BAT HABITAT USE ALONG A DISTURBANCE GRADIENT IN MANGROVE FORESTS, NORTHERN COASTAL KENYA

FINAL REPORT

JULY 2017

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ABSTRACT

Mangroves are a major component of the complex coastal ecosystems of Kenya that are very rich in biodiversity. Different organisms use the mangroves for foraging, shelter, roosting, breeding sites, and even as hideouts from predators and harsh environmental conditions. Yet, they are severely threatened by habitat loss, degradation and over-exploitation. However, few studies have been undertaken to understand effects of the loss and degradation of mangrove forests on many faunal species in Kenya. Bats are such an understudied group, not only in the mangroves but also in most parts of Kenya. Bats play vital ecological roles and indirectly affect all other forest biota. Using standard capture methods and acoustic bat detectors, this study investigated bat habitat use in mangroves with different levels of anthropogenic-driven habitat disturbance at Mida Creek, northern coastal Kenya. Eighteen bat species from six families were captured by the ground-level mist nets and twenty-five species from eight families were recorded by detectors across the three treatments throughout the study. There was no significant differences in bats captured between the dry and rainy seasons in all the treatments sampled but there was a significant different in terms of bat passes recorded. The disturbance gradients were not related to the number of bat species captured or bat passes recorded in all the study sites. This study developed a local reference call library and revealed much about how bats utilize mangroves during varying seasons. This information is important in testing and refining mangrove management practices. Additionally, public education, which was conducted around the study area, enlightened the communities living along Mida creek on the importance of bats and the general mangrove ecosystem but more intensive study and public education should be done in this area

INTRODUCTION

Coastal ecosystems in which mangroves are part of are very complex and rich in biodiversity. These ecosystems are faced with a myriad of challenges. In most of them, developmental-related activities resulting from increasing population, industrialization and urbanization are major driving factors of the degradation and habitat loss (UNWTO, 2013a). In the year 2000, the world mangrove forest areas remaining were 137,760 km^2 (Giri *et al*, 2011).

Mangrove ecosystems are biologically most productive, ecologically most diverse across the tropical belt and are keystone habitat by the sea (Ashraf & Habjoka, 2013). Mangroves provide a variety of functions to both humans and the ecosystem. They are nursery or breeding grounds for many faunal species, help in soil building, carbon sequestration, They also protect the shoreline from erosion, are used in building houses, as a source of fuel in terms of firewood, among other uses (Mclean *et al,* 2014).

Animals using mangroves as habitats range from marine to terrestrial. Marine animals include oysters, crabs, shrimps, dugong, marine turtles, porpoises and some fish species (Prance, 1998). Terrestrial organisms that may be found in mangroves include otters, snakes, monkeys, cats and bats (Prance, 1998).

In East Africa, there are nine known species of mangroves from six families (Mclean *et al,* 2014). The Kenyan coastline especially creeks and estuaries have well developed mangroves. Despite their enormous biodiversity significance, mangroves are most vulnerable to anthropogenic persecution due to varying degree of misconception surrounding its values to humans and other organisms (Ashraf & Habjoka, 2013).

These mangroves face threats like overuse; conversion of land for farming and settlement and pollution from untreated waste, pesticides, silt from erosion and oil spills (KIP, 2010). Majority of mangrove habitats are under serious threat from direct human pressures and removal (KIP, 2010).

Loss of mangroves from human disturbances results in declines in diversity and abundance of fauna (Manson *et al,* 2005). Coastal Kenya, like many parts of the country, has seen a dramatic increase in human population in the last couple of decades. This burgeoning human population is inevitably accompanied by encroachment on natural habitats such as mangroves to satisfy needs for land for settlement and agriculture. In Kenya, before a presidential ban on mangrove harvesting, enacted in

2002, 70 per cent of all wood requirements along the coastal strip were met using mangroves (KIP, 2010).

The inhabitants of mangrove ecosystems must regenerate elsewhere so the ecosystem can relocate upland and survive because mangroves are so intimately constrained to the tidal zone (Norman & Schmitt, 2015). While there is little doubt some human communities care for these habitats, there is an urgent need for all responsible, to better appreciate how these forests fundamentally differ from terrestrial forests (Norman & Schmitt, 2015).

The major problem facing mangrove forests management is the lack of the country's management plan (Dahdouh-Guebas *et al,* 2000). Another problem is that mangroves are frequently less regarded and often seen as wasteland. This is because mangrove swamps being often hot, mosquito-ridden, muddy and almost impenetrable (Martens, 1996).

Covering less than 50% of its original distribution, conservation strategies for the mangroves at Mida Creek depend on the maintenance of biodiversity in the remaining small and modified patches, and on information to help establish restoration plans (Meyer *et al,* 2008).

Some research and studies have associated mammal species richness bats included, with the diversity and naturalness of vegetation and this included forests of all kinds (Webala *et al,* 2004). Bats are best suited to examine degradations effects because they are highly mobile and ecologically diverse with a variety of feeding and roosting habits (Meyer *et al*, 2008).

East Africa has one of the most diverse bat fauna globally. In Africa, Kenya is ranked second most diverse after the Democratic Republic of Congo. To date 108 species have been recorded in Kenya (Patterson and Webala, 2012). The abundance of insect, fruit and nectar in mangroves attract bats to the mangroves (Macintosh & Ashton 2002). Apart from using mangroves for roosting, insectivorous bats utilize different insects found in the mangrove swamps (Hogarth and Peter, 1999). They are found to consume considerable quantities of insects (Macintosh & Ashton 2002).

About 200 species of fruit bats play an essential role as pollinators and dispersers of mangroves as they feed on the shoots, fruits and pollen of mangrove trees (Fujita, 1991). Ashraf & Habjoka, (2013) sited the loss of mangrove habitat as a major factor that leads to the declines in fruit bat populations.

Even though there is lack of ecological research relating species of fruit bats to mangrove pollination, it is evident that mangroves and fruit bats developed symbiotic relationship that may have in-depth implications for conserving mangroves and fruit bats (Ashraf & Habjoka, 2013). Although bats play an important role in the mangrove ecosystem, they are often misunderstood and persecuted in Kenya.

Most of Kenya's fauna is outside protected areas since only less than 10% of the country's land area is protected as National Park, Reserve or Forest Reserve (Bennun and Njoroge, 1999). This means that most of the areas bats roost and forage on are outside protected areas and therefore they interact with people all the time and some even roost in homesteads. This calls for a robust public education so that conservation of bats and mangroves become successful as people would be aware of their importance to them and the ecosystem as a whole.

Figure 1: *Cardioderma cor* roosting in roofs of houses.

Using a combination of equipment (mist nets and acoustic bat detectors), this study examined bat-habitat use along a gradient of disturbance in the mangrove forests at Mida Creek, northern coastal Kenya.

Objectives

Goal;

Assess the influence of human disturbance on the use of mangroves by bats.

Specific objectives;

1. Provide a baseline inventory of bat species extant at Mida Creek and other adjacent areas.
2. Develop a vouchered reference call library from bat echolocation calls for Mida Creek and adjacent areas to facilitate future acoustic studies and monitoring.
3. Compare bat captures and activity in mangrove forests with different levels of human disturbance.
4. Assess seasonal variation in bat habitat use in the mangroves.

MATERIALS AND METHODS

Study Area

This study was conducted at Mida Creek, Kilifi County at north coast of Kenya. Mida Creek is located about 20 km Southwest of Malindi town (03^{o}22' S and 39^{o}58' E), it borders Arabuko-Sokoke forest and Nature Reserve on the West. July to October records the lower temperatures averaging at 24° C while November to March records the highest with an average of 32° C (Osore *et al,* 2004).

Mida Creek experiences long rains from late April to early June and short rains in November and December. The dry seasons start from late December to March and from late April to October. The annual rainfall is 600-1000 mm, with May recording the highest monthly rainfall (G.O.K, 1989). The Creek gets fresh water input from ground seepage and surface runoff with no river draining into it (Osore *et al,* 2004). Habitats of Mida Creek area include mangrove forests, sand flats, rock-outcrops, sea grass beds, corals, deep waters and farmlands along the creek (Kennedy, 1988).

Covering about 32 km^2, Mida Creek is considered very productive with nine species of mangroves from six families (KWS, 2013). The nine species of mangroves at Mida Creek include: family

Rhizophoraceae; *Rhizophora mucronata*, *Ceriops tagal*, *Bruguiera gymnorrhiza*, family Avicenniaceae; *Avicennia marina*, family Meliaceae; *Xylocarpus granatum*, *Xylocarpus moluccensis*, family Sterculaceae; *Heritiera littoralis*, family Combreatceae; *Lumnitzera racemosa* and family Sonneratiaceae; *Sonneratia alba* (KWS, 2013). The dominant mangrove species at Mida Creek are *Rhizophora mucronata* and *Ceriops tagal.*

The farmlands involved in this study comprised of majorly maize crops (*Zea mays*), baobab trees (*Adansonia digitata*), *Casuarina equisetifolia* woodlots and Cassava (*Manihot esculanta*). These farmlands were around homesteads where many had cattle or goats around.

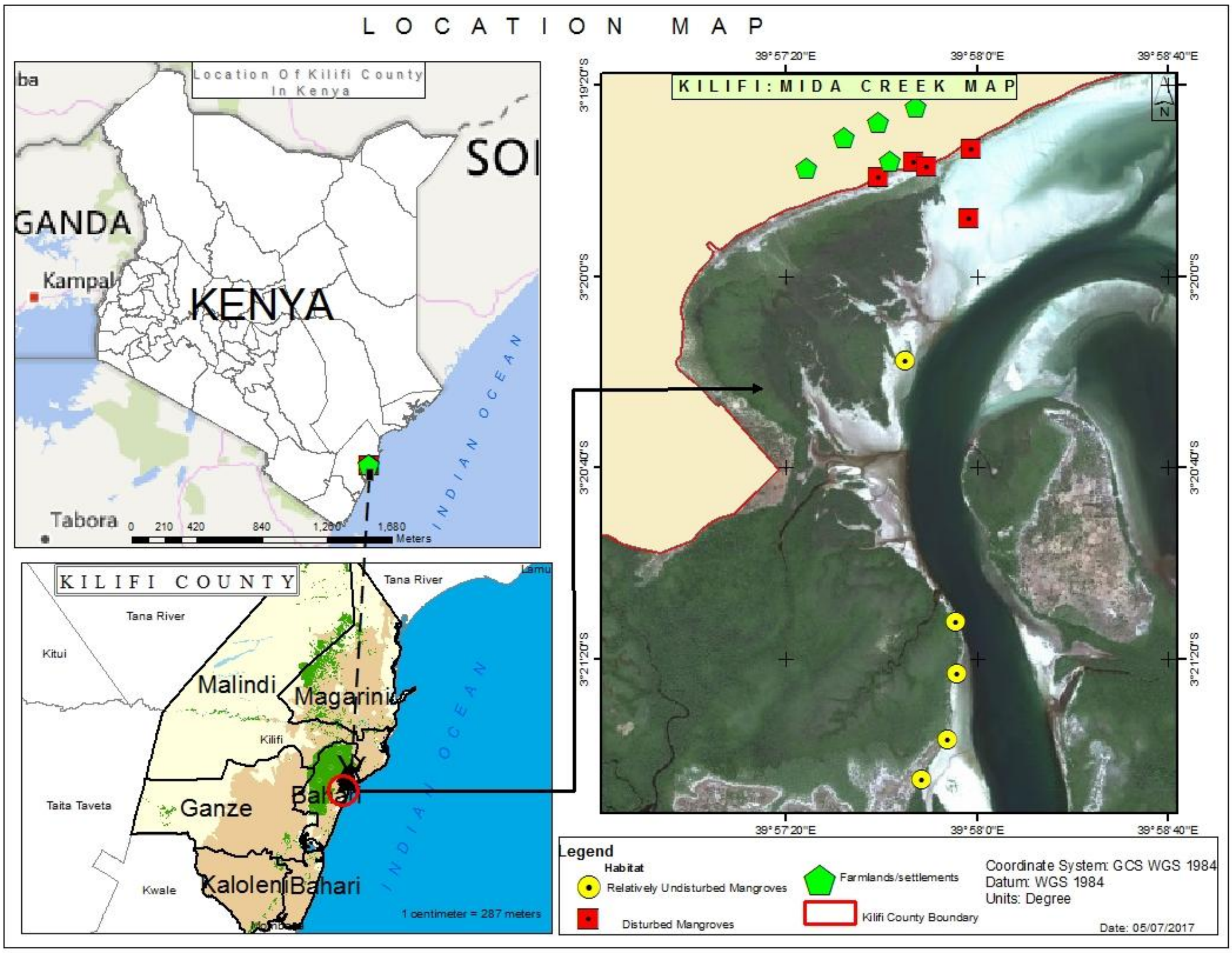

Figure 2: Study sites in Mida Creek insets showing location of Mida Creek in Kilifi County and the top inset showing location of Kilifi County in Kenya.

Field Methods

Three treatments; relatively undisturbed, disturbed mangrove patches and farmlands/ settlements were identified and sampled at Mida Creek and adjoining areas. Five sites in each treatment, were selected randomly *a prior* from the map of the area. Farmlands were included in the study because from a previous study by Gang & Agatsiva (1992), it was noted that the several agricultural land use practices in and around Mida Creek influence the mangrove ecosystem.

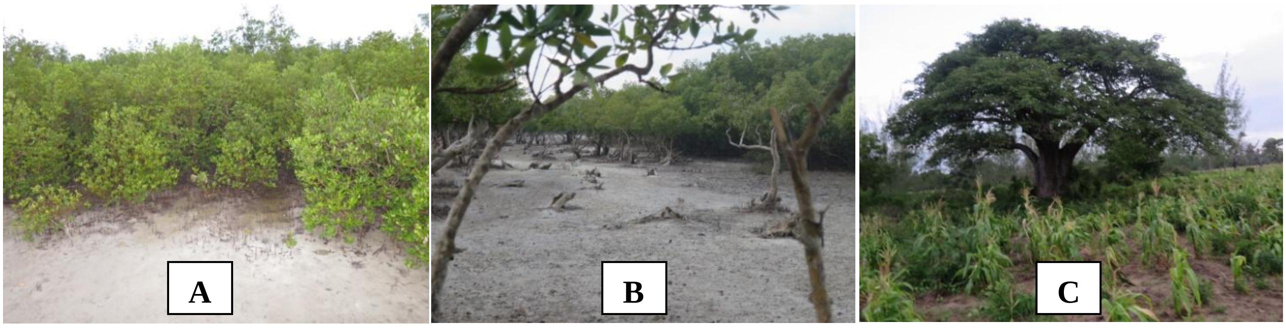

Figure 3: Samples of the study sites: **A**-Relatively Undisturbed Mangroves, **B**-Disturbed Mangroves and **C**-Farmlands/Settlements.

Net deployment

Bats were captured using standard mist nets (12 m long x 2 m high) deployed at ground level on potential flyways like open vegetation gaps (clearings) and trails to maximize capture efficiency (Heaney *et al*, 1989). Bat captures served two purposes, namely, comparisons of captures among the three treatments and also to develop a local reference call library. Bat captures were done twice, in the dry and wet seasons.

Figure 4: Setting up a net in a gap in the mangroves (left) and net set up in the farmlands/ settlements (right).

Bat trapping

At each site, six mist nets were deployed for two consecutive nights. Nets were opened at 18.30 h and monitored at intervals of 15 minutes until 23.00 h to avoid injuries and/or to reduce cases of bat predation in the nets. Nights with full moon or bright moon light were avoided due to potential reduced capture rate resulting from lunar phobia by many bats (Kunz, 1982; Lang *et al*, 2004).

Figure 5: Opening a net in a mangrove (left) and taking a bat out of a net (right).

Data collection

Bats were released at the point of capture but insectivorous bats that echolocate were hand-released in the open and their calls recorded in order to develop a local call library. Data collected from each captured bat included species, age (juvenile, sub adults, adults), sex, mass (to nearest 0.2 g using Pesola spring scales), and reproductive condition. Female reproductive condition was determined by palpating the abdomen and inspecting the mammae, age class was determined by examining the degree of epiphyseal–diaphyseal fusion (Racey, 1988).

Figure 6: Getting ready to hand- release and record the calls of a bat (left) and taking the weight of a bat in a bag before releasing it (right).

Bats were identified using available taxonomic nomenclature (e.g., Patterson & Webala, 2012). However, because it is not possible to accurately identify all species in the field, a few individuals of each species were collected and retained as museum vouchers to document captured species and to permit further identification.

These specimens were deposited in the collection of the Mammalogy Section of the National Museums of Kenya. For each specimen, morphometric measurements were taken, and these included total length (including tail), tail length, hind foot length, forearm length, ear length and tragus length, all to the nearest millimetre (Webala *et al*, 2004).

Barclay (1999) suggested that echolocation monitoring should be incorporated in bat surveys. A combination of techniques is essential for more comprehensive bat inventories (O'Farrell & Gannon 1999). Therefore for this study we also did acoustic monitoring along transects.

Transect sampling

The study sites were divided into 50 meters long parallel transects and each site had 3 transects 50 meters apart. Each transect was sampled three times per night from 18.30 h to 23.00 h with one hour break in between sampling sessions. Each transect was sampled the same way both in the dry and the wet seasons. Sampling of transects was done by walking at a constant pace from one end to the other alternating the starting end for each sampling session.

The amount of bat activity was quantified by the number of bat passes recorded at each sample site (Hayes, 1998). Echolocation calls were monitored using the DX1000 bat system (Pettersson Elektronik AB, Uppsala, Sweden).

Figure 7: Preparing the DX1000 bat detector (left) and at the start of a transect (right).

Disturbance Assessment

To explain expected variations in bat activity and number of bat captures (including species richness and diversity), level of human disturbance was estimated in 50 x 50-m plots in each of the sites. In each site, two randomly selected plots were sampled. Degree of mangrove degradation as an indicator of disturbance was indexed as density of stumps and number of footpaths in each plot. Chapman *et al*, (2007) used the density of tree stumps to account for anthropogenic disturbances.

Figure 8: Measuring the plots and making the edges with a white and red ribbon (held in hand) for disturbance assessment (left) and assessment of disturbance in a plot (right).

Public Education

Public education was done concurrently with the data collection to raise awareness about the importance of mangroves and bats to the ecosystem. Alemayehu (2014) suggested that a better management plan for the mangrove forest and the surrounding ecosystem of Mida Creek could be achieved by increasing the involvement of the communities surrounding the area.

Figure 9: Showing the public a bat and explaining the common features of bats.

Training/ Workshop

The tour guides from Mida Creek were invited for a training/ Workshop. They were told the importance of bats to the mangrove ecosystem and the need to use their position to enlighten the community and the visitors coming to Mida Creek on the same.

Figure 10: A session of the training (left) and Beryl Makori explaining the differences in fruit bats and insectivorous bats (right).

Their questions on bats were answered to the best of the team’s knowledge and contacts were exchange for further communication.

Figure 11: Sessions of the Workshop

Figure 12: Those in attendance being served with lunch.

Figure 13: The tour guides leader giving their contact information to the research team (left) and the project team with those in attendance (right).

RESULTS

Checklist of Bats

Habitat

1,116 bat passes were recorded throughout the entire study. Of this, 961 were from the relatively undisturbed mangrove patches, 99 from the disturbed mangrove patches and 56 from farmlands/settlements. 99.5% of these calls were identified (n = 1,110).

25 bat species were recorded in relatively undisturbed mangrove patches amongst which 11 were 'unique species' (not recorded in any of the other two treatments). Disturbed mangroves and farmlands recorded 12 species each in terms of bat passes. They also recorded 1 and 2 unique species respectively. *Chaerephon cf. major* recorded the highest number of bat passes and relatively undisturbed mangroves recorded the highest total bat passes.

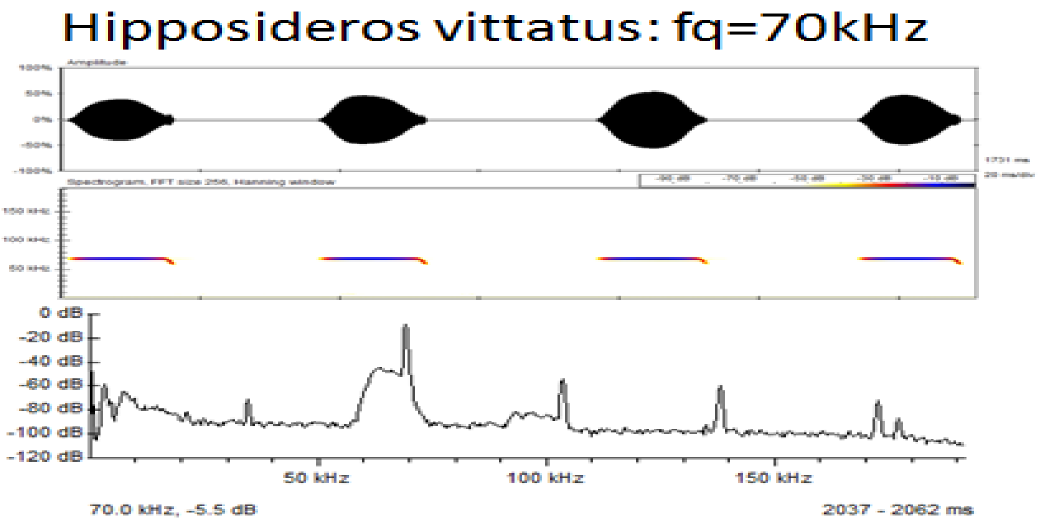

Figure 14: A sample of a bat pass recorded during the study and analyzed by BatSound software. The sample was identified to be of *Hipposideros vittatus*.

Throughout the entire study, 329 individuals were captured by mist nets. 64 individuals were captured from the relatively undisturbed mangrove patches, 184 from the disturbed mangrove patches and 87 from the farmlands/settlements. Individuals were identified at least to the genus level according to the available key (Patterson & Webala, 2012).

13 bat species were captured in relatively undisturbed mangrove patches of which 3 were unique species. Both of the disturbed mangrove patches and farmlands/ settlements recorded 11 species in terms of captures with 2 and 3 unique species respectively. *Scotoecus hindei* had the highest number of bat captures across the three treatments. Disturbed mangroves recorded the highest total bat captures.

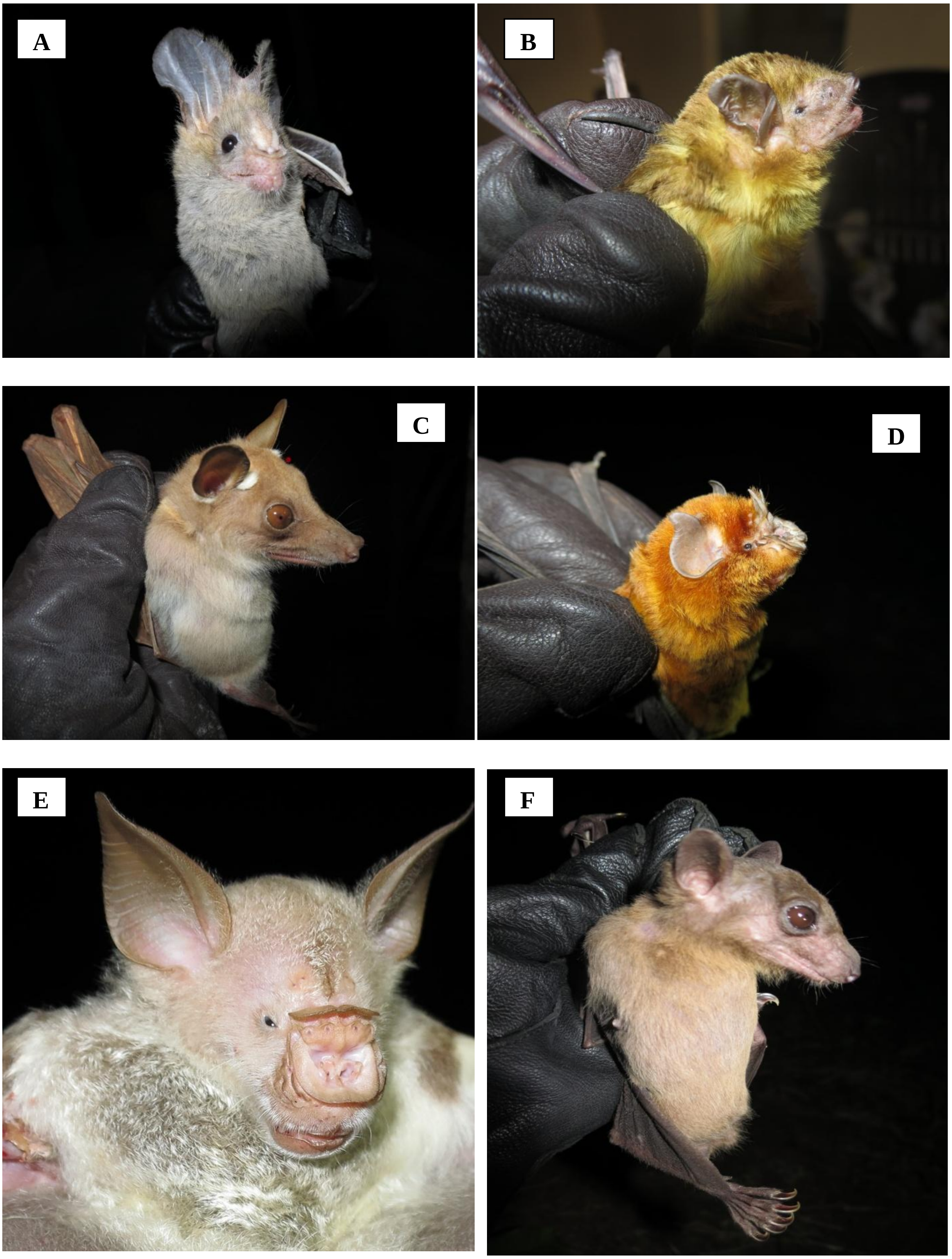

Figure 15: Samples of bats captured during the study: **A-** *Cardioderma cor*, **B**-*Scotophilus dinganii*, **C**-*Epomophorus wahlbergi*, **D**-*Triaenops afer*, **E**-*Hipposideros vittatus* and **F**-*Rousettus aegyptiacus.*

Table 1: Checklist of bat species captured and recorded per habitat.

FAMILY	SPECIES	BAT PASSES			BATS CAPTURED		
		Relatively Undisturbed Mangroves	Disturbed Mangroves	Farmlands/ Settlements	Relatively Undisturbed Mangroves	Disturbed Mangroves	Farmlands/ Settlements
Pteropodidae	*Epomophorus wahlbergi*				6	16	29
	Rousettus aegyptiacus				3	16	10
	Eidolon helvum						1
Rhinolophidae	*Rhinolophus eloquens*	15	1				
Hipposideridae	*Hipposideros caffer*	18					
	Hipposideros vittatus	74	13		2	11	3
	Triaenops afer	1				1	
Megadermatidae	*Cardioderma cor*	69			12	18	28
	Lavia frons	4					
Emballonuridae	*Coleura afra*	75	27	21			
	Taphozous hildegardeae	46	4				
	Taphozous perforatus	4					

Nycteridae	*Nycteris thebaica*	12			1		2
Molossidae	*Chaerephon bivittatus*	17					
	Chaerephon cf. major	154	4	3		3	
	Chaerephon pumilus	146	14	6		19	
	Tadarida aegyptiaca	2					
Miniopteridae	*Miniopterus cf. africanus*	14		1			
	Miniopterus minor	23	2	2			
	Miniopterus natalensis	5					
Vespertilionidae	*Neoromicia capensis*	48	7	2	4	1	3
	Neoromicia rendalli				5	7	
	Neoromicia spp	32	5	4	2		2
	Pipistrellus rueppellii	6			1		
	Pipistrellus spp	3					1
	Scotoecus hindei	98	12	5	12	65	
	Scotoecus spp	23					1
	Scotophilus dinganii	55	9	5	15	27	7

	Scotophilus viridis	17	1	1	1		
Unidentified	Unidentified 1			4			
	Unidentified 2			2			
TOTALS		**961**	**99**	**56**	**64**	**184**	**87**
S		**25**	**12**	**12**	**13**	**11**	**11**
H'		**5.05**	**2.14**	**2.07**	**2.12**	**1.95**	**1.74**
expH'		**156.69**	**8.50**	**7.95**	**8.31**	**7.05**	**5.71**
E_1		**1.57**	**0.86**	**0.83**	**0.83**	**0.81**	**0.73**

Season

The rainy season recorded the highest bat passes in total (916) and in the dry season, 200 bat passes were recorded. In terms of species, 26 were recorded during the rainy season of which 12 were unique to the season. 15 species were recorded in the dry season and only one species was unique to the dry season. *Chaerephon pumilus* recorded the highest number of bat passes.

174 bats were captured in the dry season and 161 individuals captured in the rainy season. 16 were captured in the rainy season and 13 species in the dry season. Across the two seasons, *Cardioderma cor* had the highest number of bat captures. The rainy season had the highest diversity index in terms of both bat passes and bat captures.

Table 2: Checklist of bat species captured and recorded per season.

FAMILY	**SPECIES**	**BAT PASSES**		**BATS CAPTURED**	
		DRY SEASON	RAINY SEASON	DRY SEASON	RAINY SEASON
Pteropodidae	*Epomophorus wahlbergi*			29	22
	Rousettus aegyptiacus			6	23
	Eidolon helvum				1
Rhinolophidae	*Rhinolophus eloquens*	2	14		
Hipposideridae	*Hipposideros caffer*		18	4	12
	Hipposideros vittatus	17	70	1	
	Triaenops afer	1			
Megadermatidae	*Cardioderma cor*	3	66	50	8
	Lavia frons		4		
Emballonuridae	*Coleura afra*	45	78		
	Taphozous hildegardeae	5	45		

	Taphozous perforatus		4		
Nycteridae	*Nycteris thebaica*		12	2	1
Molossidae	*Chaerephon bivittatus*		17		
	Chaerephon cf. major	32	129		3
	Chaerephon pumilus	32	134	3	16
	Tadarida aegyptiaca		2		
Miniopteridae	*Miniopterus cf. africanus*	3	12		
	Miniopterus minor	2	25		
	Miniopterus natalensis		5		
Vespertilionidae	*Neoromicia capensis*	8	49	5	3
	Neoromicia rendalli			10	2
	Neoromicia spp	20	21	2	2
	Pipistrellus rueppellii		6		1
	Pipistrellus spp		3		1
	Scotoecus hindei	16	99	29	48
	Scotoecus spp		23	1	
	Scotophilus dinganii	12	57	32	17
	Scotophilus viridis	2	17		1
Unidentified	Unidentified 1		4		
	Unidentified 2		2		
TOTALS		**200**	**916**	**174**	**161**
S		**15**	**26**	**13**	**16**
H’		**2.23**	**5.44**	**1.97**	**2.14**
expH’		**9.31**	**231.11**	**7.16**	**8.46**
E_1		**0.82**	**1.67**	**0.77**	**0.77**

Captures

Habitat

Each treatment had twenty sampling nights across the sampling period. The cumulative number of species did not reach an asymptote in any of the three treatments sampled over the twenty-night sampling per treatment. In disturbed mangroves, the cumulative number of species started to level off by the tenth capture night. Farmlands/Settlements started to level of around the eleventh capture night

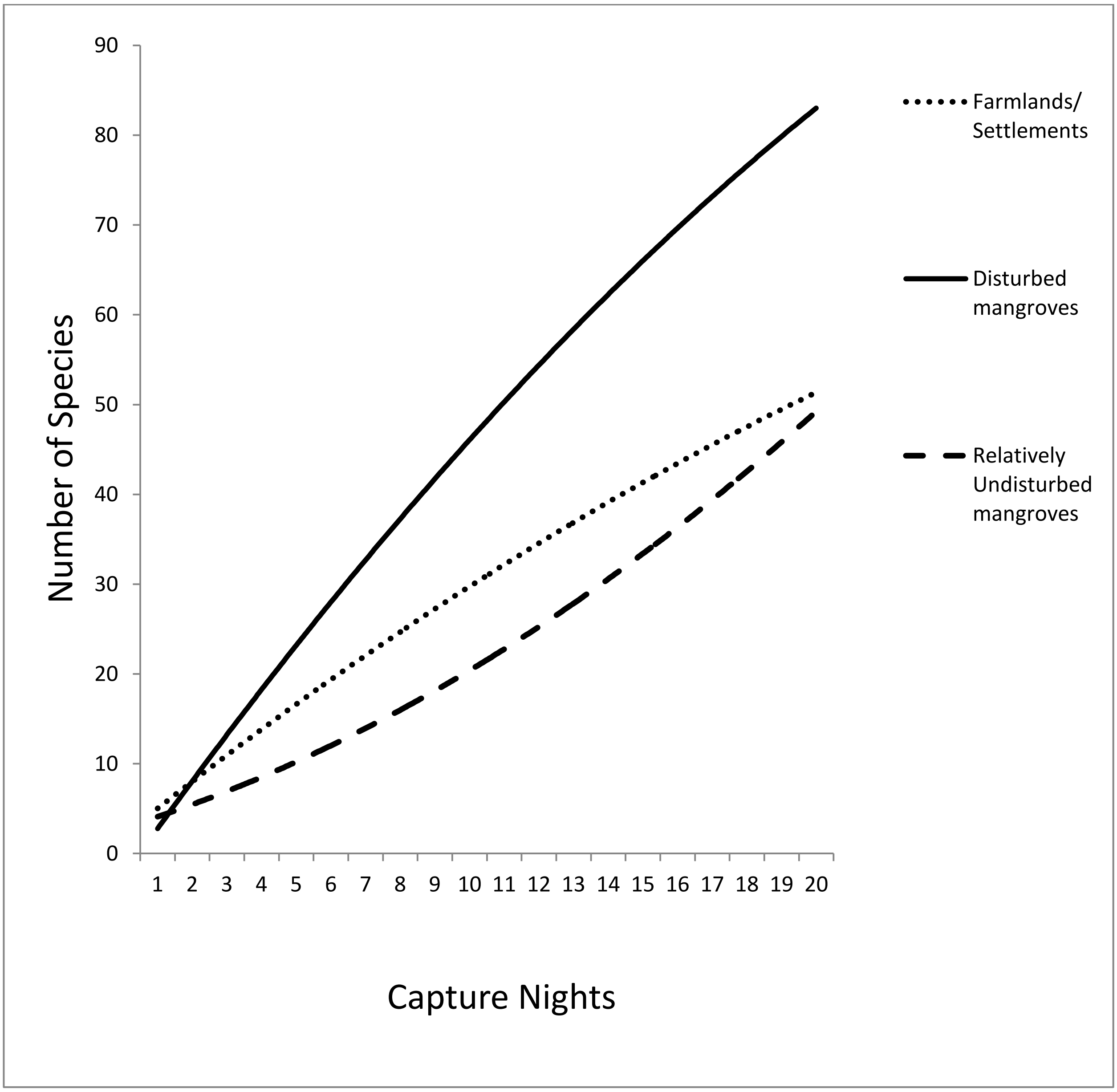

Figure 16: Cumulative number of species captured per habitat

Disturbed Mangrove habitats recorded the highest number of individuals captured, followed by farmlands/settlements and relatively undisturbed mangroves recorded the least. In terms of species, one way ANOVA showed that there was no significant difference in number of species captured in the three habitats, ($F(2,50) = 0.82$, $P = 0.447$).

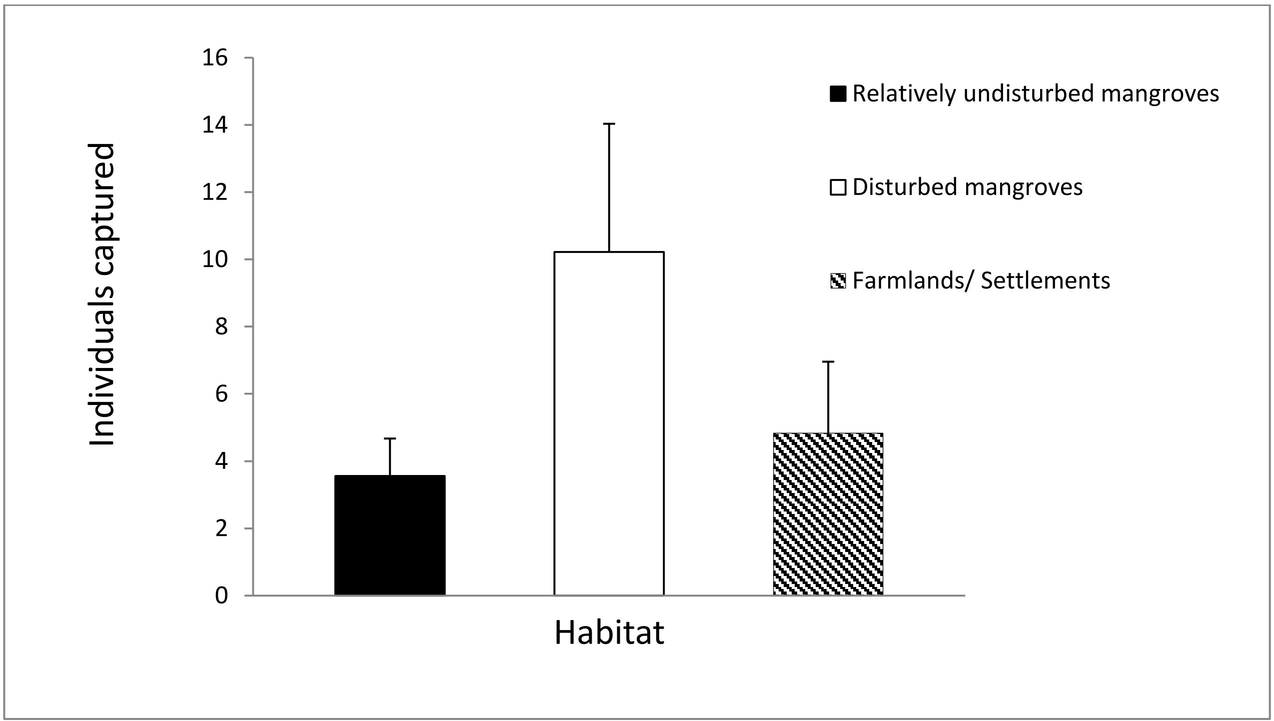

Figure 17: Mean Number of individuals captured per habitat.

Season

The results from one way repeated measures ANOVA showed that the highest number of species were captured during the dry season (mean = 9.67; SD = 14.80) while the rainy season recorded the lowest number of species captured (mean =8.94; SD = 12.51). The relationship between the different pairs of conditions was not tested because we only have two conditions (dry and wet season) making it just one pair of variables.

There was no significant main effect of season on the species captured in the different habitats recorded ($F(1, 17) = 0.053$, $P = 0.82$). Bonferroni post hoc tests showed that the rainy and dry season number of species captured did not have significant differences

These findings suggest that more species can be captured during the dry season compared to the rainy season in the habitats sampled, though the difference is not significant.

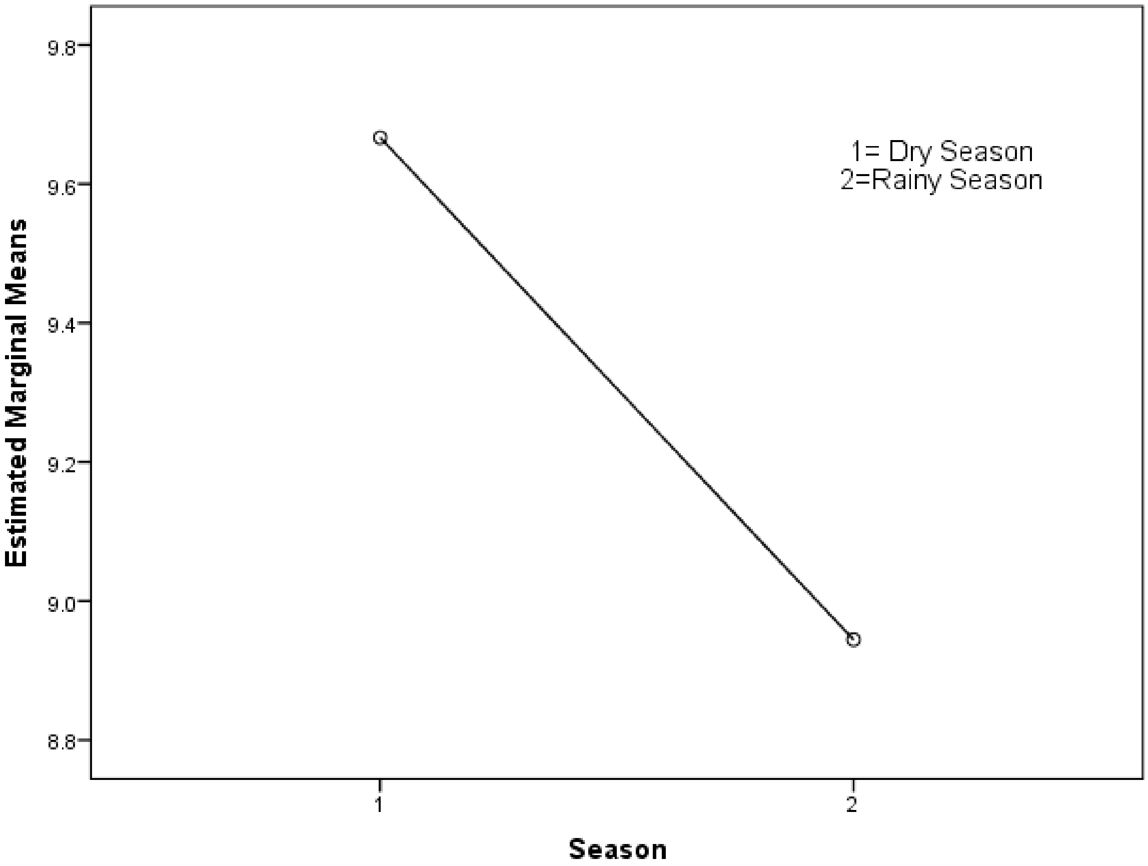

Figure 18: A comparison of mean captures in different seasons.

Calls

Habitat

Relatively undisturbed mangrove patches had the highest bat passes and farmland/ settlements the least as recorded by the bat detector during the sampling period. As shown by one-way ANOVA, the number of species that recorded bat passes in the three habitats sampled was significant ($F_{(2, 70)} = 7.57$, $P=0.001$). Post hoc tukey tests showed significant mean difference at the 0.05 level between relatively undisturbed mangroves and disturbed mangroves and farmlands/ settlements. There was no significant difference between farmlands/ settlement and disturbed mangroves.

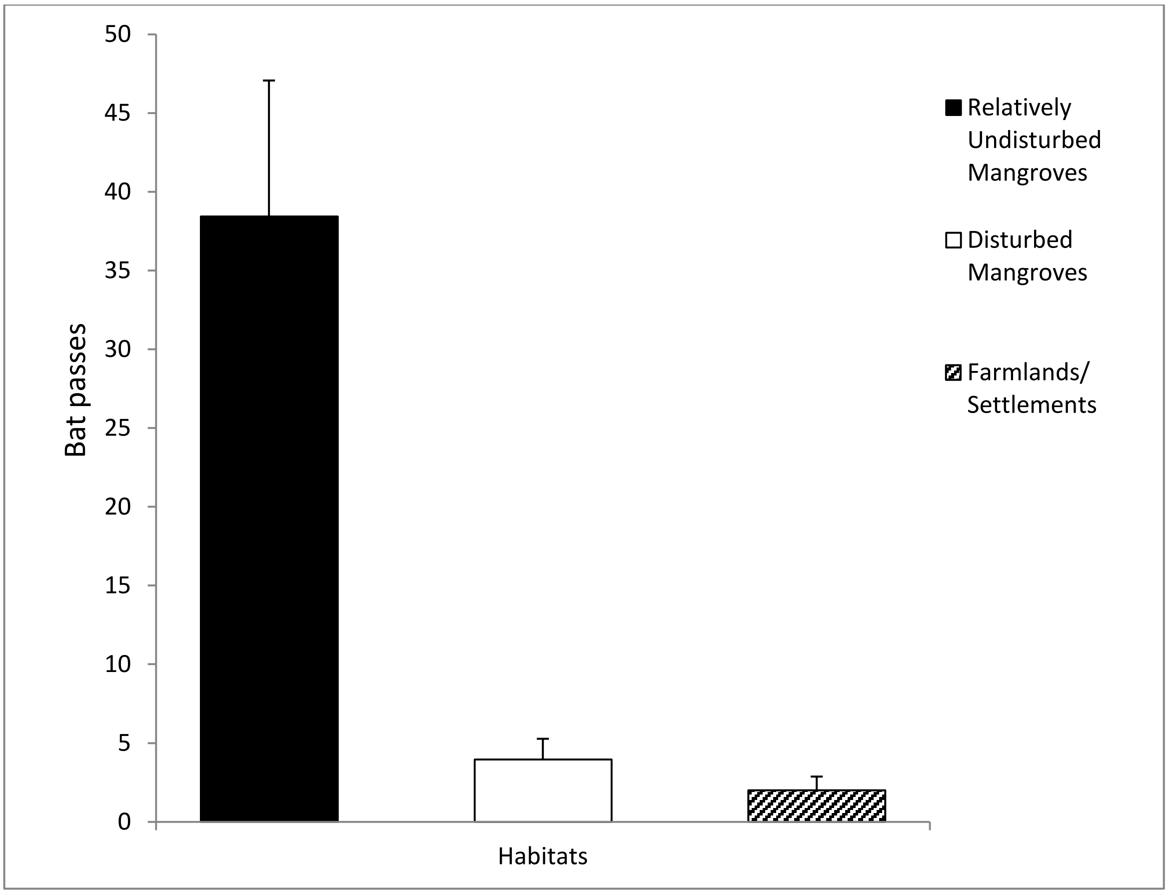

Figure 19: Mean Bat passes per habitat.

Season

One-way repeated ANOVA showed that more bat passes were recorded in the rainy season (mean = 36.48; SD=39.660) and dry season had less (mean =7.96; SD=12.408). Since we are only dealing with two variables, the test of sphericity is not considered.

There was a significant main effect of season on the species that were recorded in terms of bat passes in the different habitats sampled ($F (1, 24) = 21.86$, $P<0.001$). Bonferroni post hoc tests showed that the mean difference of bat passes recorded in the rainy and dry season had significant differences. These findings suggest that more species in terms of passes can be recorded during the rainy season compared to the dry season in the habitats sampled.

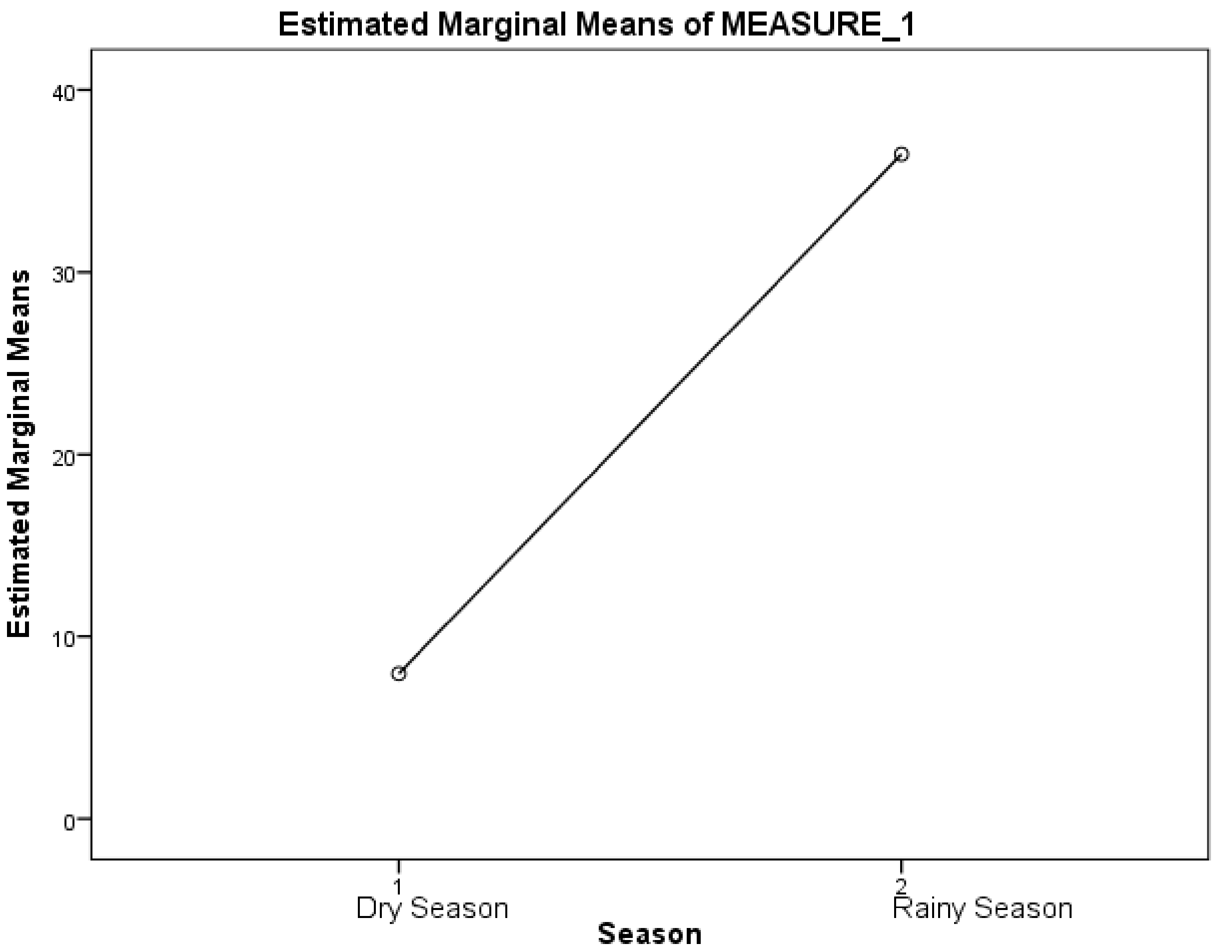

Figure 20: Marginal Means of bat passes recorded per season

Disturbance

Habitat

Relatively undisturbed mangrove patches had the highest tree density while farmlands/ settlements had the least. In terms of tree stumps, disturbed mangrove patches had the highest while relatively undisturbed mangrove patches had the least. Disturbed mangrove patches had the highest number of footpaths while relatively undisturbed had the least among the three habitats sampled.

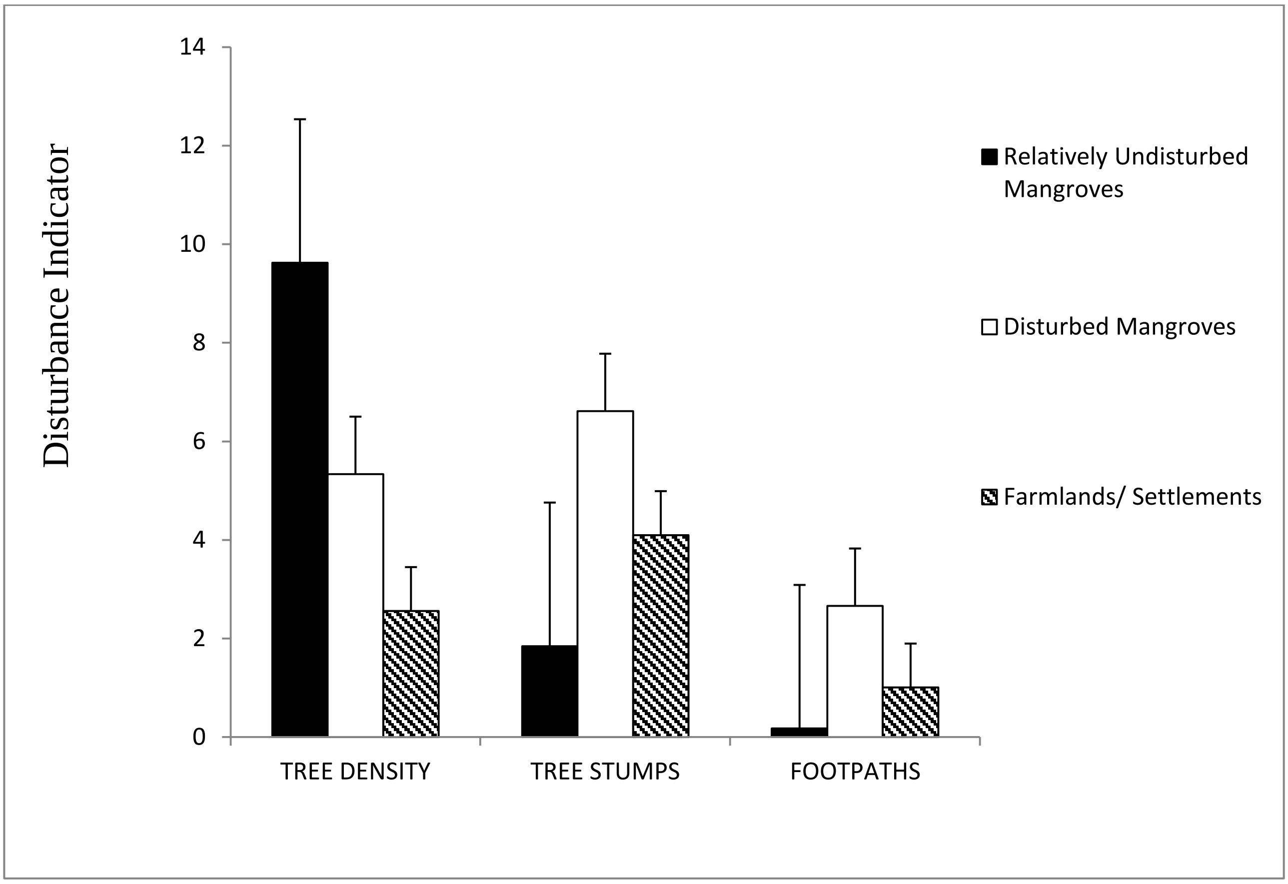

Figure 21: Disturbance indicator across habitats sampled.

Capture

Canonical correspondence analysis (CCA) suggests that the species captured in the different sites of the different habitats sampled are not linearly related to the variables which are the disturbance indicators sampled (F = 1.24; P = 0.236; Permutations=500).

Table 3: Eigenvalues, constrained inertia percentages, and cumulative percentages for the primary axes from bat capture CCA

	Axis 1	Axis 2	Axis 3
Eigenvalue	0.24	0.117	0.033
Constrained inertia (%)	61.872	29.838	8.290
Cumulative %	61.872	91.710	100.000
Total inertia	15.626	7.536	2.094
Cumulative %	15.626	23.162	25.256

The CCA results also display 61.87 % of the inertia (weighted variance) in the abundances and 29.84 % of variance in the weighted averages and class totals of species with respect to the disturbance variables. The eigenvalues of axis 1 (horizontally) and axis 2 (vertically) are 0.24 and 0.11, respectively; the eigenvalue of the axis 3 is 0.03.

The bi-plot shows that *Chaerephon pumilus* and *Hipposideros vittatus* species are associated with high number of tree stumps and areas near footpaths but low tree density. *Scotophilus dinganii* is associated with high tree density but away from footpaths and few tree stumps. *Pipistrellus* spp is associated with low tree density, few tree stumps and away from footpaths. *Scotophilus viridis* is more sensitive to tree density and *Pipistrellus rueppellii* is associated with low tree density, few tree stumps and away from footpaths.

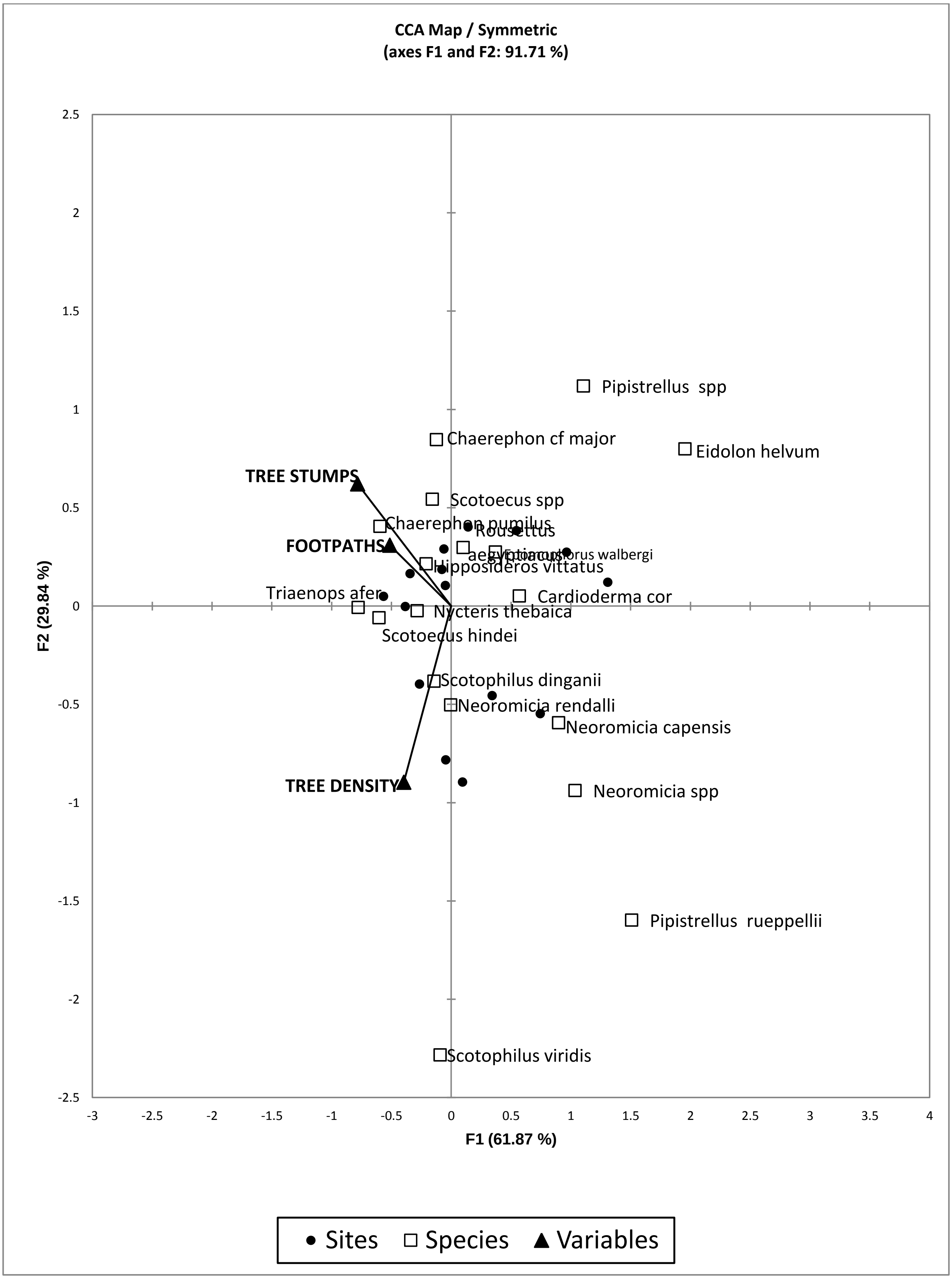

Figure 22: CCA bi-plot of bat species captured and disturbance indicators. Site labels removed to decongest the map.

3.1.1.1. Calls

CCA results as shown in table 4 , showed that the bat species that recorded bat passes in the sites of habitats sampled are not linearly related to the disturbance indicators measured (F = 1.04; P = 0.846; Permutations= 500).

Table 4: Eigenvalues, constrained inertia percentages, and cumulative percentages for the primary axes from bat passes CCA.

	Axis 1	Axis 2	Axis 3
Eigenvalue	0.126	0.107	0.068
Constrained inertia (%)	41.817	35.640	22.543
Cumulative %	41.817	77.457	100.000
Total inertia	9.249	7.883	4.986
Cumulative % (%)	9.249	17.131	22.117

There was a 41.82% of the inertia in the abundances and 35.64% of variance in the weighted averages. The results also showed eigenvalues of axis 1 (horizontally) 0.126, axis 2 (vertically) 0.107 and axis 3 is 0.068.

Rhinolophus eloquens was associated with high number of tree stumps while *Scotophilus viridis* was associated with high tree density. *Miniopterus cf. africanus* and *Scotoecus hindei* had association with low tree density, few tree stumps and few footpaths. *Triaenops afer* was more related to high tree density while *Scotoecus spp* was associated with high tree stumps and low tree density. *Scotophilus dinganii* was associated with average number of footpaths and tree stumps but low tree density.

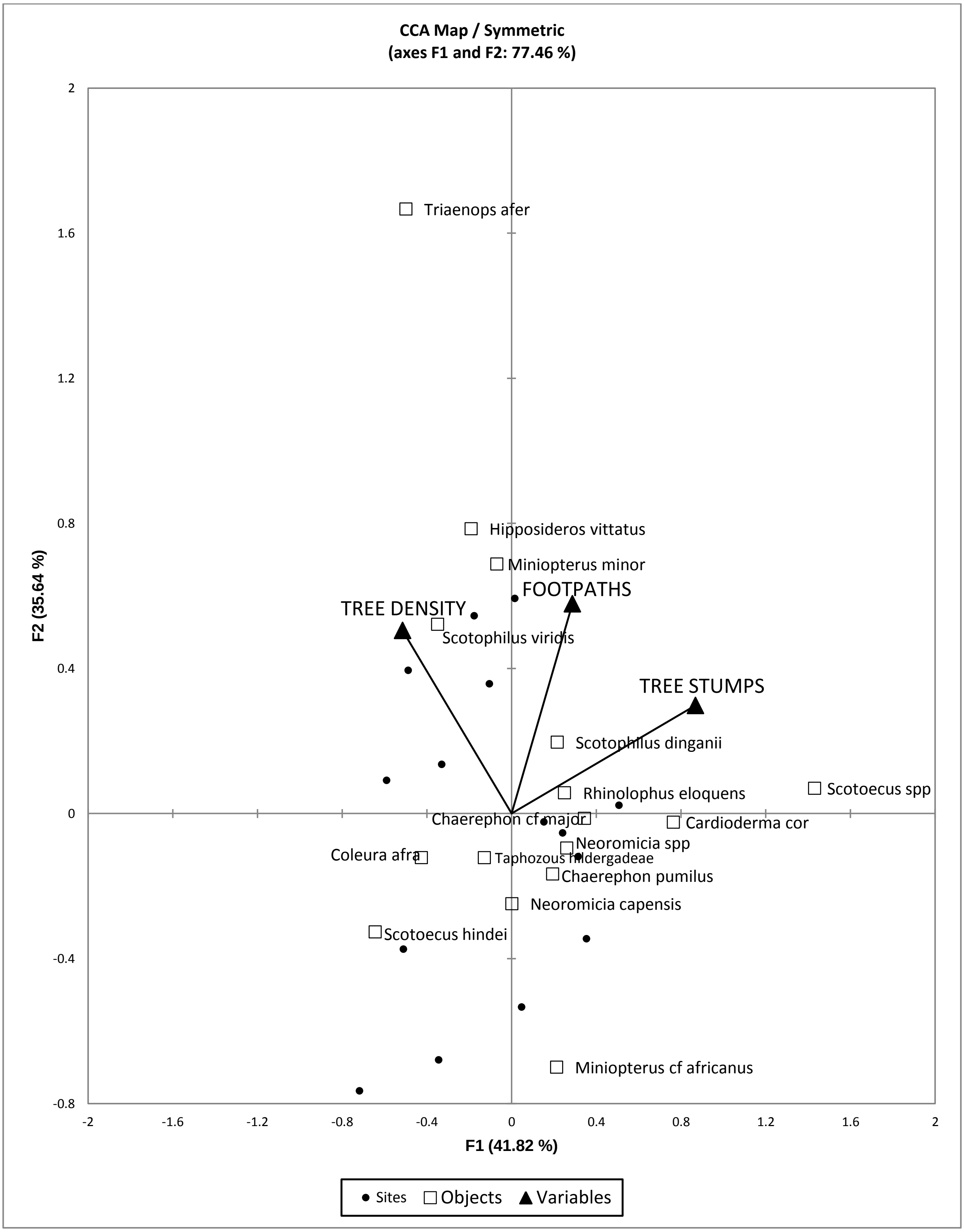

Figure 23: CCA bi-plot of bat species recorded in terms of bat passes and disturbance indicators. Site labels removed to decongest the map.

DISCUSSION

Eighteen bat species from six families were captured by the ground-level mist nets and twenty-five species from eight families were recorded across the three treatments throughout the study. Due to the limitation of a local call library, two different types of bat passes could not be identified here in listed as ‘unidentified’.

All the sites visited during this study had visible evidence of varying disturbance magnitude. Mangrove forests in Mida Creek area are not pristine (Rawlins, 1957). The term relatively undisturbed mangrove patches was chosen after the consideration of this previous study and undertaking a pre-visit of the area.

Figure 24: Setting up nets in cleared gap in the relatively undisturbed mangrove patches.

Apart from Kirepwe Island, all the other islands visited fell under the category of relatively undisturbed. It was observed that the disturbances in these small islands were mostly from fishermen who stay there during the night while fishing. This directed the decision of not calling these mangrove patches ‘undisturbed’ which would mean there is totally no disturbance evident.

The area most affected by disturbance was the disturbed mangrove patches, which also as we have seen from the results had the highest number of tree stumps and footpaths. The relatively undisturbed mangroves patches around the creek could only be reached by use of canoes, which were only owned by fishermen and Arocha Kenya for tourism services.

Relatively undisturbed mangrove patches had two more bat species in terms if captures. Further analysis showed that the differences in captures were not significant. Literature has documented that when mature trees are cleared, bat species lose potential feeding and roosting habitat hence communities shift towards disturbance-tolerant species (Basham *et al*, 2011; Threlfall *et al*, 2012). This could be the reason why there was no significant differences observed from the captures.

In the same habitat, twelve more bat species were recorded and the differences were significant. This finding agrees with previous studies that documented that acoustic sampling techniques yield a greater species richness that captures (Murray *et al*, 1999; O'Farrell and Gannon 1999). This huge difference was only observed in the relatively disturbed mangrove patches in this study.

Habitat loss or disturbance due to extensive land conversion and fragmentation result to landscapes that comprise of agro-forests, agricultural lands and sometimes remnants of the forest (Chazdon, 2014). The mangrove area is fragmented and according to Russ and Montgomery (2002), this may be beneficial to some bat species by increasing edge habitat but also can be disadvantageous to others by decreasing features that connect foraging areas.

The farm owners along the creek practiced slash and burn in their farmlands before the planting season. During this period, the bats especially around the farmlands and the neighboring mangroves were noted to be completely absent or very low in number. Large pieces of land were being burnt at the same time and sometimes the burning would go on for more than three days consecutively.

Figure 25: Farmland next to one of the study sites being burnt (left) and a tree in one of the farmlands burning (right).

Agro forestry and conversion of land for agriculture is a disturbance agent with potential influence for some bat species (Arellano *et al,* 2005). This is because habitat conversion may create refuges and promote an increase of bats in the area (Arellano *et al,* 2005).

The higher number of bat individuals captured in disturbed mangroves could suggest that, this treatment had more flyways for setting nets and for bats to fly and just enough tree density for the bats to roost, feed or patch on while resting. These findings agree with other studies that showed that bat species could persist in disturbed habitats and species diversity is frequently higher in areas with intermediate levels of disturbance compared to preserved areas (Schulze *et al,* 2000; Medellín *et al,* 2000; Williams-Guillén and Perfecto, 2011).

Another study has also shown that there is a significant reduction of bat diversity in farming systems compared to natural habitats within the same area (Webala *et al,* 2004). This could be another reason why farmland/ settlements had the lowest bat passes and captures across the treatments.

Whereas some regions like the temperate are seasonal in temperature (MacArthur, 1972), in the tropics seasonality is mostly defined by the differences in precipitation just as in the study area. It was observed that during the rainy season it rained in the mornings and/or at night. Though the differences were not significant, the dry season recorded more bats.

Seasonality of a region determines the population of bats in the aspect of food availability. Most of the bat families around the study area were insectivorous bats. Insect populations also exhibit season variation in terms of abundance. This is associated with rainfall and food availability (new leaves, fruits and other insects).

In regions that do not suffer very dry season, insect abundance decrease during the dry season and increase during the wet season (Frith & Frith, 1985). This situation might mean bat abundance would also increase during the wet season. This was observed in this study. Bat diversity was higher in the rainy season though the differences were no statistically significance.

It has been recorded in other studies that bats may avoid rain due to the energy constraints and interference of rain with echolocation (Voigt *et al*, 2011). During flight in rain, it was observed that the metabolism of bats increased twofold. When they become wet, it was noted that there was reduction in lift, thrust and thermoregulatory costs went high (Voigt *et al*, 2011).

Raindrops may also make it difficult for the bats to detect obstacles and prey by echolocation (Griffin, 1971). This statement was not true in this study since the rainy season had a higher number of bats recorded than the dry season. This may be due to other variables that were not taken into account in this study. However, the main difference was seen in the relatively undisturbed mangrove patches.

Species accumulation curves of the number of species plotted against the number of capture nights did not reach an asymptote in all the three treatments but in had began to level off in the disturbed mangroves and the farmlands/ settlements. This shows that the sampling in these treatments was not conclusive but the disturbed mangroves and farmlands/settlements suggests that the species captured was an approximate number trappable by the ground mist nests that were used (Colwell *et al*, 2004).

Since in this study only ground- level nets were used, just as in some previous studies (Simmons & Voss, 1998; Meyer *et al*, 2011), high fliers, sub-canopy and canopy bats that forage or fly beyond the height of the nets may not have been adequately represented or may have completely been absent. Bat recorder was used to compliment the ground- level mist nets to sample the high fliers and those that might avoid the nets too.

Footpaths and tree stumps that signified disturbance were not linearly related to the bat species captured or bat passes record. This shows that these disturbance indicators do not affect the abundance and diversity of bats in the mangroves. Bat tolerance to disturbances may be related to their ability to use available habitats in the modified environmental matrix (Estrada *et al*, 2004).

Figure 26: A network of footpaths in the mangroves (left) and a mangrove tree stump with signs it was cut down by humans

Tree density seemed to have an effect because fewer bats were related to it. This could mean that some bats species found it difficult to maneuver in the area with higher tree densities. Different bat species were associated to different disturbance gradients in this study. This shows that each species has a different tolerance capacity and is able to utilize habitats differently.

Figure 27: Mangrove tree cover of one of the study sites

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Disturbance may limit the availability of suitable roosting and / or foraging sites (Medellín *et al,* 2000) but still some species may prefer to forage or roost in the disturbed areas compared to undisturbed areas. Although excessive disturbance that lead to a complete habitat change like the farmlands/ settlements that were seen in this study may not be preferred by bat diversity of an area. Even though bats are highly mobile, their richness and composition may vary depending on the different levels and types of habitat degradation and disturbance (Willig *et al,* 2007).

During the study, there was evidence of the communities living along the creek using the mangrove trees for grazing their cattle in the mangroves and cutting down mangroves for firewood and other household uses. Pollution was also seen to be rampant in the mangrove area; it was noted that the communities do not have proper waste disposal plan in their settlements. All these waste was being dumped in the mangrove area, which is filled with plastics and all sorts of wastes. This could be detrimental to the mangrove communities, which in turn affect the bat diversity.

Figure 28: Cattle grazing in mangroves (left) and mangrove tree cut for household use (right).

There was evidence of charcoal burning in some parts of the mangrove area and the community was getting firewood from the mangroves.

Figure 29: **A-**A woman clearing charcoal just burnt from mangrove evident by mangrove leaves and twigs around the area, **B-** a spot that a mangrove tree was cut down and burnt there for charcoal and **C-** women carrying firewood from the mangroves.

The community practice beekeeping in the mangrove area, which is a mostly non-invasive use of the mangroves, which should be encouraged.

Figure 30: Beehives in different mangrove patches.

The public education carried out concurrently with the data collection showed that the people around the creek including tour guides and other stakeholders know very little about bats and their importance to the ecosystem. Even the knowledge that bats may be using the mangrove area as a roost or for foraging was lacking.

Recommendations

Extensive study needs to be carried out in the area especially the seasons could be replicated to make better-informed conclusions.

The stakeholders of Mida Creek should be informed of the importance of the mangroves to the bats and the bats to the ecosystem for better conservation of the mangrove ecosystem.

Alternative source of fuel, timber and use of less fuel should be taught to the community to reduce use of mangrove trees for source of fuel.

The communities living along the creek may be educated on proper waste disposal and the harm some of this waste cause to the mangroves and the fauna like bats found in the area.

ACKNOWLEDGEMENTS

I would like to thank my supervisors Dr. Paul Webala (Masaai Mara University, Kenya) and Dr. Mugo Mware (Karatina University, Kenya) for their support, advice, guidance, positive criticism and help with equipment throughout the process of the project.

I appreciate Dr. Jens Rydell (Swedish Environmental Protection Agency and Lund University, Ulricehamn, Sweden) and Dr. Bruce Patterson (The Field Museum of Natural History, Chicago, IL, USA) for their help and counsel at different stages of this work. I also recognize Simon Masika (Karatina University) and Vinya Ndoro Kadenge (Mida Creek Tour Guides Association) for the immense help I got from them as they worked tirelessly with me during the data collection process for this work.

I acknowledge the entire fraternity of Mida Creek and the management of Kenya Forest Service for their support and permitting me to undertake the study in Mida Creek.

I am thankful for the grants I received from Rufford Foundation (Grant number: 19315-2) and Council on Africa of The Field Museum of Natural History, Chicago, IL, USA that enabled me undertake the fieldwork.

Above all, I thank Almighty for his protection and good health throughout this process.

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