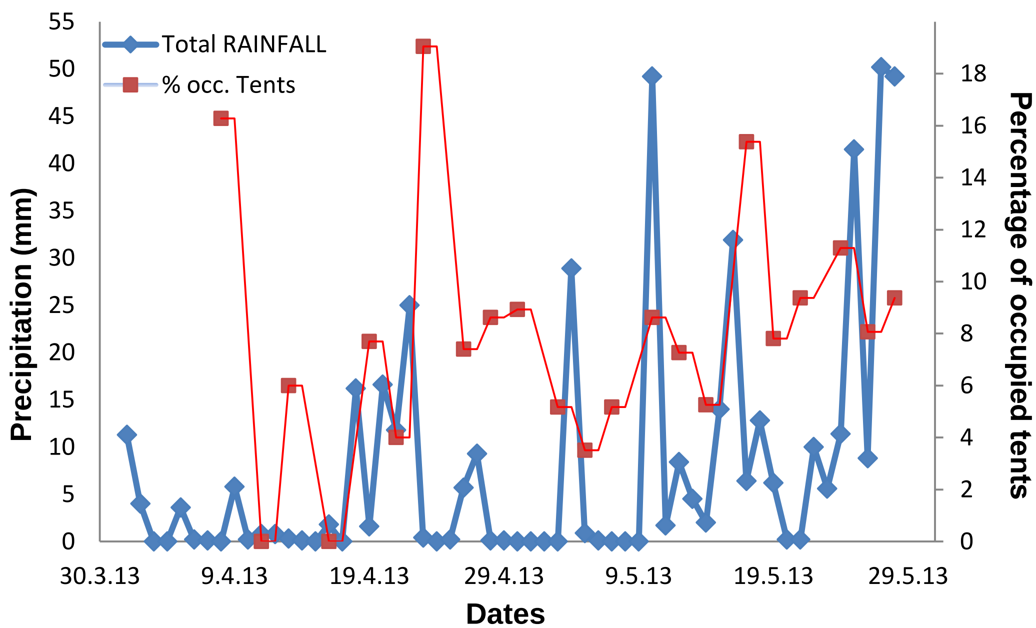

Figure 9: Comparison of rainfall and tent occupancy for CPBS April/May 2013. The graph shows that the two patterns do not correlate.

4.5. Distance of tents to the canal against tent height and/or forest type

4.5.1. Rationale

An additional criterion to satisfy a relationship of bat roost behaviour and weather extremes was to analyse the location of the tents (see Figure 3, p.23 and Raw Data in Appendix A6, p.63). It was to be tested if the distance from the canal, different tent heights as well as the forest type played a significant role in selecting the best roosting site. This could be a measure of catering for flooding of the swamp forest particularly during the rainy season. The expected outcome of this was that in areas, more prone to flooding, tents were built higher to cater for the reduced distance to the canal and additional riverine predators, such as caimans. Four categories of tent heights were selected (see Figure 10 and Table 2, p.25) and analysed in combination with the two forest types, i.e. mono-specific swamp versus transitional mixed species forest. For height category four there were no tents found in transect part two. The vertical lines demonstrate the mean difference in distance to the canal between the two transect parts.

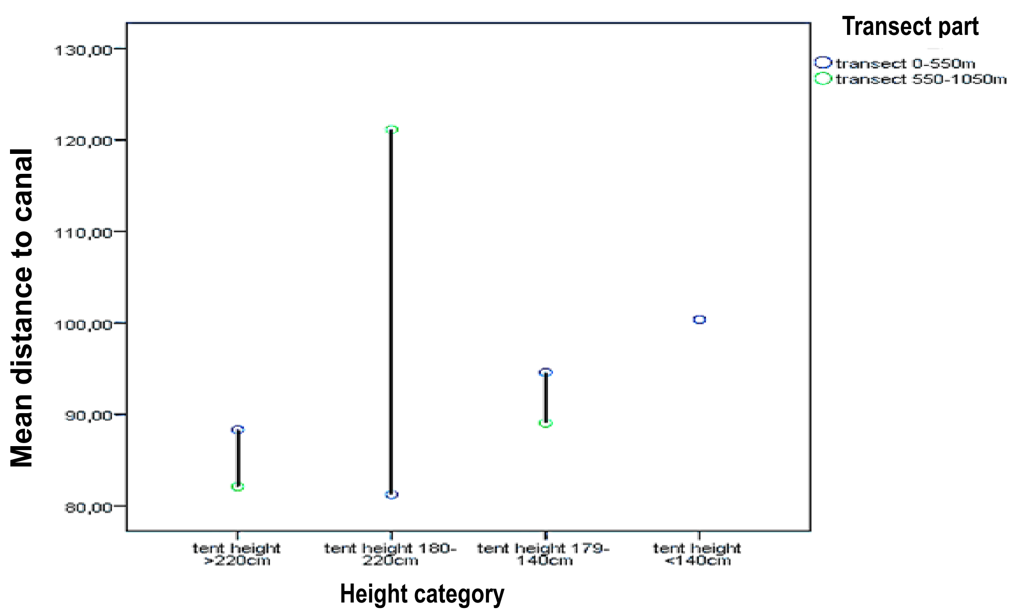

Figure 10: Results of Tukey Test - Differences of tent distances to the canal between the two forest types separated in the four tent height categories. The blue circles show the mean distance to the canal in the first forest type; the green circles the mean distance to the canal in the second forest type.

4.5.2. ANOVA result summary

The results of the two-way ANOVA show an interesting observation (see Table 4 and Figure 10, p.36). Neither tent height nor forest type were solely responsible for selecting the distance at which to roost away from the canal.

Table 4: Two-way ANOVA of distance to the canal of tents of different height categories in combination with two forest types.

Two- way ANOVA					
Dependent variable: Distance					
Source	Sum of Squares Type III	DoF	Mean Squares	F	P
Height Categories	2571.762	3	857.254	1.27	0.29
Transect part	640.906	1	640.906	0.95	0.33
Height Categories * Transect part	5872.026	2	2936.013	4.34	**0.02**
Error	43935.668	65	675.933		
Corrected total	51261.364	71			

However, seen in combination, there was a significant difference of roost selection as demonstrated in Figure 10, p.36 and Table 4 above. While a clear linear pattern followed through for the height categories 1, 3 and 4 (see Table 2, p.25 for category definitions and Figure 10, p.36) with a tendency to move further away from the canal the lower the tent was built to the ground, category 2 fell completely out of place. Here distances to the canal differed significantly between the two forest types. It also became apparent that the category above 220cm was the preferred tent height for tent-roosting bats in this forest with 44 tents found under this category (see Table 2, p.25). The rest of the tents were located in the following combination: 19 tents in the category 180-220cm, 7 tents in the category 140-179cm and 2 tents in the category below 140cm (See Raw data in Appendix A5, p.61).

In terms of forest type (see also Table 2, p.25), more tents were found in transect part 1 (42 tents) in comparison with the second part (30 tents).

No tents of the lowest height category were found on the second half of the transect, i.e. the swamp forest and on only two occasions were tents occupied at this low height. It means that height category 4 could neither be included in the forest type nor the combined forest type/distance to canal variance.

5. Discussion

5.1. Overall findings

5.1.1. Primary versus secondary forest

Contrary to previous research by Smit (2012), where abundance of tent-roosting bats was much greater in primary forest than in secondary forest, bats seemed to inhabit the secondary forest more densely. Poorer visibility due to denser plant cover and the fact that the primary forest site was closer to a small human settlement could be part-responsible for this observation. And, another explanation could be greater competition with opposing frugivores, such as monkeys (Hulatt, unpublished report). Further causal research could shed more insight into the complexity of tent-roosting behaviour of bats. The secondary forest was not only very young, offering pioneer species plenty of opportunities to conquer the area, but also less disturbed than the primary forest near the village. What is more, the two transects varied in too many factors to make a proper and clean comparison. Future projects could be conducted where two transects would be cut that would be more similar in the non-biological criteria.

5.1.2. Positive trend in abundance of tent-roosting bats on the station grounds

Tent occupancy for Troolie Palms was significantly higher in this study (9.23% on average, see Raw Data in Appendix A4, p.60) than in the occupancy study conducted by Mulcahy (1993), where 1-2% of the 75 Troolie Palm tents were found occupied. This goes hand in hand with Figure 1: Change in Forest Cover for Costa Rica; p.5 and Cole's records (1994) of the station´s periphery, i.e. a positive trend in reforestation. This probably meant that the biological station also showed signs of the effects of deforestation in the 1990s and was in the recovery process. Another reason, why tent occupancy records were higher, might have been the less invasive approach of data collection that led to reduced flight reactions of the animals. Even if this study did not necessarily demonstrate a clear correlation with changing weather conditions, it led to a status report of tent-roosting bats with an overall positive trend in the last 20 years. However, caution must be executed since sampling times did not match. While Mulcahy (1993) surveyed the area in December and thus outside a nursing period, this project ran across the gestation/lactation period of *A. watsoni*. Since roosting fidelity would have altered in these two sampling frames (Chaverri *et al.* 2007a), the percentage of occupancy might partially have reflected this.

5.1.3. Dominance of one bat species in the study area

Figures 5-7 on pp. 29/30 demonstrated clearly that *A. watsoni* was not only the dominant tent-roosting bat species (see Figure 7: Percentage of bat species found under tents, p.30) on the station grounds but also that it was a pioneer species taking over the mono-specific palm swamp forest (Smit, 2012; O´Toole 1993). This was reflected in the type of tent, plant and habitat it roosted in, i.e. bifid tents of modified Troolie Palms in partially flooded swamp forests, plus the lack of abundance of other tent-roosting bat species in the vicinity. The survey concluded that a near 100% of bifid tents of the modified Troolie Palms were built by *A. watsoni* with one exception of *A. jamaicensis* found once under a bifid tent. Since the literature (Rodriguez-Herrera *et al.* 2007; Melo *et al.* 2009) states that *A. jamaicensis* often roosts under pre-constructed tents of other species, it was likely that in this one incidence *A. jamaicensis* occupied an abandoned *A. watsoni* tent. Taking into account that the unknown bats in Figure 7, p.30 were also most likely *A. watsoni*, the results would give a near 90% dominance of this species, and thus a clear species monopoly on the grounds of the biological station at the time of this study. Chaverri *et al.* (2007a) stated that roost fidelity in this species was higher when plant species diversity was lower. This could be concurred in this study, for many times most likely the same bats were found under the tents that were inhabited by this species. This deduction was made according to continually consistent numbers of individuals found under certain tents, which likely meant they were the same individuals. When juveniles were born during this time, these steady numbers only increased by the number of new-borns. It also coincides with the fact that the station grounds are currently still dominated by very few plant species and the preliminary study of the primary forest and the secondary forest showed higher roost fidelity in the less diverse secondary forest. A future research project could be to observe the territorial behaviour of this species to see whether they not only defend their territory against conspecifics but also against other species.

5.1.4. Opportunistic choice of plant host by *A. watsoni*

Interestingly, *A. watsoni* chose only one plant species and one tent type in this study area, despite the fact that it can be far more diverse in its roost choice according to Rodriguez-Herrera *et al.* (2007) and Kunz *et al.* (1994). This species is, in fact, the most flexible when it comes to host plants (modification of at least 42 plant spp.) and also masters the construction of 5 types of tents (see Table 1, p.9). While other research (Kunz *et al.*1994; Smit 2012; Chaverri and Kunz 2006) identified *Anthurium ravenii, Asplundia sp., Carludovica spp., Cyclanthus bipartitus, Heliconia spp., Calathea spp., Musa x paradisiaca, Astrocaryum strandleyanum, Asterogyne martiana, Bactris wendlandiana, Cocos nucifera* and *Geonoma spp.* as the main roosting plants for this species in Costa Rica, *A. watsoni* seemed opportunistically occupying *Manicaria saccifera*, the dominant understorey plant on the station grounds. Other species that are known to take over newly reforested areas, such as *A. jamaicensis* and *U. bilobatum,* did not confirm a dominance in abundance in this study (Willig *et al.* 2007; Pedersen *et al.* 2009). This pioneer and opportunistic behaviour probably speaks for good chances of survival in altered environments for *A. watsoni*.

5.2. Tent abundance in relation to climatic factors

As shown in the results, tent abundance was not significantly influenced by weather factors in the short term. This means the Null hypothesis that tent abundance was not correlated to daily rainfall or temperature could be accepted.

This came to no surprise, since the tent structures lasted from several weeks to several months and were unlikely to be influenced by daily weather changes (Kunz 1994). However, in future it might be useful to analyse whether tent abundance varies in relation to monthly precipitation levels, i.e. whether less tents are being built during the drier in relation to the wetter season.

The average temperature measured at the station, even when looked at on a monthly time scale, did not deem to be a major influencing factor in tent abundance. This was due to the steadiness of mean temperature throughout the year. It hardly deviated per month in this region. Temperature could therefore only play a role in long-term studies when a rise in mean local temperature could clearly be proven.

The rise in tent abundance (see p.34, Figure 8: Trend in tent abundance across survey) could be the result of a number of factors: Tent degradation on average took longer than two months (Kunz 1994), since most tents, counted at the beginning of the research period, were still accounted for on the last survey. The rate of tent construction must have been higher than the rate of tent degradation, as it took much less time to construct a tent than for it to fall apart (Rodriguez-Herrera, *et al.* 2007). It is also noteworthy that the researcher got accustomed to identifying tent roosts increasing the detectability of these roosts over the survey period.

5.3. Do weather factors play a role in tent occupancy?

According to the statistical analysis to find any correlation between temperature or precipitation and tent occupancy, daily weather changes did not significantly influence tent occupancy. Once again, also these Null hypotheses related to tent occupancy could be accepted. Nonetheless, in Table 3, p.33, one value nearly reached the 95% confidence value of statistical viability. Setting daily temperature deviation of the mean maximum temperature against tent occupancy resulted in a negative correlation of 35.6% at a 6.7% one-sided significance. Even though this could not be used to reject the Null hypothesis that there was no change in occupancy due to climate factors, it is worth monitoring in the long run. Since climate experts predict a rise in temperatures across the globe including the tropics (Enquist 2002; LaVal 2004), the two mentioned values might become more significant, leading ultimately to a reduction in tent occupancy in this region with rising temperatures.

As already stated by LaVal (2004), bats seem to be less sensitive to climate factors than other groups such as amphibians or reptiles. This is due to the fact that, on the one hand, the metabolism of the latter two ectothermic animal groups is directly affected by external temperatures and, on the other hand, because bats, overall, can inhabit different life zones and are therefore more diverse and flexible (Medellin *et al.* 2000). This study was coherent with his long-term findings of bat ecology in higher altitudes. LaVal's study showed no significant change in bat abundance and therefore could not prove any overall climate change effects. However, during his fieldwork some lowland species seemed to have been captured more frequently over time. This suggests that these species do correspond to the higher temperature at mid-elevation as found in the elevated cloud forest of Monteverde, Costa Rica. This might be due to the fact that bats can adapt well to new roosting conditions (Medellin *et al.* 2000).

5.4. Distance to the canal selection according to forest type and tent height

The findings of the two-way ANOVA showed clearly that bats seemed to make careful and complex choices when selecting their roosting site. It seemed that higher tents were preferential in general, as the number of counted tents increased with the next higher tent height category (see Table 2 p.25, i.e. number of tents/category: 2<7<19<44). From the limited number of tents in category 4 (two tents), it could probably be concluded that a certain height minimum was required when selecting a suitable roosting site in order to minimise predation. For example, *A. watsoni* inhabits on average tents between 1.5 and 5 metres (Kunz and Fenton 2005).

Furthermore, it has become apparent that tent-roosting bats seemed to prefer the more species diverse transitional forest, which was less likely to be flooded. Again, this was documented by the higher numbers of tents within the first 550 metres of the transect (42 in relation to 30 tents in the last 500 metres). In fact, Presley *et al*. (2009) provided further evidence that tropical bats can be good indicators for altered forest states, as species occupying the same ecosystem respond more or less successfully to different forest stages after human manipulation. In some cases in neotropical forests, moderate levels of disturbance had indeed a positive effect on habitat heterogeneity and hence could promote bat diversity (Gorresen and Willig 2004).

Studying the interaction of these factors (see Table 4, p.37) showed that:

1.) no single factor produced a significant difference for the tent-roosting bats on the station grounds among its intra-factorial categories;
2.) only in combination of the two factors did the two-way ANOVA show a significant result (p=0.02);
3.) the error rate was relatively high, pointing towards a large variance in data (see Table 4, p.37)
4.) the distance to the canal was farther in the swamp forest for height categories one, three and four, probably due to the higher chance of flooding in this area (see Figure 10, p.36), and;
5.) the tents for height category two (180-220cm) were on average closer to the canal in the first part of the transect (14 tents, see Appendix A5 - raw data on distance to the canal, p.61). Out of the five tents found under this height category in transect part two, three tents were found significantly further away from the canal than the other two (see Appendix A5 - raw data on distance to the canal).

It is worth noting that except for two tents in category three, all other tents in the swamp forest part were built higher than 180 centimetres. For *A. watsoni* this fell perfectly in their tent height range of 1.5 to 5 metres according to Kunz and Fenton (2005). This means that on average tents were constructed higher in the area more prone to flooding and therefore tent-roosting bats took the higher elevation of the ground into consideration when choosing the most suitable height for their tents.

5.5. Research method analysis

Studying tent-roosting bats only by means of visual observation bore both advantages and disadvantages. Due to this less invasive approach, a clear advantage was the lower recording bias of fleeing animals that might not return to the study site. Additionally, it guaranteed a lower risk of zoonotic disease transmission and of stressing the animals. A disadvantage was the inaccurate identification of certain bat species, e.g. *Artibeus watsoni* and *Artibeus phaeotis* that could not only be distinguished without examining their molars or by genetic tests (Chaverri and Kunz 2006). Since both species construct bifid tents, the roost was also no indication of which species was present. It means that this method could not conclude species-specific behaviour and only served as a generic observation of this group of bats.

5.5.1. Incoherent data collection of long and short-term surveys

Due to inconsistency in survey personnel, which consisted mainly of volunteers, and the discrepancy of survey approach, i.e. the data from the mammal survey (see Raw Data in Appendix A2, p.58) and that of the bat tent study (see Raw Data in Appendix A4, p.60), collected data could not be combined to produce a longer term analysis. Standardisation and strict adherence a clear protocol such the one by MacKenzie and Royle (2005) could solve this problem in future. Alternatively, parallel surveys, i.e. the more generic and long-term mammal survey and a short-term specific species/mammal group survey, could be used to calibrate the data and check for compatibility. For this scenario, even more limited data from the mammal survey could provide an inside into the ecology of specific mammal groups/species and would allow the researchers to check for roosting trends. Additionally, interpretation according to microhabitats could also produce more meaningful results in terms of habitat adaptations.

5.5.2. Critical analysis of study approach and suggestions for improvement

In hindsight, it could have been expected that there would not be any significant changes in animal behaviour over the course of the study period. This was, on one hand, due to the limited amount of research time. Climate issues cannot be highlighted within one annual cycle, let alone a few weeks. It needed to be put in perspective and compared in the long term over several years and decades. Another point is that changes in temperature, for examples, are *per se* so minimal for this region that a short-term view of two months would not have yielded in any results. Throughout the year the temperature on average fluctuates only between a few degrees (2-3°C) for both extremes, and maximum and minimum temperature lie year around roughly less than ten degrees apart (IMN 2013). This meant that animals for this region were unlikely to be influenced by such minimal temperature changes in relation to the annual cycle. However, there is evidence that tent-roosting bat species have reacted to long-term climate changes, as the study of La Val *et al.* (2004) showed.

Therefore, despite the fact that this research project on its own did not yield in demonstrating the influence of weather changes on tent-roosting, it could be used as part of long-term data collection, possibly contradicting the short-term findings of this study. Instead, it would make more sense to undertake a meta-analysis of climate influences on these bats and to incorporate the field work into this long-term data analysis. This could be done in a very methodological approach following a strict protocol that could be conducted at least twice a year, for example during the rainy and drier seasons or in comparing breeding with non-breeding periods.

An alternative could be to compare altered states of habitat due to climate change and other factors (e.g. the EPI indices). Then habitat – species ecology comparisons could be conducted, such as those by Medellin *et al.* (2000). It might be better to select ecotones as research sites as they offer themselves as more suitable habitats for climate transitional shifts, as suggested by Kappelle *et al.* 1999.

Knowledge gaps in relation to tent-making bats became apparent during the course of the study giving rise to further research questions in relation to climate research. A particular point of interest could be the species composition, for example. Which are the abundant species? Is this composition changing over time? What would this tell us about environmental factors? Medellin *et al.* 2000 provided a suitable protocol to conduct such a study. Could tent-making bats be used as environmental indicators in the long run, similar to their relatives of the Phyllostomidae family demonstrated by Fenton *et al.* (1992), Medellin *et al.* (2000) and Jones *et al.* (2009), as well as other bats (Adams 2010; Jiang *et al.* 2010; and Frick *et al.* 2012)? Is there an environmental trend emerging corresponding to the changes of habitat preference of certain bat species? Furthermore, do other factors such as microclimate, in particular roost temperature, play a role in roost selection of tent-making bats as proposed by Boyles *et al.* (2007)?

5.6. Suggestion on potential research projects

One suggestion for future research would be a long-term study of abundance, species composition of a species diversity index such as the one of Shannon-Wiener for tent-making bats in both primary and secondary forest sites available to the station. A good protocol could be obtained from Medellin *et al.* (2000). Against Smit's findings (2012), that this group of mammals was more abundant in primary forest than in secondary forest, it was shown in this study that in these two forest types tent-roosting bats, especially of the genus *Artibeus,* behaved contrarily. As regular surveys along the existing transects (Cerro and CPBS) consistently showed lower frequencies of bat presence in this primary forest (Cerro) (see Raw Data in Appendix A2, p.58), Smith's hypothesis that tent-roosting bats prefered to inhabit this type of rainforest over secondary habitats might be disputed. In fact, logic followed more the findings that bat abundance and composition was negatively affected by human disturbance (Medellin *et al.* 2000, Presley *et al.* 2009, Fenton *et al.* 1992, Jones *et al.* 2009). Further investigation might offer a different solution to this phenomenon.

6. Conclusions

Overall, this thesis offered an insight in the complex relationship of bat species reactions to changes in their surroundings. The grounds of the biological station invite to do further research to either confirm or disprove current knowlegde on the dynamics of bioindicators. Despite the fact that the methodology was not fully sound, as the project arose *ad hoc* in the field (the initial proposal could not be followed through), the overall content aims to make up for these short-comings. The field work shed light in mammal surveying and allowed me to get a feel for rainforest ecology, methodology and protocols.

If I were to conduct a similar study on bats as bioindicators again, I would follow Medellin's *et al.* (2000) example and compare altered habitats with graded levels of disturbance. This could not only be executed in a short-term project, but would also more readily provide results that could assist in argumentations for rainforest conservation.

All in all, it was an intense learning process in and out of the field. The application of the gained knowledge and critical thoughts will enable me to conduct research that would be much better designed and executed. It was an experience not to be missed!

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Appendix A Raw Data

A1 - Summary of the occupancy data in relation to plant taxa, bat taxa and type of tents encountered for CPBS

Plant taxa	No. Tents	% tents
Manicaria sp.	61	71.76
Potalia sp.	15	17.65
Heliconia sp.	2	2.35
ARACEAE spp.	7	8.24

Tent Type	No. Tents	% tents
Bifid	61	71.76
Boat	3	3.53
Conical	14	16.47
Bo/ap	3	3.53
Apical	4	4.71

Table 5 The discrepency in tent numbers for bat species and the other two tables comes from counting the total tents in the two tables above and the occupied tents in the bat species table

Bat sp.	No. occ. tents	% tents
Artibeus watsoni	31	77.5
Ectophylla alba	2	5
Artibeus jamaicensis	1	2.5
Uroderma bilobatum	2	5
unknown bats	4	10

A2 – Tent occupancy and tent abundance of the two transect sites

Months	CPBS/ % occ. tents	CPBS/ total tents	Cerro/ % occ. tents	Cerro/ total tents
Jul-12	29.41	17	0	2
Aug 12	16.67	6	100	1
Sep 12	50	4	50	2
Oct 12	7.69	13	0	0
Nov 12	55.56	9	25	4
Dec 12	75	8	100	8
Jan 13	19.05	21	28.57	7
Feb 13	31.03	29	100	1
Mar 13	35.29	17	66.67	3
Apr 13	82.14	28	7.69	13
May 13	100	2	0	0

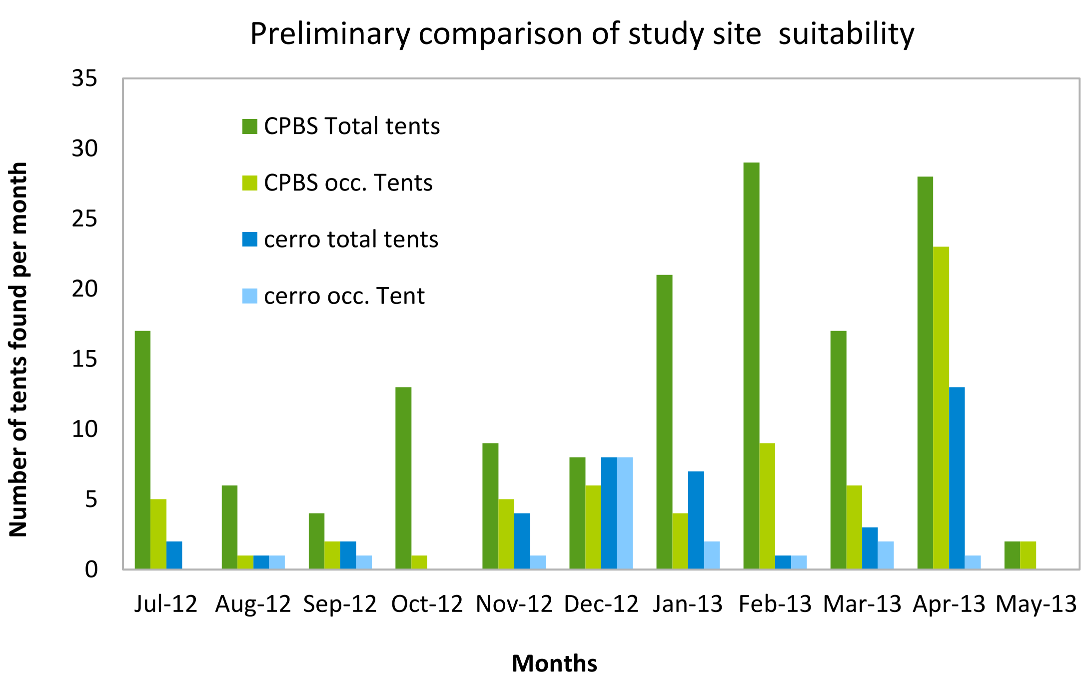

Figure 11 Monthly tent abundance at the two transect sites. The partially high number of occupied tents is probably due to recording bias, where only tents that were likely to host bats were noted included

A3 – Weather data from Caño Palma Biological Station for the time period 1 June 2012 to 31 May 2013 and from Tortuguero, Limòn for the year 2011

Climate data for Tortuguero	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total precipitation/ year
Av. Temp.max. (°C) Tortuguero '11	31.11	31.11	30.56	30.56	30.56	30.56	31.11	30	30.56	30.56	29.44	31.11	
Av. Temp.min. (°C) Tortuguero '11	20	20	20.56	21.67	21.67	21.67	21.67	21.67	21.67	21.67	20.56	20.56	
Av. Temp.max. (°C) CPBS '12/13	26.89	27.25	26.67	28.22	28.36	28.07	26.75	27.76	26.83	27.39	25.02	26.02	
Av. Temp.min. (°C) CPBS '12/13	22.73	22.50	23.03	23.83	24.01	23.92	23.54	23.74	23.28	22.63	22.25	22.52	
Av. Rainfall Tortuguero	317.5	210.82	203.2	276.86	279.4	297.18	426.72	312.42	144.78	208.28	391.16	444.5	3512.82
Rainfall CPBS (2012/2013)	267.3	127.45	386.6	116	351.4	317.6	1303.8	275.6	376.4	438.3	1653.7	801.4	6415.57
Total rainfall, Limón, Limón	293.3	257.4	212	244	367.6	287.7	425.6	311.6	150.4	205.7	287.1	416.9	3459.3

NB: The discrepancy in temperature is probably related to the fact that Tortuguero is a village much more exposed to the sun, while the Biological Station (CPBS) is directly surrounded by shading rainforest.

A4 – Summary of occupancy and abundance data of total tents and only for bifid tents collected from the bat survey at Caño Palm Biological Station

	8.4.13/ W1/ am	11.4. 13/ W2/ pm	13.4. 13/ W2/ pm	16.4. 13/ W2	19.4. 13/ W2	21.4. 13/ W3	23.4. 13 / W1 / pm	26.4. 13/ W2	28.4. 13/ W1/ am	30.4. 13/ W1/ am	3.5.13/ W1/ pm	5.5.13/ W3/ am	7.5.13/ W1/ am	10.5.13/ W2/ am	12.5.13/ W2/ am	14.5.13/ W1/ pm	17.5. 13/ W2/ pm	19.5. 13/ W2/ am	21.5. 13/ W1/ am	24.5. 13/ W2/ am	26.5. 13/ W4/ am	28.5. 13/ W2/ am	total
Total Bats found	2	15	0	7	12	5	17	16	11	14	11	6	8	14	10	9	25	16	15	14	18	11	256
Total occu-pied tents	1	7	0	3	4	2	8	4	5	5	3	2	3	5	4	3	10	5	6	7	5	6	
total tents		43		50	52	50	42	54	58	56	58	57	58	58	55	57	65	64	64	61	61	63	86
% occ. Tents		16.28		6.00	7.69	4.00	19.05	7.41	8.77	8.93	5.26	3.57	5.26	8.77	7.27	5.26	15.38	7.81	9.38	11.67	8.33	9.68	9.09
Occu-pied bifid tents		4		2	3	1	7	2	4	4	1	1	2	3	1	1	8	4	5	5	4	4	
Total bifid tents		19		28	37	33	31	34	38	39	38	38	35	36	36	38	45	43	41	40	40	42	
% occ. bifid tents		21.05		7.14	8.11	3.03	22.58	5.88	10.53	10.26	2.63	2.63	5.71	8.33	2.78	2.63	17.78	9.30	12.20	12.50	10.00	9.52	9.23

NB: For the dates 8.4. and 13.4 the data was added to the successive survey since at the beginning it took so long to find the tents that the survey was split in two days. Hence, the data for 11.4. and 16.4. is a summary of two survey days combined..

A5 – Distances of tents of different height categories

Cat. A		Cat. B		Cat. C		Cat. D	
118.46	0-550	43.86	0-550	70.71	0-550	82.66	0-550
117.80	0-550	73.01	0-550	93.72	0-550	118.07	0-550
115.26	0-550	74.32	0-550	99.09	0-550		
114.98	0-550	77.42	0-550	118.56	0-550		
112.61	0-550	79.61	0-550	90.82	0-550		
96.25	0-550	82.33	0-550	69.89	550-1050		
93.51	0-550	82.66	0-550	108.21	550-1050		
92.56	0-550	84.43	0-550				
88.46	0-550	84.50	0-550				
84.29	0-550	86.56	0-550				
83.87	0-550	87.85	0-550				
83.76	0-550	89.47	0-550				
82.66	0-550	92.66	0-550				
81.84	0-550	98.72	0-550				
81.27	0-550	65.80	550-1050				
80.62	0-550	76.06	550-1050				
76.28	0-550	131.14	550-1050				
70.83	0-550	135.21	550-1050				
70.71	0-550	197.39	550-1050				
68.41	0-550						
64.82	0-550						
63.60	0-550						
205.06	550-1050						
109.59	550-1050						
107.63	550-1050						
100.66	550-1050						
95.41	550-1050						
89.05	550-1050						
87.46	550-1050						
83.23	550-1050						

A=>220 cm

B=180-220 cm

C=140-179 cm

D=<140 cm

83.10	550-1050
76.06	550-1050
73.93	550-1050
72.84	550-1050
68.88	550-1050
65.73	550-1050
65.51	550-1050
65.30	550-1050
63.51	550-1050
62.37	550-1050
61.19	550-1050
60.80	550-1050
58.14	550-1050
50.80	550-1050

A6 – Middle values and summary statistics of the distance to the canal of tents according to the height categories and forest type/ transect part

	Cat A	% tents per forest types	Cat B	% tents per forest types	Cat C	% tents per forest types	Cat D	% tents per forest types	total obs	total exp
Median	81.84		84.47		96.40		100.36		83.10	90.77
Mean	85.21		91.74		93.00		100.36		88.50	92.58
Median 0-550	84		84		94		100		84	90
Median 550-1050	73.38		131.14		89.05				76.06	97.86
Mean 0-550	88.31		81.24		94.58		100.36		87.11	91.12
Mean 550-1050	82.10		121.12		89.05				90.71	97.42
total no.tents	44		19		7		2			
no.tents 0-550	22	50	14	73.68	5	71.43	2	100	43	
no.tents 550-1050	22	50	5	26.32	2	28.57	0	0	29	

The categories are as follows: Cat. A = >220cm, Cat.B = 220-180 cm, Cat. C = 180-140cm and Cat D = <140 cm.

Appendix B – Project Proposal

IS THERE A CORRELATION BETWEEN TENT OCCUPANCY AND DISTRIBUTION OF TENT-ROOSTING BATS AND PRECIPITATION ON THE PREMISES OF CAÑO PALMA BIOLOGICAL STATION, LIMÓN, COSTA RICA

HANAH AL-SAMARAIE

Edinburgh Napier UNIVERSITY

Research Dissertation Proposal Draft, MSc Wildlife Biology and Conservation,

School of Life, Sport and Social Sciences, Edinburgh Napier University
13 May 2013

Objective

To compare occupancy and distribution of roosts of tent-roosting bats in relation to precipitation at Caño Palma Biological Station, Limón, Costa Rica over the course of eleven months.

Null hypotheses:

1. The variation of precipitation does not significantly influence tent abundance.
2. The level of precipitation does not significantly alter the distance at which bats build tents away from the river
3. There is no significant difference in roost occupancy of tent-roosting bats in relation to precipitation.

Introduction

Costa Rica, situated in the tropical belt and a bottleneck site for migratory animals, harbours a wealth of resident and vagrant species making it a hotspot for biodiversity. Four per cent of all species in the world can be found in an area that covers 0.03% of the planet's surface (National Biodiversity Institute – Costa Rica, 2013). Among this diversity the second largest group of mammals can be found – bats. They are very versatile and can be encountered on all continents except Antarctica. As an example of their ability to adapt, bats use a variety of roosts from caves, abandoned buildings to tree hollows, branches and even constructed tents. This study focuses on exactly the latter kind of roost. In terms of longevity, tents are the least stable housings and a lot of time and energy are invested to keep building them. However, they offer flexibility due to abundance of plant sites, and the ease at which they can be built wherever needed. In addition, tents offer protection against predation, ectoparasites, sun as well as rain and help regulate body temperature (Stoner, 2000). Nonetheless, the architecture is limited to certain plant species with large leaves and follows eight tent structures. The Costa Rican Bat species that roost in them construct all of the tent types, namely apical, bifid, boat/apical, boat, conical, paradox, pinnate and umbrella (Rodriguez-Herrera, et.al. 2007). The construction is linked to harem building, as often one male is found with several females. Height, age and angle of the leaf are also important factors for the roost selection (Stoner 2000). It is believed that the animals use different tents during the night when they forage to the ones they occupy during the day when they sleep. This is likely a strategy to hide the roosting sites where they are more vulnerable to predation (Boinski and Timm, 1985).

Costa Rica is an ideal study area for tent-roosting bats as 10 out of 17 of these neotropical specialists can be found in the country (Rodriguez-Herrera *et.al.* 2006).

The Environmental Performance Index (EPI) for 2012 ranks Costa Rica at fifth place in the world compared to the third place in 2010 categorising it still among the strongest EPI performers globally. However, both the EPI trend and Costa Rica´s ecosystem vitality are decreasing (Yale Center for Environmental Law & Policy, 2012).

The Costa Rican tent-roosting bats of the Phyllostomidae family play a crucial role in seed dispersal in the tropics of the Americas, as they are all frugivores. Disturbance of their roosting sites reflects negatively on plant abundance dispersed by bats in the proximity of the feeding area (Melo, *et.al.* 2009). Therefore, their presence is a good indicator of forest health and monitoring bat prevalence could be an easy measure to understand their ecology and consequently assess the need for conservation action.

Increasing threats to these ecosystems include habitat destruction, deforestation and de-fragmentation (Rodriguez-Herrera, et. al. 2007), also tourism development, climate change, increasing natural disasters and pollution. In fact, Bergoeing (1998) documented that forest cover was drastically reduced within a 50-year time frame from 80% initially to 20% in the late nineteen nineties. In the fight for survival, bats have two options to adjust to such disruption. They either move elsewhere or they adapt to the newly found living conditions. This study aims to reveal whether there is a significant difference in roost occupancy and distribution at times with varied degrees of humidity.

It will be interesting to see whether roosts and their location show a different pattern throughout the wet and dry season. For example, is there a significant difference between tent type abundance, percentage of tent occupancy, relative distance to the canal and changes during the gestation and lactation periods.

Methods

Equipment: Binoculars, watch, recording sheet, geographical map of the research area, measuring tape, bat and tent field guide, plant id booklet, marking tape

In order to test this, tents are counted and their location is recorded together with weather data. The transect leads through a secondary lowland rainforest on a relatively flat plan west of the canal Caño Palma. Eight of the Costa Rican species have been sighted on the grounds of Caño Palma Biological Station with the two missing species being *Vampyressa thyone* and *Mesophylla macconnelli* (COTERC, 2010).

An existing transect of approximately one kilometre in length will be selected, situated in Barra del Colorado Wildlife Refuge near the Caribbean coast of Costa Rica. During the day, a ten-metre wide corridor along the path will be searched regularly for tents at the different vegetation levels. Temporal gaps between visits shall reduce the disturbance of the tents and the bias of fleeing animals. The coordinates together with the accuracy will be recorded on a GPS map to mark the location of the tent and show distribution patterns. In addition, tents are marked with a tape to improve visibility and checked regularly for occupancy. The height at which the tent is found will be categorised in three levels 0-1m, 1-2.50m, 2.5m+. In addition the type of tent (conical, bifid, boat, pinnate, umbrella, apical, paradox, boat/apical) will be determined according to the field guide by Rodgriguez-Herrera, *et. al.* (2007) . Tent type, plant species, numbers of individual animals per tent and the bat species will be noted on a recording sheet. In addition, weather data (daily precipitation and river depth), any kind of disturbance and unoccupied tents will be recorded. And finally, the peripheral landscape of the tation grounds will be described on a map in order to demonstrate the set up of the terrain. The observation will last 50 days, canvassing the site several times in order to obtain statistically relevant data and to record roost changes over time.

Further to the fieldwork, a temporal comparison of occupancy of tent-roosting bat species of the transect will be carried out using the data of the COTERC Mammal Survey of the past nine months (COTERC, unpublished data). This ought to provide a more coherent trend in roost selection over time. Sexual cycles will be included in the analysis in order to see whether this might be one of the variables that influence the tent occupancy.

In order to test the Null hypotheses I will carry out three linear regression analyses comparing

1. Precipitation against tent abundance

2. Precipitation against distance of tents to the river, and

3. Tent occupancy against precipitation

Whenever a tent is encountered, the flora density will be described at three rainforest levels as appropriate: ground cover, shrub and canopy quantified as:
For ground cover and shrub (Velander, K. 2012)

Table 1 Categories for vegetation cover at the ground and shrub level

1	Dense – inability for a small animal to move amongst ground vegetation
2	Moderately dense – small animal e.g. cat could move through undergrowth, but not a larger animal, e.g. a goat or sheep.
3	Moderate – a goat or sheep or animal up to human could walk through, but with some difficulty.
4	Moderately open – human could walk through easily single file
5	Open – several people would walk through easily, open canopy more akin to mature rain forest.

For canopy:

Table 2 Categories for vegetation cover at the canopy level

1	Closed vegetation – crowns or shoots interlocking
2	Open vegetation – crowns or shoots not touching
3	Sparse – crowns or shoots separated on average by more than the plant's crown or shoot diameter

Timeline

29 March 2013	Project proposal finalised
01 April 2013	Arrival at Caño Palma Station, Tortuguero NP, Costa Rica
01-07 April 2013	Familiarisation of local plant and bat species and structuring of the census
08 April – 30 May 2013	Distribution mapping
31 May 2013	Departure from Caño Palma Station
15 June 2013	Methods and Results complete
25 June 2013	Introduction complete
05 July 2013	Discussions and Abstract complete
10 July 2013	Final Draft complete

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Appendix C - Field Work Risk Assessment

SCHOOL OF LIFE SPORT AND SOCIAL SCIENCES

RISK ASSESSMENT FOR EXTERNAL ACTIVITIES AND VISITS

Name(s):	**Hanah Al-Samaraie**
Module:	**BMS11102 MSc Research Project**
Activity:	**Field work on tent-making bats for MSc thesis**
Date(s) of activity:	**01 April 2013 – 01 June 2013**
Ref No.	**09014398**

Summary of Activity: Describe what is being done and indicate whether High/Medium/Low Risk

Two rainforest transects of proximately 1000 metres each will be selected under the supervision of an experienced researcher. Both paths are situated on the grounds of the research station in the Barra del Colorado Wildlife Refuge near the Caribbean coast of Costa Rica. During the day, stretches of the transect will be searched daily for tents at the different vegetation levels. The location will be recorded on a map and checked regularly for occupation. Tent type, plant species as well as numbers of individual animals per tent and the bat species will be allocated to a vegetation map. All research is carried out from the ground and is purely observational. In addition, weather data, in particular precipitation and water level of the nearby river as well as unoccupied tents will be recorded. The observation will last 50 days, canvassing both transects regularly in order to obtain statistically relevant data and to record roost changes over time.

The activity will be supervised and protective clothing will be worn to avoid contact with poisonous or otherwise dangerous animals and minimise transmission of zoonotic diseases. A radio must be carried at all times in case of an emergency and observation will be carried out as much as possible by a minimum of two people. This reduces the risk of injury or illness.
Low Risk

Description of Site(s): Name and describe site and indicate whether High/Medium/Low Risk

Caño Palma Biological Station is a research site in the Limon Province of Costa Rica. It is situated within the Tortuguero Conservation Area of the northeastern part of the Caribbean. The area has a large variety of biological diversity due to the existence within the reserve of eleven different habitats, including rainforest, mangrove forests, swamps, beaches, and lagoons. Located in a tropical climate, it is very humid, and receives up to 250 inches (6,400 mm) of rain a year.

Caño Palma Biological Station is situated approximately 8 kilometres (5 miles) north of the village of Tortuguero. The Caño Palma Biological Station is located within the Barra Del Colorado Wildlife Refuge adjacent to Caño Palma, a 20 metre palm-filled canal which separates the Biological Station from the Caribbean by 200-300 metres. There are no roads in the area, and visitors to Caño Palma arrive by boat via a network of rivers and canals.

There are medical facilities in Tortuguero accessible 5 days a week. There is also a 24 hour clinic in the city of Cariari which can be reached by boat in an hour and a half, and a hospital in the city of Guapiles, which is an additional 20 minute drive from Cariari. A boat-ambulance is available locally, and a helicopter from San Jose can be arranged if an airlift is required. The station has a first aid kit, including snake anti-venom. **Low Risk**

Physical Hazards: List the hazards encountered and indicate whether Major/Serious/Slight

Sunstroke/ sunburn – **Moderate hazard**
Dehydration – **Serious hazard**
Flooding – **Slight hazard in April, medium hazard in May**

Chemical/Biological Hazards: List the hazards encountered and indicate whether Major/Serious/Slight

There is a possibility of insect bites leading to allergic reactions – **Medium hazard, as I am slightly allergic**
The unusual food and poor water quality in some places might cause stomach upsets – **Slight hazard**
Insect bites – **Serious hazard**
Animal bites/ stings including poisonous ones – **Medium hazard**
Scrapes from branches, etc. - **Low hazard**

Control Measures: Explain how the above hazards will be controlled eg safety equipment

Vaccinations against Rabies, Tetanus, Polio, Diptheria, Pertussis, Hep A and B
Supervision by an experienced researcher will reduce the risk of coming in contact with dangerous animals and dangerous sites. An essential list of items will be carried at all times including a first-aid kit, sun protection, a water bottle, insect repellent, and a rain coat.
Protective clothing should be worn at all times that covers most of the body and sturdy footwork will protect from injuries and bites by snakes, ticks or other animals. If an animal needs to be handled, it should only be done wearing gloves.
A mosquito net will minimise the risk of being bitten during the night.

Instructions for Students:

Apply insect repellent and sun cream regularly. Drink bottled water wherever possible and drink regularly. Eat thoroughly cooked food. Avoid ice cubes. Do not touch any animals if not absolutely necessary. Never work alone to minimise all risks. Always follow the instructions of the supervisor.

First Aid: Explain what personnel and equipment is available

The first-aid kit should include two crepe bandages, one sling, waterproof plasters, antiseptic cream, anti-histamine cream and tablets, disposable gloves, dioralyte sachets, NSAIDs of some form, anti-biotic.

In addition, water and antiseptic wipes would be of an advantage.

Emergency Procedures: Explain what arrangements are in place

Liaise with the NGO on how to proceed. Medical care is available as stated above.

Emergency numbers in Costa Rica:
Dial 911 in case of an emergency and they should have an English-speaking operator
For an ambulance, call 128
To report a fire, call 118.

Emergency contact in the UK: Jay MacKinnon, phone: (+44) 131 455 5720

For any legal problems contact the German Embassy:

La Embajada Alemana de San Jose
Dirección:Edificio Torre Sabana, Sabana Norte, del ICE, 2 cuadras al oeste, 8° piso.
Apartado: 4017-1000
Tel.: (506) 2290 9091
Fax: (506) 2231 64 03

Horario de Trabajo
Lunes a jueves de 7:30 a 16:30 hrs
Viernes de 7:30 a 13:30 hrs

Horario de Atención al Público
Lunes a viernes de 9:00 a 11:30 hrs (Para los asuntos consultares es necesario una cita, ver información a continuación)

Other Useful Telephone Numbers- Dial 113 for directory assistance and 124 for international directory assistance.

Any Other Comments:

Click here to enter text.

Assessment of Overall Risk:

Low Risk

Signed **(Student)** **Date** **31/03/2013**

Hanah Al-Samaraie

Signed **(Supervisor)** **Date**

Appendix D - Travel Risk Assessment

Risk assessments are a necessary part of ensuring the safety of students – this guide is for staff responsible for students needing to travel as part of their course of study and is a brief summary of the requirements. If travel is required as part of a Student Placement then this guide should be read in conjunction with that guide. To access any hyperlinks - hold down the Ctrl key and click on the link.

Heads of School or any other supervisory staff including School Safety Advisors are legally required to ensure they safeguard the health and safety of students including whilst travelling as a required part of their course of study.

Students have a similar responsibility to ensure they remain safe whilst engaged in any required activity as part of their studies including travelling.

Overseas Travel by Students on University Business

APPLICATION FOR APPROVAL OF VISIT (STUDENTS)

Students travelling overseas are required to obtain School/Service approval for travel prior to their journey and to make sure their trip complies with the University's insurance conditions, particularly if it is to an area of risk.

Please complete **Parts A and C.** Please print and sign the form and obtain your **Head's** signature in **Part B.**

Please then copy the form and send the **original.**

A : By filling in this form, I declare that:

1. I have completed a suitable and sufficient **risk assessment** in line with the University Health and Safety Policy for Travel Overseas.

1. I have **either**, sought and received appropriate health advice in relation to this overseas visit, **or**, I am travelling regularly to the same area and have ensured that the advice and information which I have is up to date.

2. I have checked whether the area I wish to visit is the subject of advice not to travel on http://www.fco.gov.uk.

3. I am physically fit to travel and have no medical condition that may be exacerbated or may endanger me by travelling to the proposed area(s).

Signature: ________________________________(traveller) Date: ____31/03/2013__

B : Head of School/Service must sign to indicate approval for this trip

Signature: _______________________(Head of School/Service) Date: _____________

C : Date of journey and contact details

1	Name and Designation	Caño Palma Research Station, Limon, Costa Rica
2	School/Service	School of Life Sport and Social Science
3	Date of departure from UK	31.03.13
4	Date of return to UK	01.06.13
5	Towns and countries to be visited and stop-overs en-route with dates	Madrid, Spain (31.03.13 and 01.06.2013) San José, Costa (31.03.13 and 31.5.13)
6	Contact details while overseas	Email:station@coterc.org; halsamaraie@gmail.com Phone of research station: 0-11-506-2709-8052
7	Name and ext no of School staff who hold details of your itinerary and contacts	Jay MacKinnon, Ext. 5720
8	Host Institution	NGO Canadian Organisation for Tropical Education and Rainforest Conservation
9	Purpose of visit	Field work in relation to the MSc dissertation

Risk Assessment

1 Contact Details	
Your full name:	Hanah Al-Samaraie
School/Service	School of Life Sport and Social Science

2 Risk Assessment *

Risk/Hazard	n/a	Low	Medium	High
Theft of laptop computer / mobile phone		X	Only during arrival and departure in the country	
Theft of passport		X	Only during arrival and departure in the country	
Theft of travellers cheques	X			
Theft of luggage		X	Only during arrival and departure in the country	
Travelling alone in buses / trains	X			
Arriving after dark / late night	X			
Risky / dangerous locations		X	Only during arrival and departure in the country	

Risk of accident / breakdown (i.e. hiring a car)		X		
Possibility of assault		X	Only during arrival and departure in the country	
Possibility of mugging		X	Only during arrival and departure in the country	
Risk of sickness from food / drink			X	
Risk of altitude sickness	X			
Risk of location-related illness (specify)			X (Dengue fever, illness due to ainmal poison e.g. snakes, spiders, bullet ants, amphibians, scorpions)	
If there are any other specific hazards that are not listed above, please list them below:				
Risk of being attacked by predators		X (Jaguars, peccaries, snakes, caymans and crocodiles)		
3 Documentation required **				

	Yes	*No*
Is a visa required for the country or countries you are visiting?		X

Do you have a photocopy of your passport?	X	
Do you have a photocopy of your driving licence?	X	
Do you have a separate list of your Travellers Cheques?		N/A
Do you have a European Health Insurance Card (EHIC) detailing your medical care entitlement?		X but travel insurance with health cover

Notes:

*** Section 2**

The purpose of this section is to raise your awareness of potential risks while travelling. Use the list to identify which hazards you may be at risk of when travelling or during your visit. Show how likely these are to occur, as far as you can estimate, by ticking the appropriate box in the right-hand column. The list is not exhaustive but is designed to help you assess the potential risks of your trip. You may find useful information about the country you are visiting on the Foreign Office website (www.fco.gov.uk/travel). If the occurrence of any of these hazards would have a significant effect on your circumstances, then take additional precautions – as in the Quick Guide if the advice is not to travel you must follow that advice.

*** Section 3**

Use the checklist to ensure you have all the necessary documentation for your trip. If you have answered "No" to questions 2 and 3, you should make copies as evidence of the original documents in case they are lost or stolen. Keep these copies separate from the original documents.

Travellers Cheques can only be replaced if you have a list of their numbers. Keep these numbers separate from the original cheques.

Signature: ____

31/03/2013

Date: ____________________________

In the event that any risk gives cause for concern, the Head of School must contact the Head of Procurement so they can alert the insurers and obtain approval prior to approving the journey.

THIS FORM SHOULD BE ATTACHED TO THE STUDENT TRAVEL AUTHORISATION FORM AND HELD WITHIN THE SCHOOL