THE BATS OF THE MAYA GOLDEN LANDSCAPE

End of Project Report

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Wrinkle-Faced Bat, Centurio senex *(Bladen Nature Reserve, 2015)*

1. INTRODUCTION AND RATIONALE

Bats in the neotropics are a highly diverse group that have specialised to fill a huge range of ecological niches – they eat insects, fruit, nectar, reptiles, amphibians, fish, small mammals, other bats, blood. As such, the diversity of bats found in a given area can be a useful indicator of ecosystem health (Jones *et al*., 2009). Bats are important as they disperse pollen and seeds, facilitating forest regeneration, and act as natural pest control agents by keeping insect populations in check (Kunz *et al*., 2011).

In Belize bats constitute more than half the mammal species (Reid, 2009). Belize's bat diversity can partly be attributed to it's large expanses of undisturbed rainforest, littered with limestone caves and small rural populations. The Maya Golden Landscape (MGL), a region of southern Belize managed by Ya'axche Conservation Trust (YCT) exemplifies this – large forested areas inter-mixed with small developing communities and mixed agriculture.

The MGL was set up to protect biodiversity and livelihoods in the watershed of the Golden Stream and surrounding areas, and maintaining healthy ecosystems alongside healthy communities is essential for this to work. Bats were ranked as a high priority taxon in the 2009 Maya Golden Landscape Biodiversity Research, Inventory and Monitoring (BRIM) Strategy report (Wicks, 2009), as high diversity of bats was considered an indicator of healthy riparian and forest ecosystems, and technical and logistical capacity to monitor bats is cost-effective and relatively easy to establish. There has been relatively little bat research in southern Belize to date however, and what has been done has been led by foreign researchers who have since left, taking knowledge and skills gained from bat work with them.

For bat conservation in Belize to be successful in the long run it must be carried out by Belize nationals. This project therefore aimed to set up a bat monitoring programme in the MGL, lay foundations to enable this to carry on after the project ended, and to ensure research efforts in future could be led by locals.

2. PROJECT OUTPUTS SUMMARY

The key outputs of the project are summarised below, and each point is then covered in greater detail in subsequent sections of this report.

i. *Capacity Building*
- two Belizean interns were recruited and trained in bat research methodology
- the first bat biology course for Belizeans was held in January 2016
- interns, students, YCT and the Environmental Research Institute (ERI-UB) were all put in contact with the Red Latinoamericana para la Conservación de los Murciélagos (RELCOM) and a dialogue was opened on how to progress bat conservation and monitoring in future

ii. *Maya Golden Landscape Surveying*
- an inventory of bat species was compiled, their distribution within the different habitats of the MGL was assessed
- a high quality reference library of the echolocation calls of captured bats was started

iii. *Evidence-Based Sustainable Development*
- results of the MGL surveys provide baseline data on biodiversity in different agricultural landscapes, this will help inform future planning decisions and provide YCT with a solid starting point for future monitoring
- lessons learnt through survey work are being used to guide the soon-to-be-drafted national bat monitoring protocol

3. CAPACITY BUILDING

The long-term goal of the project is to initiate the creation of a self-sustained bat conservation group. The creation of such a group is essential for long-lasting bat conservation in Belize as it will allow information sharing, technical support/advice among members and lobbying for the conservation of bats. It will also allow for collaboration with a broader network of bat conservation organisations throughout the world.

For such a group to form it is necessary to have trained individuals with an interest in bat conservation. With this aim in mind two graduate interns were recruited to help with bat surveys being conducted as part of this project. Ingvar Alonzo and Tyrell Reyes worked on the project from early November to mid-December 2015 and were trained in mist netting, harp trapping, bat handling, identification and call analysis. The interns were keen to learn, picked up a lot of new skills quickly, and by the end of their internships they were able to carry out all tasks largely unsupervised.

In January 2016 a bat biology and conservation course for Belizeans was held at YCT's Golden Stream Field Station. Attendees included students from the University of Belize, a local high school graduate, the project interns, Dr. Elma Kay and Ivanna Whight of ERI-UB and YCT Science Director Said Gutierrez. Prof. Rodrigo Medellin, founder of RELCOM, delivered the week-long course, which covered subjects such as bat evolution, morphology, monitoring bats as indicators and measuring environmental services provided by bats. The course also had a strong practical element, and in the evenings students were given the opportunity to set up mist nets and handle bats.

The bat training course put interested students, emerging Belizean biologists and members of key Belizean institutions in contact, got them thinking about bats and opened a dialogue with RELCOM. It also provided everyone with a wealth of information on what's happening in the field of bat conservation. These were the first steps towards the creation of a well established and internationally connected Belizean bat group.

4. MGL SURVEYING

Surveys were undertaken to provide baseline data as a starting point for improving existing bat monitoring. The long-term goal is to have the MGL serve as a flagship for Belizean bat work.

Survey Design

Initial surveys were carried out from November 2014 to April 2015 and further work was carried out from November 2015 to February 2016. Surveys were conducted in four different habitat types: small Maya agroforestry farms in Golden Stream and Indian Creek and a larger farm in the Belize Foundation for Research and Environmental Education (coded AGR in figures and tables), mature forest in the Bladen Nature Reserve (BNR), secondary forest in Golden Stream Corridor Preserve (GSCP, coded GSC) and two monoculture orange orchards (ORG) (Figure 1).

Two different surveying approaches were used: capturing bats with mist nets and harp traps, and recording echolocation calls of passing bats with an ultrasonic bat detector. This approach maximises the number of bats it is possible to sample – some species fly too high to be caught in the net, and some use low intensity echolocations calls that are too quiet to be picked up on the bat detector (Gannon *et al*., 2005; MacSwiney *et al*., 2008). By using both approaches it is possible to sample more species than with one approach on its own.

Trapping and recording was carried out concurrently. Sampling locations were selected based on suitability for placement of nets, proximity to habitat features such as openings, rivers etc., aiming to maximise sampling effectiveness.

Trapping

Bats were sampled using a number of 12m and 9m mist nets erected at ground level. In addition to this a harp trap (G7 Forest Strainer, Bat Conservation and Management, USA) was set on trails close to nets. Occasionally a high net system was used to capture bats at sub-canopy level, this comprised three 9m mist nets stacked vertically using a pulley system, giving a total height of just under 8m.

Nets were set every night at sunset and left open for four hours. Trapping was not conducted on bright nights around the full moon, to avoid bat lunar phobia (Saldaña-Vázquez and Munguía-Rosas, 2013), and trapping was not conducted on consecutive nights to prevent mist net avoidance (Marques *et al*., 2013). Methods were standardised and sampling effort was kept as equal as possible among sites.

Each net was attended by a trained operator at all times, bats were extracted promptly and kept in bat holding bags until processed. Biometrics were taken (weight, forearm size and sex), species determined, and bats were then released. Species identification was done with the aid of an identification key for Belizean bat species (available on the project website http://batsofbelize.wordpress.com/).

When individuals could not be identified in the field (e.g. cryptic species or individuals of intermediate size between two species) samples were taken and species determined by DNA barcoding. This took place in collaboration with the Petters Research Institute Biodiversity Centre of Belize (PRI-BioBelize) in Dangriga, Stann Creek.

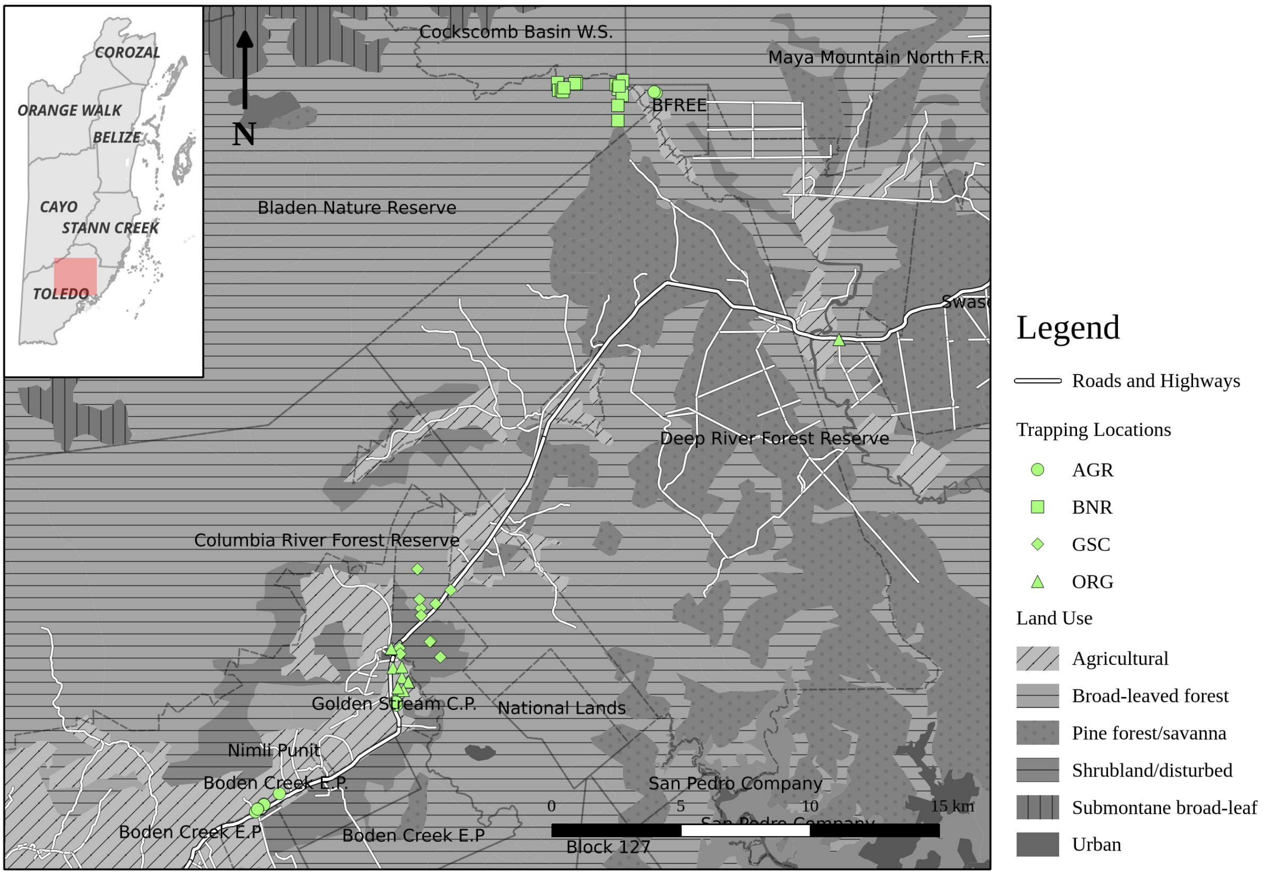

Figure 1 *– Trapping and acoustic monitoring locations in the MGL*

Acoustic Surveying

Ultrasonic detectors were deployed at all trapping locations, close to nets but far enough away to ensure that vocalisations of captured bats were not recorded. Over the course of the project two types of detector were used for monitoring bat activity: a frequency division Batbox Baton (Batbox Ltd.) with a separate digital recording device and an Anabat Express (Titley Scientific), that records in zero-crossing format. In addition to this two full spectrum bat detectors were used for compiling a high quality library of echolocation calls from captured bats: a Pettersson M500 (Pettersson Elektronik) and an Echo meter EM3+ (Wildlife Acoustics). Full spectrum detectors give better quality recordings. However the resulting files are large, and the specific models being used were not practical for night-long deployment. While the Anabat and the Baton give lower quality recordings they were better suited to being left out at length.

The detectors were set to start recording at sunset and were left to record for approximately 5 hours every night – activity of aerial insectivores decreases considerably after this time (Estrada-Villegas *et al*., 2010) so further recording was deemed unnecessary. Detectors were placed in the most open space available in each habitat to minimise variability in call quality and detection. Vegetation structure at every site was not identical however, and some sites were inevitably more cluttered than others. Due to detector malfunctions, weather etc. it was not possible to make full recordings every night of trapping. As a result there are full night recordings for only about 70% of the nights trapped.

Analyses

Ultrasound recordings were used to identify species by comparing call parameters (such as shape of call, duration, and peak frequency) with known species parameters from published literature. This is summarised in a spreadsheet available on the project website. Analysis of frequency division and full spectrum recordings was carried out using Audacity (http://www.audacityteam.org/), and zero-crossing calls in Analook (http://www.titley-scientific.com/au/index.php/software_firmware).

Species accumulation curves were plotted using EstimateS (Colwell, 2013), randomly resampled x100. Separate curves were calculated for trapping and audio data. Because trapping methods were highly biased towards Phyllostomids, only this group was used for the accumulation curve, and only individuals from mist netting. Non-phyllostomids are represented in the audio data accumulation curve. EstimateS includes a number of algorithms that can be used as estimators of true species richness. These were used to get an idea of inventory completeness.

Species found in previous studies (Brewer *et al*., 2013), from YCT ranger sightings, or from outside standardised surveys were added to the inventory to give as complete a picture of bat diversity in the MGL as possible; however they were not included in analyses.

Capture rate from trapping was estimated by dividing the number of bats captured by the number of mist net hours (bats/mnh) or harp trap hours (bats/hth). Not all DNA barcoding results were available at the time of writing, so individuals that were not identified to species level were not considered for analysis (because their numbers were negligible; *Artibeus sp, Carollia sp* and *Glossophaga sp*), and genera that had large numbers of individuals not identified to species level were grouped (*Dermanura gen*).

Recordings with very faint bat passes or recordings from which it was not possible to identify species reliably were classified as ‘unknown’ (12% of recordings that contained calls) and were not considered for analysis. Additionally, species of some genera are not possible to tell apart by acoustics alone, and as a conservative measure were grouped for analyses: *Eumops gen* (*E. nanus*, *E. auripendulus* and *E. glaucinus*), *Myotis gen* (*M. keaysi* and *M. elegans*), *Lasiurus gen* (*L. ega* and *L. intermedius*), Vesper 50kHz (*Bauerus dubiaquercus, Rhogeessa tumida* and *R. aenerus*).

While individual bats cannot be counted using acoustic methods, their relative activity may be quantified through the number of passes in a standardised time interval (Fenton, 1970). For this report we used the Acoustic Activity Index (AI) developed by Miller (2001), where species presence in one-minute time blocks is used to calculate activity levels relative to sampling effort, enabling comparison of activity between sites. The AI is calculated as follows:

$$AI = \frac{\sum p}{P}$$

where p stands for any given one-minute time block in which the species was present and P is the total number of one-minute time blocks in the sample. For example, if in a 10 minute recording a bat is present in 3 one-minute blocks, the AI will be calculated as 30%. This method compares bat activity at a sampling point rather than bat abundance, although both variables are correlated (Wickramasinghe *et al*., 2003).

Results Overview

Over the course of the project a total of 576 net hours and 72 harp trap hours were conducted, and 187 hours of recordings were analysed (Table 1). Overall, 39 species were trapped and 19 species were positively identified from recordings, giving a total 51 species found with both methods (Table 4). There were four species found in previous studies that were not encountered during this project's trapping sessions, and one additional species only encountered outside standard surveys. There were also four phonic types recorded that could not be identified to species level, as each type could represent 2-3 species.

Table 1 – *Sampling effort in different habitats of the MGL*

Site	***Visits***	***Net (h)***	***Detector (h)***	***Harp Trap (h)***
AGR	13	139.5	56.38	20.08
BNR	16	157.2	43	25.17
GSC	16	146.3	44.75	20.67
ORG	13	135.7	43.17	10.27
Total	*58*	*578.6*	*187.2*	*76.18*

Trapping Results

A total of 1,639 individual bats were captured across all sites – 507 in agroforestry, 500 in BNR, 339 in GSCP and 293 in orange orchards. Mist netting yielded a total of 1,578 bats while the harp trap captured 61 bats. Of the 39 species found, 29 were not logged on the detectors. Species belonged to the Emballonuridae, Mormoopidae, Natalidae, Noctilionidae, Phyllostomidae and Vespertilionidae families. The number of bats caught by mist netting, relative to trapping effort, is shown in Figure 2. Eighty percent of the individuals sampled belonged to the Phyllostomidae family, and 15.6% to the Mormoopidae. Members of the Mormoopidae family were more common in forested sites (BNR and GSCP).

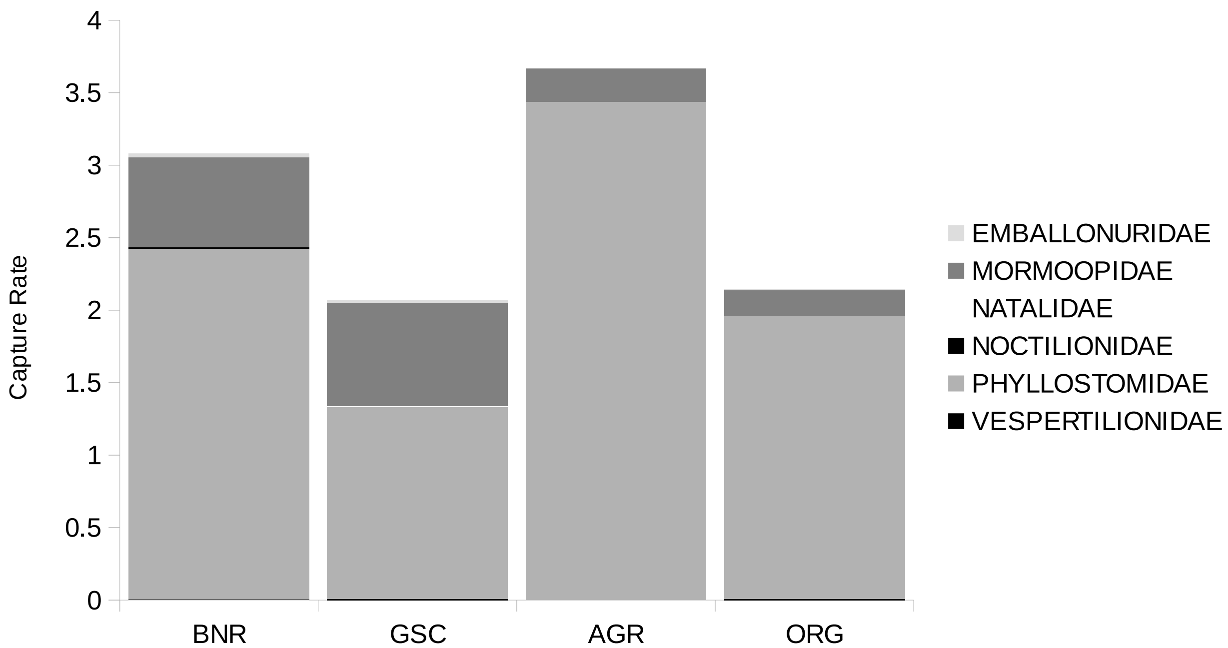

Figure 2 – *Capture rate of bats at each site (families caught in low numbers may not be displayed clearly)*

Mist net capture rate was highest in agroforestry with 3.66 bats/mnh, followed by BNR with 3.1 bats/mnh, orange orchards with 2.1 bats/mnh and finally GSCP with 2.05 bats/mnh. Harp trap capture rate was highest in GSCP, followed by BNR, agroforestry and orange orchards with 1.7, 0.64, 0.45 and 0.2 bats/hth respectively – the harp trap was ineffective in open areas such as agroforestry and orange orchards, but successful at capturing bats in thick forest on well-established trails.

The most species rich site was BNR with 29 species, followed by the orange orchard with 23, then agroforestry and GSCP both with 19 species. Figure 3 shows the relative abundance of species in each trapping location. BNR is dominated by two species (*Artibeus jamaicensis* and *P. mesoamericanus*). *P. mesoamericanus* was to a lesser extent the dominant species in GSCP. Agroforestry and orange orchards had similar bat species composition, the most common species captured being *Glossophaga soricina*, *Carollia perspicillata* and *Sturnira parvidens*.

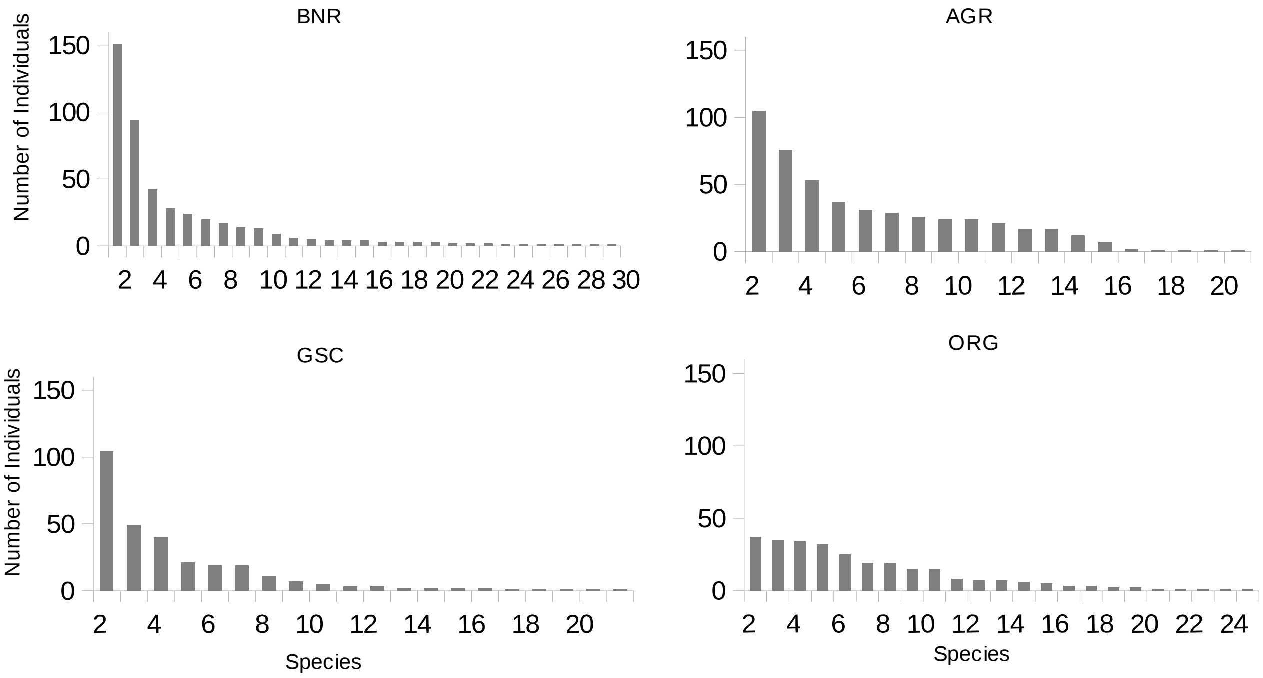

Figure 3 – *Relative abundance of species at each site for trapping*

The accumulation curve for mist netted Phyllostomids was close to plateauing (Figure 4), suggesting the sample was close to the true species richness found in the MGL. Twenty-nine Phyllostomid species were caught in the nets (Table 4), and statistical estimates of true species richness ranged from 28 to 31 (Table 2). Two species of the genus *Dermanura* were grouped together for the analysis and there are three additional species known from other studies, so the results are definitely an underestimate.

Table 2 – *Different estimates of true species richness of Phyllostomids from mist netting data*

Estimator	***Species Est.***	***SD***	***% Complete***
ACE	29.5	0.00	95.0
ICE	29.8	0.00	94.1
Chao 1	29.0	1.82	96.6
Chao 2	28.5	1.01	98.3
Jack 1	31.0	2.18	90.5
Jack 2	29.1	0.00	96.2
Bootstrap	30.0	0.00	93.5
MMRuns	28.4	-	98.7

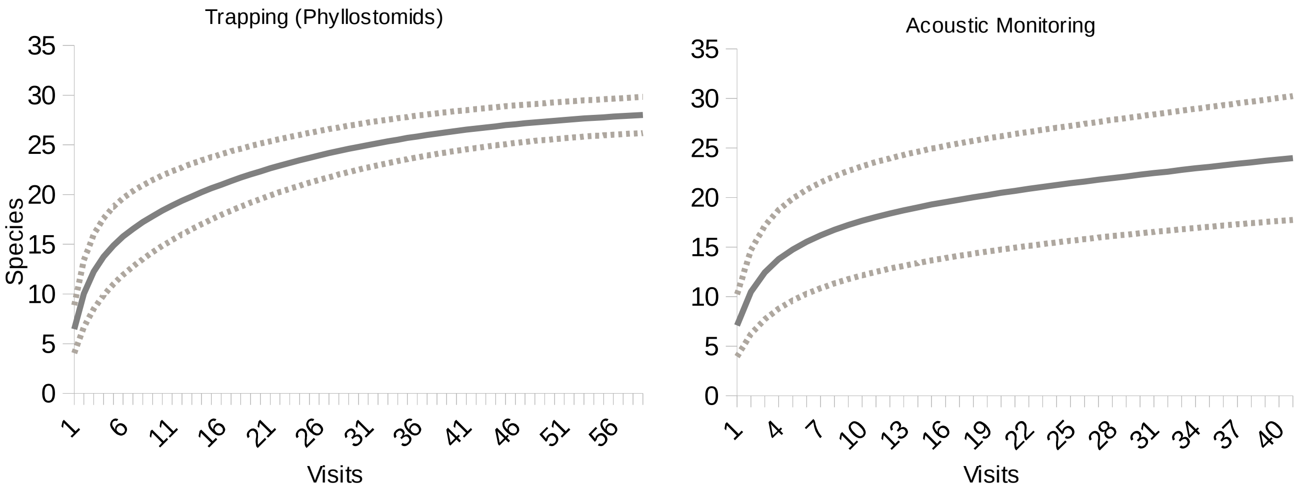

Figure 4 – *Species accumulation curves for trapping (Phyllostomids from mist netting data only) and acoustic monitoring, showing 95% confidence limits*

Acoustic Surveying Results

In the 187 hours (11,220 minutes) of recording, 4,110 minute blocks with bat calls were logged (37% of total recording time). The 19 species identified belonged to the families Emballonuridae, Molossidae, Mormoopidae, Noctilionidae and Vespertilionidae. Additionally one phonic type belonging to the Molossidae family and three to Vespertilionidae were recorded, and a member of the Natalidae family was recorded outside of standard surveys. The analysis of sound data revealed the presence of 13 species that were not found using capture methods.

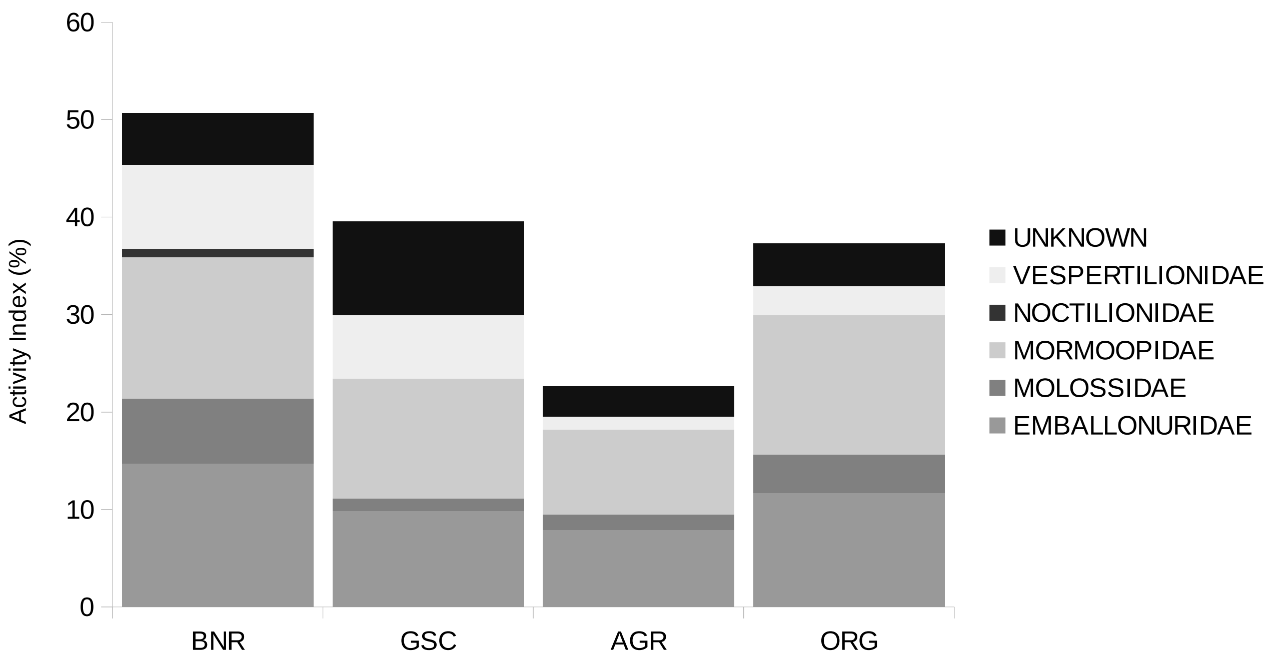

Figure 5 – *Acoustic activity index of bats recorded at each site*

Figure 5 shows that the highest level of activity was recorded in BNR, while the lowest levels were recorded in agroforestry. The conservative count of species was highest in BNR, followed by agroforestry farms and orange monoculture. The lowest number of species were recorded in GSCP, however a lot of poor quality recordings with unidentified species were made (25% of total calls with bats). Relative abundance of species recorded in each site is shown in Figure 6.

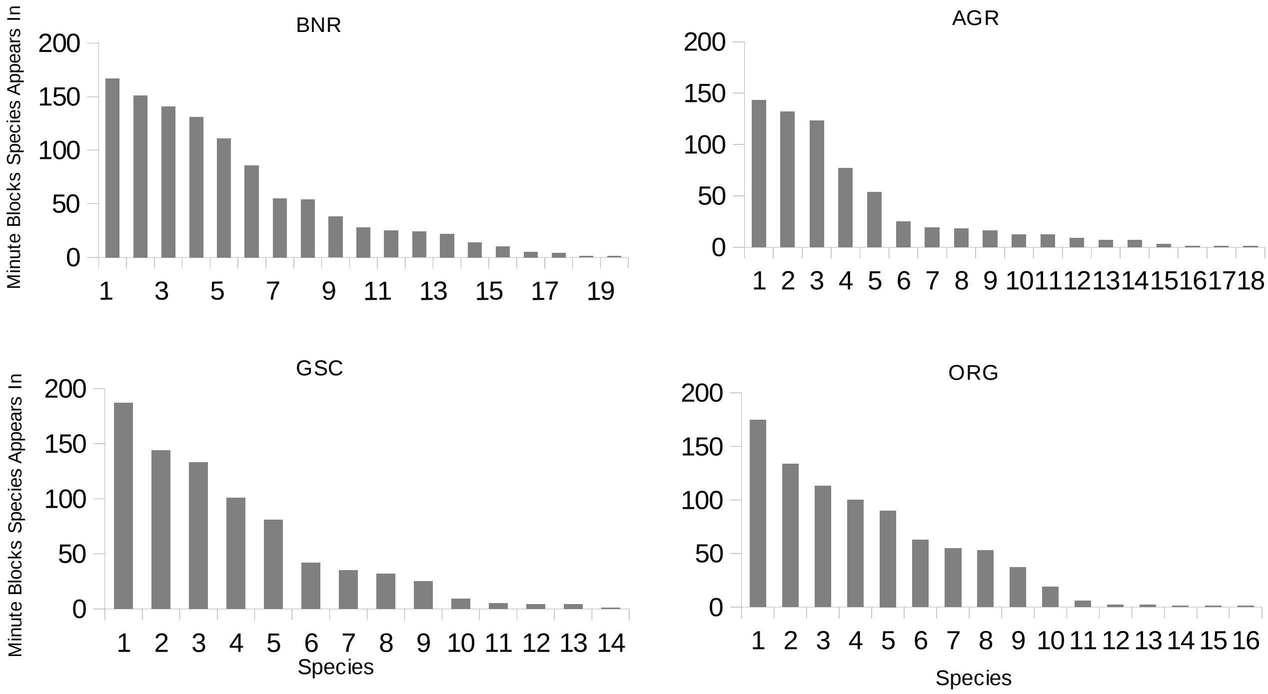

Figure 6 – *Relative abundance of species at each site for acoustic monitoring*

Individuals of the Mormoopidae family were the most frequently recorded in all habitats of the MGL, in particular *Pteronotus mesoamericanus* and *Pteronotus davyi*. Recordings showed *P. mesoamericanus* as the most common in BNR and GSC, while in agroforestry and orange orchards *P. davyi* ranked first. Lists of species recorded did not greatly differ in the habitats surveyed however, with same species and rankings recorded in all habitats. Species of the genera *Peropteryx* (Emballonuridae family) were common in the orange orchards and members of the Vesper family were more often recorded in forested sites.

The species accumulation curve of non-Phyllostomids does not level out (Figure 4), indicating that true diversity is likely much higher than that found from the sampling in this study. Estimates of true species richness were as high as 34 (Table 3). Three distinct phonic types were found that could represent up to seven species, one species is known from other studies and another species was recorded outside of standardised surveys, meaning that the 19 species confirmed from audio data is likely a significant underestimate.

Table 3 – *Estimates of true species richness from audio data*

Estimator	*Species Est.*	*SD*	*% Complete*
ACE	23.2	0.00	99.0
ICE	30.8	0.02	74.7
Chao 1	23.0	0.52	100.0
Chao 2	30.3	7.99	75.9
Jack 1	28.9	2.64	79.7
Jack 2	33.6	0.00	68.4
Bootstrap	25.4	0.00	90.7
MMRuns	22.7	-	101.5

***Table 4** – Inventory of species recorded in the Maya Golden Landscape, by ground or sub-canopy nets (N), harp traps (H), acoustic methods (A) and roost search/observation (R). * Species recorded exclusively by acoustic methods; ɤ one or more species that can't be distinguished by acoustics; ** trapped or recorded outside of standard surveys; [a] species identified in previous studies (Brewer* et al.*, 2013)*

Taxon	AGR	BNR	GSC	ORG
Emballonuridae				
*Centronycteris centralis**		A		
*Peropteryx kappleri**	A	A	A,R	A
*Peropteryx macrotis**	A	A	A	A
Rhynchonycteris naso		N,A,R	N,R	
Saccopteryx bilineata	A	A,R	A,R	N,A
*Saccopteryx leptura**	A	A	A	
Molossidae				
*Cynomops mexicanus**	A			
*Eumops sp*ɤ*	A	A	A	A
*Eumops underwoodi**	A	A		
*Molossus molossus**	A	A	A	A
*Molossus rufus**	A	A	A	A
*Nyctinomops laticaudatus**		A		
Mormoopidae				
Mormoops megalophylla	A	A	A	N,A
Pteronotus davyi	A	N,A	N,H,A	N,H,A
*Pteronotus gymnonotus**				A
Pteronotus mesoamericanus	N,H,A	N,H,A	N,H,A,R	N,A
Pteronotus personatus	H,A	A**		A
Natalidae				
Natalus mexicanus	A	A	N,H,A	A
Noctilionidae				
Noctilio leporinus		N,A		
Phyllostomidae				
Artibeus intermedius	N	N		N
Artibeus jamaicensis	N	N	N,R	N
Artibeus lituratus	N	N	N	N
Carollia perspicillata	N,H	N	N	N
Carollia sowelli	N,H	N	N,H	N
Centurio senex		N		
Chiroderma villosum			N	N
Chrotopterus auritus		N	N	
Dermanura phaeotis	N	N	N	N
Dermanura watsoni	N	N	N	N
Dermanura toltecus[a]		N		
Desmodus rotundus	N	N	N	N
Diphylla ecaudata		N		
Glossophaga commisarisi	N	N	N,H	N
Glossophaga soricina	N	N	N	N,H
Hylonycteris underwoodi[a]		N		
Lichonycteris obscura[a]		N		
Lonchorhina aurita		N		
Lophostoma basiliense		N		
Lophostoma evotis	N		N	N
Micronycteris microtis	N,H	N	N	
Mimon cozumelae	N	N	N	N
Mimon cremulatum		N		
Phyllostomus discolor	N			N
Phyllostomus hastatus	N	N		
Platyrrhinus helleri	N	N	N	N
Sturnira parvidens (S. lilium)	N	N		N
Tonatia saurophila		N		
Trachops cirrhosus	N	N		N
Uroderma bilobatum	N	N	N	N
Vampyressa thyone		N		
Vampyrodes caraccioli			N	N
Thyropteridae				
Thyroptera dicifera		R**		
Vespertillionidae				
Bauerus dubiaquercus[a]		N		
*Eptesicus furinalis**	A	A	A	A
*Lasiurus blossevillii**				A
*Lasiurus sp*ɤ*	A	A	A	A
Myotis keaysi	A	A	N,H,A	A
*Myotis sp*ɤ*	A	A	A	A
*Rhogeessa aeneus***		N**		
Rhogeessa sp				N
Vesper 50kHz,ɤ*	A	A	A	A

Discussion

Trapping results were particularly biased towards Phyllostomid bats – this was expected because Phyllostomids are more likely to be captured by mist nets due to their sensory ecology and flight behaviour (Kalko and Handley, 2001). On the other hand bat detectors only pick up non-Phyllostomid bats. The results complement each other and provide a good overall picture of the bat biodiversity in each site.

A large number of unidentified species were recorded on the detector in GSCP, and to a lesser extent in BNR. Habitat structure can impact call detection and the forests in GSCP are the most cluttered of the four habitats surveyed, hence fewer calls being recorded overall, and more poor quality calls that could not be identified. Acoustic detectors are more likely to pick up species with high intensity calls (Duffy *et al*., 2000) which tend to be fast-flying bats characteristic of open landscapes (Broders *et al*., 2004), and so are biased to work better in open spaces. This needs to be borne in mind when looking at the acoustic results.

Trapping results show a difference between bat assemblages in the mature forest of BNR and the other three sites. BNR had the highest species diversity and although it was dominated by two species – *Artibeus jamaicensis* and *Pteronotus mesoamericanus* – it logged a high number of rare species. The disproportionate number of *A. jamaicensis* can be linked to the proximity of a known cave with a large colony just up-river from a number of trapping locations. High abundance of this species in continuous mature forest has been found in previous studies (Schulze *et al*., 2000). The most common species captured in the other sites were the nectar feeding bat *Glossophaga soricina* and small frugivores like *Carollia perspicillata* and *Sturnira parvidens.* Dominance of these species has been shown to be associated with disturbed habitats ((Medellin *et al*., 2000; Schulze *et al*., 2000). More individual bats were trapped in the agroforestry than anywhere else, however there were fewer species found here than in other habitats.

Acoustic data show that the highest bat activity and species richness of non-Phyllostomids was found in BNR. Contrary to trapping data, agroforestry recorded the lowest bat activity, but a higher species richness than orange monoculture and GSCP. In orange monocultures acoustic detectors recorded high bat activity; the most common species included aerial insectivores such as *Pteronotus davyi, Mormoops megalophylla* (Mormoopidae) and *Peropteryx macrotis* (Emballonuridae), species that fly in open spaces. The orange orchard was the most open habitat looked at in this study, which is likely to have resulted in an increase in call detectability and so an increase in overall activity levels recorded at this site. The opposite happened in GSCP samples, where cluttered vegetation may have contributed to low bat activity rates and a large amount of unidentifiable bat calls.

In conclusion, results show differences among bat communities between sites. The bat assemblage with highest overall species richness and abundance was found in BNR. The results are similar to those found in some other studies in neotropical fragmented areas and secondary forests, where dominant species found in agroforestry, orange monocultures and GSCP are linked to disturbed areas. Contrary to expectations, GSCP had the lowest overall species richness and activity. Some studies have noted that recovering forest generally supports fewer bat species (Avila-Cabadilla *et al*., 2012; de la Peña-Cuéllar *et al*., 2012), however habitat structure may be partly responsible for low activity found in acoustic monitoring.

The accumulation curve for trapping data suggests that the Phyllostomid inventory for the MGL is near-complete. Including species known from other studies gives a good picture of what is probably close to true Phyllostomid diversity in the MGL. A few more species will likely be found with further work, however this is a good starting point. There are a large number of non-Phylostomids that were not encountered, as the accumulation curve suggests, which implies more acoustic survey work is needed to get closer to a full species inventory.

5. EVIDENCE-BASED SUSTAINABLE DEVELOPMENT

Demand for agricultural land in the Toledo district has increased in recent years, fuelled by population growth. This has resulted in an increasingly fragmented landscape (Ruscalleda, 2014). Ya'axche Conservation Trust's main focus is to promote sustainable development by protecting forest cover and soil quality, and encouraging farmers to take up agroforestry has been one of the major methods used to achieve this.

It has been suggested that agroforestry systems can help support greater biodiversity than traditional farming (Bhagwat *et al*., 2008). Agroforestry obviously cannot replace forest, however growing agricultural demand needs to be met somehow, and agroforestry can help conservation outside protected areas by providing more favourable habitat than monocultural farming (Jose, 2009). It takes careful planning to maximise the potential benefits associated with agroforestry and to make sure it is deployed in the most effective way however (Schroth and Harvey, 2007), and conclusions should only be made using evidence-based data. Prior to this study the species diversity found in MGL agroforestry farms has not been studied (to the author's knowledge), and there is little data on the effect this change in land use is having on biodiversity in the MGL.

The results of this study show that agroforestry can support large numbers of Phyllostomid bats, albeit a relatively low-diversity assemblage, dominated by species that are associated with disturbance. They also show that agroforestry can support reasonable diversity of non-Phyllostomid bats, though at relatively low activity levels compared with forested sites.

Solid conclusions on bat diversity in agroforestry in the MGL cannot be drawn without long-term monitoring. The data presented in this report provide a starting point, but long term data will give a better representation of true diversity and population trends. Bats are not the only indicators of ecosystem health, and research should be extended to other taxa.

6. RECOMMENDATIONS FOR DECISION MAKERS

The following recommendations are based on what was learnt over the course of the project, and on information gleaned from scientific literature.

Conservation Actions
In Belize the main threats bats are facing are loss of habitat and persecution. To develop effective conservation actions it is important to understand and assess each conservation issue on an individual basis.

- *Habitats and roosts* – the expansion of agriculture (primarily cattle ranching, sugar cane and cacao) is the main cause of deforestation in the region (Hutson *et al*., 2001). Planned habitat management with targeted priorities for research need to be developed; impact assessments before major land clearings and infrastructure projects need to be undertaken, and the impacts of pesticide use in agriculture needs to be assessed.

  Key cave sites need to be surveyed, and if important roosts sites are identified, appropriate conservation and management schemes should be implemented.

- *Education campaigns* – there is a widespread belief that all bats are a dangerous pest and spread diseases. Therefore, an education programme about the role of bats in pest control, pollination and seed dispersal needs to be developed.

- *Common vampire bats (*Desmodus rotundus*)* – in Belize it is common practice for farmers to persecute bats, thinking they are targeting vampires (personal observation). These actions can often impact non-target species and can pose a threat to bat populations if not addressed correctly. For example, McCarthy (1987) reported that in Belize anti-coagulant paste was smeared on randomly collected bats of many species by untrained collectors, resulting in deaths of many bats. Vampire population control activities need to be carried out by trained personnel and be applied when a substantial problem has been reported, such as bites to humans, vampire bat-related rabies outbreaks or high incidence of bites in domestic animals.

Poisons such as warfarin have been used for decades to control bat populations in the region. However, recent studies show that this only provides temporary rabies control (Streicker *et al*., 2012) and could actually have a negative effect by spreading the disease through increased geographical dispersal of individuals (Blackwood *et al*., 2013). Culling programs have also been shown to be less economically efficient than prophylactic vaccination of livestock (Anderson *et al*., 2012). Vampire bat control activities need to be carefully thought out and ecologically informed to be able to obtain a positive result.

Rabies control efforts should go alongside public awareness programmes that explain risk associated with vampire bats and the environmental damage that can result from inappropriate control methods.

Assessing Land-Use Impacts

Determining the effects of different agricultural regimes on biodiversity is crucial for providing evidence-based suggestions on how to improve current agricultural systems to further biodiversity conservation (Park, 2015). Therefore, extending biodiversity surveys in agroforestry concessions and other agricultural systems for bats and other taxa is highly recommended.

Designing a Bat Monitoring Protocol

The neotropics harbour some of the richest bat biodiversity in the world and these bats fill a variety of ecologically significant roles, including pest insect population control, pollination and seed dispersal for many important plants, that in turn facilitates ecosystem recovery. Many bat populations have seen serious declines over the past decades, most likely in response to human activities, such as deforestation and climate change (Hutson *et al*., 2001; Meyer *et al*., 2010; Park, 2015). Neotropical bats seem to be highly sensitive to loss and fragmentation of their natural habitat, experiencing local decreases in species richness and population size in response to disturbance (Medellin *et al*., 2000; Schulze *et al*., 2004). Long-term monitoring of bats is needed to be able to gauge population trends, and to assess the potential for bats to be used as bioindicators (Medellin *et al*., 2000; Jones *et al*., 2009).

There are a number of things to take into account when designing a monitoring protocol:

- *Areas to be monitored* – monitoring efforts need to be focused on key sites and species. Before establishing monitoring sites the global and local conservation status of species and habitats need to be taken into account. Preliminary surveys are required to produce an up-to-date species list for each surveying area. Large roosts (e.g. in caves) should be targeted as sites for monitoring population trends.

- *Obtaining sufficient statistical power for detection of population trends* – to obtain reliable data for the detection of long-term population trends it is strongly recommended that data should be collected for at least 15-20 years, that each monitoring location include sufficient spatial replicates, and a minimum of 2-4 within-year visits per plot are conducted annually, covering major seasons and transitional periods (Meyer *et al*., 2010). In addition, the standardisation of sampling design and effort in each monitoring site is essential (Meyer *et al*., 2010; Cunto and Bernard, 2012). Meyer *et al.* provide more detail on specific requirements for successful long-term monitoring of tropical bats – a valuable resource for anyone setting up a long-term monitoring programme.

- *Choosing indicator species* – To use any taxon as a bioindicator the objectives of the study must be clearly formulated, and the information any chosen indicator can provide must be well understood.

McGeoch (1998) defines three types of indicator: biodiversity, ecological and environmental. Biodiversity indicators reflect elements of biological diversity such as species richness and diversity. Environmental indicators respond directly to specific environmental disturbances while ecological indicators respond indirectly via ecosystem changes, such as insect abundance (McGeoch, 1998). There are examples in the literature of bat species richness/activity levels responding to changes in all these contexts (e.g. Medellin *et al*., 2000; Avila-Cabadilla *et al*., 2012; Korine *et al*., 2015; Jung and Threlfall, 2015).

There is no magic formula, however. Cunto and Bernard (2012) observed that often, due to lack of standardisation, studies assessing bats as indicators have contradicting results. Further surveys are needed in the area, and studies quantifying the response of bats and other taxa to environmental change in a wider range of habitats are needed.

- *Methodology and equipment to be used* – because mist netting is biased towards the capture of Phyllostomid bats, the use of multiple methodologies is strongly recommended. Some species are rarely captured in ground nets so, in addition to normal mist netting, roost searches and the use of canopy nets and harp-traps are strongly advised (Meyer *et al*., 2010; Cunto and Bernard, 2012).

  To maximise inventory completeness trapping efforts should be complemented with acoustic surveys (Sampaio *et al*., 2003; MacSwiney G. *et al*., 2008; Furey *et al*., 2009; Cunto and Bernard, 2012). The application of transect-based sampling using acoustic point counts is also recommended to maximise species detection (Estrada-Villegas *et al*., 2010).

  Full spectrum bat detectors are recommended over zero-crossing (Anabat) systems. Modern full spectrum detectors are more sensitive than old Anabat systems, and allow for better discrimination of bat species from recordings (Fenton *et al*., 2001; Adams *et al*., 2012). Additionally, monitoring schemes in neighbouring Latin American countries are increasingly collecting full spectrum acoustic data (RELCOM, personal correspondence), so the use of full spectrum detectors will help to keep data comparable.

- *Data management* – data collected in the field, particularly audio data, require a lot of digital storage space. It is therefore important to have a plan for data storage and to implement a logical folder naming system to avoid confusion and data loss.

- *Local capacity* – training programmes need to be established for mist netting, bat handling, and especially for specialist skills such bat call analysis.

  Collaboration with – but not dependence on – international researchers is key. Neighbouring countries share the same species and conservation challenges and many have existing bat monitoring schemes in place, and can therefore be useful allies.

  The creation of a national bat conservation group will enable Belize to join international conservation schemes such as RELCOM, which will provide excellent training and networking opportunities.

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