Biodiversity Synthesis Report

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Said Gutierrez
Science Director

Ya'axché Conservation Trust
20A George Price Street, P.O. 177
Punta Gorda, Toledo District
Belize

Phone: (+501) 722-0108
Fax: (+501) 722-0108
E-mail: info@yaaxche.org
Web: yaaxche.org

Contributors

Bat Research and Inventory – Olatz Gartzia and Thomas Foxley
Land Use Change – Stephanie Smith and Jaume Ruscalleda
Tree Phenology Monitoring – Jean Linsky

Field work conducted by Ya'axché's ranger team

Anignazio Makin, Indian Creek Village
Andres Chen, Trio Village
Henry Cus, San Miguel Village
Hilberto Rash, Trio Village
Marcus Cholom, Golden Stream Village
Marcus Tut, Trio Village
Mateo Rash, Medina Bank Village
Octavio Cal, Golden Stream Village
Rosendo Coy, Indian Creek Village
Victor Bonilla, Indian Creek Village
Vigilio Cal, Golden Stream Village

And supervised by

Said Gutierrez – Science Director
Jean Linsky – Research Officer
Marchilio Ack – Protected Areas Manager
Lee McLoughlin – Protected Areas Program Director

Edited by

Alyssa Thomas – Protected Areas Project Manager
Jean Linsky – Research Officer
Karla Hernandez – Protected Areas Program Director
Maximiliano Caal – Marketing and Communications Officer
Stephanie Smith – Sustainable Land Use Officer

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Acronyms

AI	Activity Index
AI%	Activity Index Percent
BFREE	Belize Foundation for Research and Environmental Education
BNR	Bladen Nature Reserve
BRIM	Ya'axché's Biodiversity Research, Inventory and Monitoring strategy
CRFR	Columbia River Forest Reserve
DBH	Diameter at breast height
ENS	Effective Number of Species (or True Diversity)
GIS	Geographical Information System
GSCP	Golden Stream Corridor Preserve
IUCN	International Union for Conservation of Nature
MGL	Maya Golden Landscape – Ya'axché's working area
MMNFR	Maya Mountain North Forest Reserve
NGO	Non-Governmental Organization
PSP	Permanent Sample Plot for vegetation monitoring
REA	Rapid Ecological Assessment
SP	Species Richness
Ya'axché	Ya'axché Conservation Trust

Summary

Ya'axché Conservation Trust is a Belizean community-based NGO that works to protect and promote the sustainable use of the natural resources of the Maya Golden Landscape, a 770,000 acre mosaic of public and private protected lands, and communities. Ya'axché manages the Golden Stream Corridor Preserve (15,000 acres, private) and co-manages the Bladen Nature Reserve (100,000 acres) and the Maya Mountain North Forest Reserve (36,000 acres) in collaboration with the Government of Belize. Since 2006, Ya'axché has been monitoring biodiversity to observe possible changes in the environment and track the effect of unsustainable human activities on these and other protected areas not co-managed by Ya'axché. The intention of this monitoring is to inform our conservation actions. Initially the Biodiversity Monitoring Program only included bird and mammal transects, but over the years we have added other taxa and methods such as freshwater macro-invertebrates, bats, land-snails, vegetation, weather monitoring, road traffic density and road crossings, and finally land-use change monitoring. Methods include point, transect and plot sampling in the field, digital data management and digital analysis using GIS, covering the entire Maya Golden Landscape.

In 2015, transect monitoring effort was comparable with previous years although visits to transects were slightly less than in 2014. Village lands recorded a higher species richness than in 2014, particularly for target bird species and was comparable to that of forested lands and savannah. However, village lands species richness was influenced by the abundance/dominance of disturbance indicator species. Game species indicators were completely absent from village lands. The forest transect BNR2, considered the least disturbed of the transects, exibited high species richness for both bird and mammal target species with dominance by one or two forest indicators. Overall the forest transects in Bladen Nature Reserve and Columbia River Forest Reserve recorded higher target species richness than transects in the still recovering, hurricane damaged, Golden Stream Corridor Preserve.

Bat monitoring was replaced by an inventory of the bat fauna across three "disturbance" gradients in the Maya Golden Landscape. A total of 51 species of bats were recorded and three new families were documented. This represented a significant increase from the number of species and families recorded in previous years. GSCP yielded the lowest diversity for bats and unlike in other years, bat diversity was higher in BNR2. In the future, bats will be included in our group of indicator species that could give us more information about the health of our ecosystems.

Tree monitoring was established in 2012 and by 2015 we had collected enough data to be able to report on the phenology study of a few threatened and rare tree species. This study provides valuable information about species that lack life-cycle data which can be instrumental in the development of sustainable harvest and management of species. As

a result of the monitoring we are able to share information on seven species that we consider to be either valuable to general biodiversity or of socio-economic importance.

Data collection from the weather stations from both Golden Stream Field Station and Bladen Ranger Base remained consistent throughout the year. The data shows a wetter year as compared with 2014; with a short intense dry season and a major increase in rainfall in Bladen but less evident in Golden Stream. It is likely that 2015 weather patterns were influenced by the onset of El Niño in February of 2015.

There is a continuing trend of the advancement of the agriculture frontier in the MGL. Over the past three years there has been a steady increase in the acreage of previously untouched forest that is now being converted into agricultural land. Historically cultivated lands are also being cleared with fallow periods decreasing in length as the demand for fertile agricultural land increases with the growing rural population in Toledo. There also seems to be a tendency to cultivate land albeit illegally within protected lands. This means that Ya'axché will need to invest major time and effort into promoting and encouraging the adoption and use of sustainable agricultural practices or alternatives.

Ya'axché continuously strives to improve its efforts at data collection in order to provide the conservation community and the general public with reliable, accurate and high quality information. It is not always possible to conduct data collection considering limitations beyond our control and the number of tasks carried out by the Ya'axché ranger team. However, the quality of work conducted by the team is of the highest standards and Ya'axché aims to keep improving its monitoring program through constant capacity building and targeted and focused approaches. Ya'axché is committed to adopting national strategies for research and monitoring and pledges to make every effort to assist the national development of these where possible for the continued improvement of biodiversity conservation in Belize.

Introduction

Ya'axché Conservation Trust (Ya'axché) is a Belizean organisation which aims to maintain a healthy environment with empowered communities by fostering sustainable livelihoods, protected area management, biodiversity conservation and environmental education within the Maya Golden Landscape. The organization's geographical focus is the Maya Golden Landscape (MGL), which encompasses twelve protected areas in Toledo, as well as the buffer communities around them (see Figure 1). Three of these protected areas are managed by Ya'axché. The Golden Stream Corridor Preserve (GSCP) is a 15,000 acre preserve owned and managed by Ya'axché that forms part of the link between the Maya Mountain Massif and the coastal ecosystems of the Caribbean Sea. The Bladen Nature Reserve is a 100,000 acre strictly protected nature reserve (IUCN Category 1a), owned by the Government of Belize and co-managed by Ya'axché since 2008. The Maya Mountain North Forest Reserve, a key biodiversity area, is a 36,000 acre forest reserve that serves as a model for sustainable use and extraction of natural resources within Belize's protected areas system.

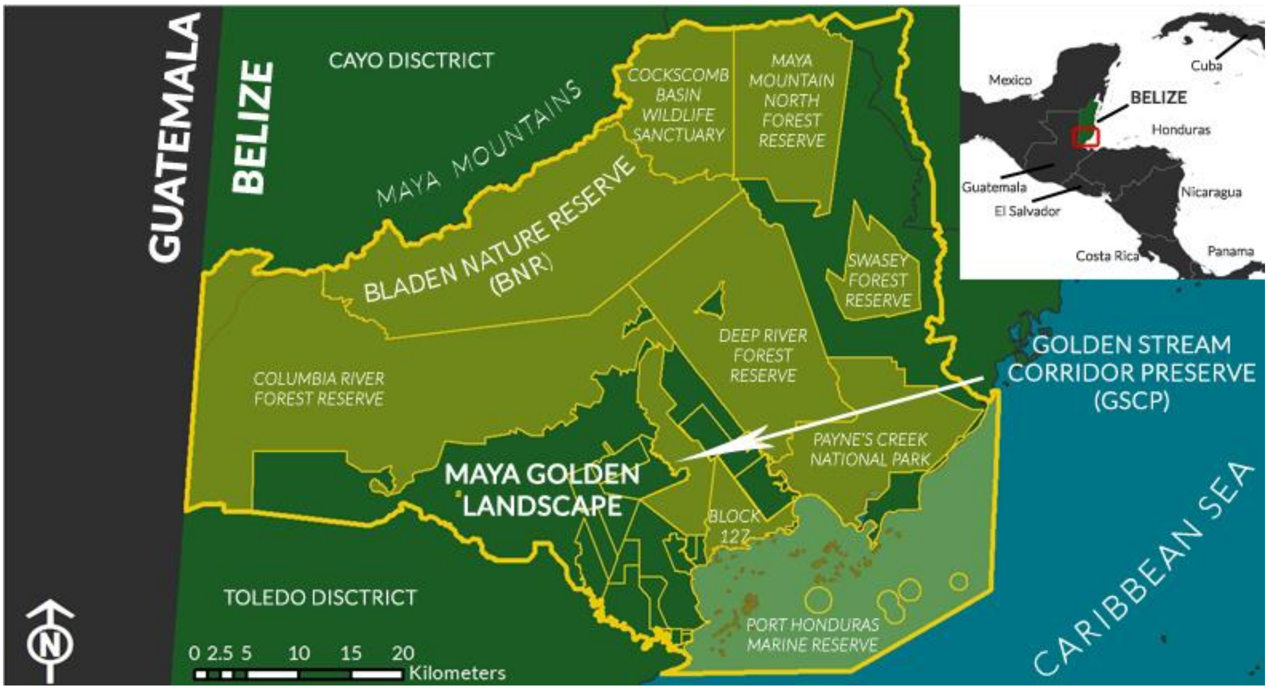


Figure 1. Location of the new Maya Golden Landscape and it's protected areas

Over the past seven years Ya'axché has been implementing a biodiversity monitoring system to observe possible changes occurring in the natural environment that could indicate unsustainable human activities. When Ya'axché accepted co-management of the Bladen Nature Reserve in 2008, a Biodiversity Research, Inventory and Monitoring (BRIM) strategy was drafted by Ya'axché, Fauna & Flora International (FFI) and Toledo

Institute for Development and Environment (TIDE) as a necessary planning exercise. This strategy details the questions that Ya'axché face when managing and co-managing protected areas, and recommends a number of target groups (e.g. birds and mammals, freshwater invertebrates, vegetation) to be monitored in order to answers these questions. The BRIM strategy provides short outlines of the methodology to be used, and general guidelines for the analysis of the data gathered. It also prescribes the annual analysis of the data, to facilitate comparison among years and provide information to guide management decisions.

Ya'axché has collected data on birds and large mammals using transect monitoring throughout the Maya Golden Landscape since 2006. A formal structure was put in place in 2009 and since then, the ranger team has been trained in freshwater macro-invertebrate sampling and freshwater physiochemical monitoring by freshwater ecologist, Dr. Rachael Carrie, who also initiated the weather monitoring activities. In 2011, bats were added to the monitoring program and data collection and sampling improved between 2013 and 2015 by Ya'axché's Research Coordinator Olatz Gartzia and Consultant Thomas Foxley, both experienced bat researchers. In 2012, Ya'axché's botanist, Gail Stott, in collaboration with plant ecology consultant Dr. Steven Brewer, added vegetation monitoring to the existing programme by establishing two one-hectare Permanent Sample Plots (PSPs) according to international standards. In 2013 a collaboration between Ya'axché and The Global Trees Campaign established phenology monitoring for 19 species of rare, data deficient and threatened trees.

Finally a GIS specialist, Jaume Ruscalleda, continued improving Ya'axché's capacity to use remote sensing utilizing satellite imagery to monitor land use and land cover change. The main targets of this monitoring include the conversion of forested areas into farmland, as well as forest burned by escape fires and its potential impacts to biodiversity. Fire plays an important role in the lives of people in southern Belize, who regard the use of fire as a necessity for successful farming, and use it as a hunting technique and to clear vegetation from roadsides. However, many people are ill-equipped and lack the fire management knowledge to control the fire once started. Escaped fires are therefore one of the main threats to forest and biodiversity conservation in the area. By combining land-use change monitoring and other abiotic parameter monitoring, Ya'axché has been implementing an inclusive landscape-scale approach to conservation in the MGL.

As a result, the Biodiversity Research, Inventory and Monitoring programme not only observes changes on species biodiversity in the MGL, but also abiotic components that could affect the former, such as freshwater quality, weather, land-use change and road traffic monitoring.

This report continues the efforts made throughout the past 6 years to ensure the fulfilment of the BRIM requirement to annually report findings. This year we have included bird and mammal transects, bat inventory, wildlife observations, tree monitoring, weather and land-use change. Due to logistical difficulties, we were unable to collect camera trapping data and freshwater monitoring data and as such this has been omitted from this year's report. Road traffic monitoring data will be presented in 2016's report as it is only conducted once every two years.

This report has seven important sections including this Introduction and the Summary. The following section, Methodology, consists of an in-depth description of the methodologies used to collect data and the statistical tools used for analysis, which is then presented in the fourth section titled Results. This is followed by a set of Conclusions as well as Recommendations to improve data collection and analysis for the coming years and how to overcome identified shortcomings. Finally, a section is included to acknowledge the people and organisations that helped in the fulfilment of this report.

Methodology

Bird and large mammal transects

Transect monitoring in 2015, as in previous years, involved birds and large mammals as key taxa. Transects are located in and around some of the protected areas in the Maya Golden Landscape (see Figure 2). These are transect point counts and sign transects, all 1km in length with stopping points every 200m to observe and listen. Birds were detected using sight and sound cues, while mammals were detected using direct sightings, tracks and an array of different signs such as faeces, smell, sounds and scratch marks among others. For both focal groups a previously generated list of indicator species was used and recordings were limited to the selected species (see Table 3 for birds and Table 4 for mammals). These species lists are taken from Ya'axché's BRIM strategy, and adapted to the current lists used in the databases.

Our target species list is classified in six indicator groups (see Table 1) and each species in the list indicates a different factor based on their habitat preferences and ecology. This classification is taken into account when analysing bird and mammal data and is used to facilitate making conclusions from the monitoring results. For example, an increase of 'Disturbed forest indicators' could indicate habitat degradation, whereas decreased 'Game species' richness could indicate a high level of hunting pressure and/or habitat degradation.

Table 1. Description of Indicator groups for both mammal and bird target species

Code	Class	Description
M	Migration route health indicator	Generalist migrant species without specific habitat requirements in Belize
D	Disturbed forest indicator	Species from fallow lands, forest gaps, human impacted landscapes
F	Forest health indicator	Species only found in primary forests or undisturbed secondary forest
G	Game species	Regularly collected species
W	Wetland indicator	Species linked to littoral or riparian habitats
P	Pine-savannah indicator	Species linked to pine savannah habitats

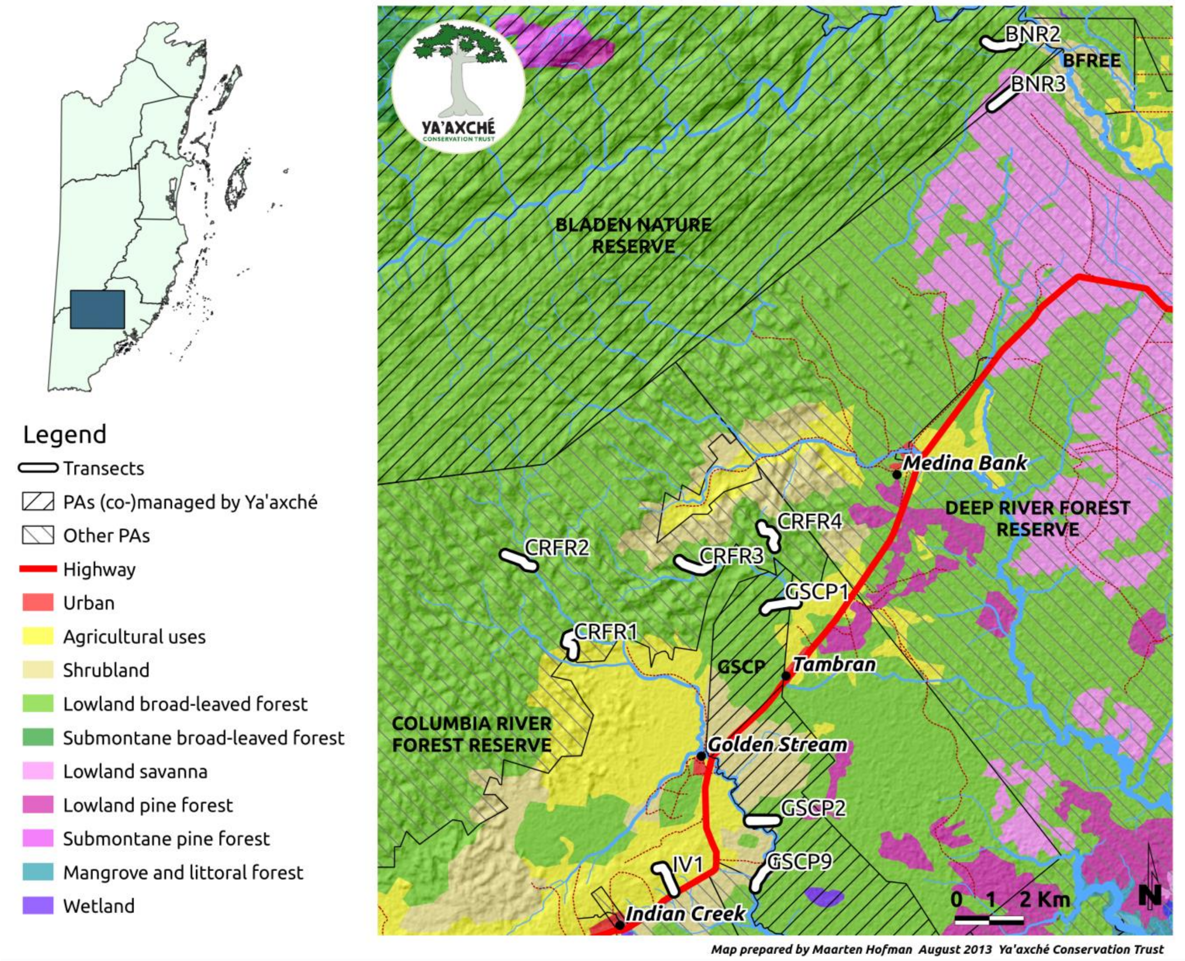


Figure 2. Location of biodiversity monitoring transects within the MGL

Species from both mammal and bird lists are assigned to one of the indicator groups based on, respectively, the 'Field guide to the mammals of Central America and Southern Mexico' (Reid 2009) and 'Birds of Belize' (Jones & Gardner 2003), and validated by the local knowledge of Ya'axché's field ranger team.

Not all indicator groups in Table 1 are applicable to the mammals of the Maya Golden Landscape. There are no long-distance migrants and the fairly large roaming distances of some of the species means that their preference for a specific habitat will be less clear (e.g. Red brocket deer will prefer the forest, but can be seen in the savannah). Therefore, we assigned all mammals to either Forest health indicators, Game species or Wetland indicators, and only a small number of species were not assigned to any group due to their "generalist" habitat nature (see Table 2). The Tables 3 and 4 in the next page present a more detailed species list and their corresponding indicator group.

Table 2. Distribution of species in the indicator groups and serves as a reference for when the distribution of indicator groups among transects and/or habitats are reported in the results.

		D	F	G	M	P	W	N/A
Birds	# species	4	10	3	7	3	3	0
	% species	13.3%	33.3%	10.0%	23.3%	10.0%	10.0%	0.0%
Mammals	# species	1	7	6	0	0	2	3
	% species	5.3%	36.8%	31.58%	0.0%	0.0%	10.53%	15.79%

Table 3. Selected target bird indicator species (n=30)

Common Name	Migratory	Class
American Redstart	Y	M
Black and White Warbler	Y	M
Blue-gray Gnatcatcher	Y	P
Bronzed Cowbird	N	D
Brown-hooded Parrot	N	F
Cerulean Warbler	Y	F
Chestnut-sided warbler	Y	M
Common Yellowthroat	Y	M
Crested Guan	N	G
Dickcissel	Y	D
Golden-winged Warbler	Y	F
Grace's Warbler	N	P
Great Curassow	N	G
Great Tinamou	N	G
Hooded warbler	Y	M
Keel-billed Motmot	N	F
Keel-billed Toucan	N	F
Kentucky Warbler	Y	F
Little Tinamou	N	F
Louisiana Waterthrush	Y	W
Magnolia warbler	Y	M
Northern Waterthrush	Y	W
Painted Bunting	Y	D
Plain Chachalaca	N	D
Prothonotary Warbler	Y	W
Slaty-breasted Tinamou	N	F
Swainson's Warbler	Y	F
Wood Thrush	Y	M
Worm-eating Warbler	Y	F
Yellow-headed parrot	N	P

Table 4. Selected target mammal indicator species (n=19

Common Name	Class
Agouti	G
Baird's Tapir	W
Brown Brocket Deer	NA
Coatimundi	NA
Collared Peccary	G
Howler Monkey	F
Jaguar	F
Jaguarundi	D
Margay	F
Naked-tail Armadillo	NA
Neotropical River Otter	W
Nine-banded Armadillo	G
Ocelot	F
Paca	G
Puma	F
Red Brocket Deer	F
Spider Monkey	F
White-lipped Peccary	G
White-tailed Deer	G

Data collection

Transect location and habitat

The core data collected in transects are the number of species observed and the number of individuals observed per species. The number of transects is 10: four transects in Columbia River Forest Reserve (CRFR 1, 2, 3 and 4), one on the village lands in Indian Creek (IV1), three in Golden Stream Corridor Preserve (GSCP1, 2 and 9) and two in Bladen Nature Reserve's forest (BNR2) and Savannah (BNR3). The diversity of habitats within the transects makes our monitoring program a landscape scale approach. Table 5 contains information about each transect, and a map showing the location of the transects is presented in Figure 2.

Disturbance gradient

Among the transects in forest habitats, a gradient of natural and human disturbances can be observed. The transects in Bladen Nature Reserve are the least disturbed and the ones in Golden Stream Corridor Preserve the most disturbed. This gradient is not equally prevalent at every transect location and is not quantified other than by calculated damage from hurricane Iris (2001) and the estimated proximity of residential and agricultural areas (see Table 5). The gradient is thus to be considered a rough approximation of disturbance levels.

Table 3. Description of the currently active transects, their location, level of human disturbance and general ecosystem type through which the transects run.

Transect Name	Length (m)	Area	Land administration	Disturbance	Ecosystem
BNR2	1000	Bladen	Nature Reserve	Minimal	Primary forest on karst hills
BNR3	1000	Bladen	Nature Reserve	Minimal	Lowland savannah with pine
CRFR1	1000	Columbia river	Forest reserve	Minimal; 0-20% hurricane damage (2001); proximity of agriculture	Primary forest on karst hills
CRFR2	1000	Columbia river	Forest reserve	Minimal; 0-20% hurricane damage (2001)	Primary forest on karst hills
CRFR3	1000	Columbia river	Forest reserve	Minimal; 0-20% hurricane damage (2001)	Primary forest on karst hills
CRFR4	1000	Columbia river	Forest reserve	Minimal; 0-20% hurricane damage (2001)	Primary forest on karst hills
GSCP1	1000	Golden Stream	Private Protected Area	60-75% hurricane damage (2001); proximity of village and agriculture	Secondary forest on karst foothills
GSCP2	1000	Golden Stream	Private Protected Area	60-75% hurricane damage (2001); proximity of agriculture	Secondary forest in coastal plain
GSCP9	1000	Golden Stream	Private Protected Area	60-75% hurricane damage (2001); proximity of agriculture	Secondary forest along riverside in coastal plain
IV1	1000	Indian Creek	Community lands	60-75% hurricane damage (2001); proximity of highway and agricultural clearings	Mosaic of farms, secondary forest and residential

Transect visit schedule

Transects were visited according to a pre-set monthly schedule (see Table 6). Dates were kept flexible to allow for access uncertainty such as seasonal bad weather and/or other ranger tasks (e.g. expeditions or deep patrols) interfering.

For bird monitoring, the transects occured twice daily: early morning and late afternoon. Some transects require a day walk-in, for which the afternoon visit would be performed first and the morning visit the second day, after a night camping. Large mammal monitoring was combined with the transect visits for bird monitoring, but signs and sightings were only recorded during either the morning or the evening visit to avoid double-counting. A more detailed description of the methodology used on the transects can be found in the BRIM strategy document.

Table 4. Transect visits in 2015; shaded areas indicate periods of inaccessibility

	Month	BNR2	BNR3	GSCP 1	GSCP 2	GSCP 9	CRFR 1	CRFR 2	CRFR 3	CRFR 4	IV1	Total
Dry season	Jan	1	1	1		1	1	1			1	**7**
	Feb	1	1		1				1	1	1	**6**
	Mar	1	1	1		1	1	1			1	**7**
	Apr	1	1		1				1	1	1	**6**
	May	1	1	1		1	1	1			1	**7**
	Jun	1	1		1				1	1	1	**6**
Wet season	Jul	1	1			1						**3**
	Aug	1	1		1				1	1	1	**6**
	Sep	1	1			1	1	1			1	**6**
	Oct	1	1								1	**3**
	Nov	1	1	1			1	1			1	**6**
	Dec	1	1		1				1	1	1	**6**
Total		**12**	**12**	**4**	**5**	**5**	**5**	**5**	**5**	**5**	**11**	**69**

Data quality

Ya'axché field staff is constantly facing challenges with data collection both for enforcement and compliance and for biodiversity monitoring. While data collection, database management, and quality of the data has significantly improved since the first Biodiversity Synthesis Report, logistical limitations can often hinder the amount and quality of data collected. Transect visit schedules are flexible and prioritized when possible over other activities, allowing for an increase in our monitoring effort. Ya'axché has continued running refresher training sessions for the ranger team to enhance data entry skills and field monitoring techniques, which has increased the level of accuracy and detail of their recorded data. As a result, data inconsistencies such as observations without species name or number of individuals observed are virtually eliminated from the database. No observations lacked species name for birds and mammals, and observations that lacked number of individuals in the database were set conservatively to '1'. Ya'axché's monitoring program is expected to expand, encompassing the farming landscape of the MGL after 2016. This will require a proactive restructuring of the team and of our current databases.

Data analysis

Data analysis uses the instructions in the BRIM strategy as a starting point, but were largely built on the progress accomplished in previous Biodiversity Synthesis Reports. Analysis was mostly done per transect, thereby pooling together the data from all visits for each transect. This was considered a suitable way to achieve a good overview of larger scale differences between transects. Additionally, for a more landscape level approach, we have compared our indicator groups between different habitats (savannah, forests and village lands) as we did in the last three biodiversity reports (Gartzia and Gutierrez 2015; Gartzia, 2014; Hofman et. al, 2013).

Actual number of observed species (Target Species Richness)

The actual number of species observed or the target species richness is the simple illustration of the total actual biodiversity of the ecosystems. It is calculated for every transect on which at least one individual of the target species was observed. It needs to be stressed that the species richness has an upper limit equal to the number of target species on the lists mentioned above (see Table 3 and Table 4), hence the name Target Species Richness.

Diversity profiles

As in previous years' reports, we have combined relative abundances, individual diversity indices and the Effective Number of Species per transect into an approach called **Diversity profiles** (Tóthmérész 1995; Magurran 2004; Hill & Mar 1973). The diversity profiles will inform us in an integrated fashion about the species diversity among different transects and the effects of dominance; they visualize the Effective Number of Species calculated from the different diversity indices (Target species richness [R], Shannon's index [*H*] and Simpson's index [λ]).

These three diversity measures reflect the same diversity, but, to estimate the Effective Number of Species, they weigh species differently according to their relative abundance (i.e. rarity or dominance). Target species richness counts every species equally, no matter how many times it was detected, and thus doesn't take into account the relative abundance. Shannon's index weighs every species according to its relative abundance, making the rarest species contribute less to the Effective Number of Species estimate. Simpson's index goes further and gives proportionately more weight to those species with the highest relative abundance, hence amplifying the dominance of certain species. This gradient is called the 'order' of diversity, and is captured using a scaling factor (α), derived from Rényi's entropy (Rényi 1961):

$$D_\alpha = \frac{1}{1-\alpha}\sum_{1=i}^{S} p_i^\alpha$$

Where D_α represents the species diversity of order α, p_i indicates the relative abundance of species *i*, and S stands for the total number of species. When α equals zero, we obtain the target species richness. When α equals 1, we obtain the Effective Number of Species that corresponds to the exponential of the Shannon's index (e^H). And when α equals 2, we get the Effective Number of Species that is equivalent to the inverse of Simpson's index. If we plot the Effective Number of Species as a function of the value of α, we obtain a diversity profile, which enables us to detect both species richness and dominance effect (or 'evenness' of relative species abundance) at the same time.

The higher the profile, the higher the diversity. If two diversity profiles cross, the communities have different levels of dominance and are said to be non-comparable (Tóthmérész 1995; Jost 2010). The diversity profiles were plotted using the PAST v3.12 software (Hammer et al. 2001).

Rarefaction curves

Since transects have an unequal number of transect visits, abundance data cannot be interpreted easily. Transects that have been visited once or twice, cannot possibly have uncovered the same number of species than transects that have been visited four times or more.

To take this into account, we make use of rarefaction curves (Gotelli & Colwell 2001; Magurran 2004) that allows comparison of species accumulation between transects at a set number of transect visits. This set number of transect visits is determined by the transect with the least visits.

Rarefaction curves are created by repeatedly drawing a random subset of transect visits from one transect (with varying number of visits per draw), registering the species richness per draw, and then plotting the average number of species found as a function of the number of transect visits. Thus rarefaction generates the expected number of species in a small collection of transect visits drawn at random from the large pool of transect visits of that transect. The rarefaction curves were calculated and plotted using the PAST v3.12 software (Hammer et al. 2001).

Indicator Groups

To measure the effects of habitat disturbance on the species composition, we sum up all individuals observed and calculate the percentage that fall in each Indicator Group. We use percentages to standardize visit frequency and number of species across transects and to compare between transects and habitats.

Bats

For 2015 we used two different methods to survey bats: passive acoustic monitoring using ultrasonic detectors to pick up echolocation calls, and trapping at ground level using mist nets and harp traps. Combining methods maximises the number of bats we are likely to find – some species fly too high to be caught in nets and harp-traps and some echolocate too quietly to be picked up on the bat detector. By using both approaches we are able to sample more species than with one method alone.

Surveys were conducted in four different habitats: the mature forests of BNR, the recovering forests of GSCP, small agroforestry farms and orange monocultures within the MGL (see map in Figure 3). These sites were chosen based on logistical feasibility. Each habitat was sampled between 12 and 16 nights during both the wet and the dry season. Sampling on consecutive nights at the same location was avoided.

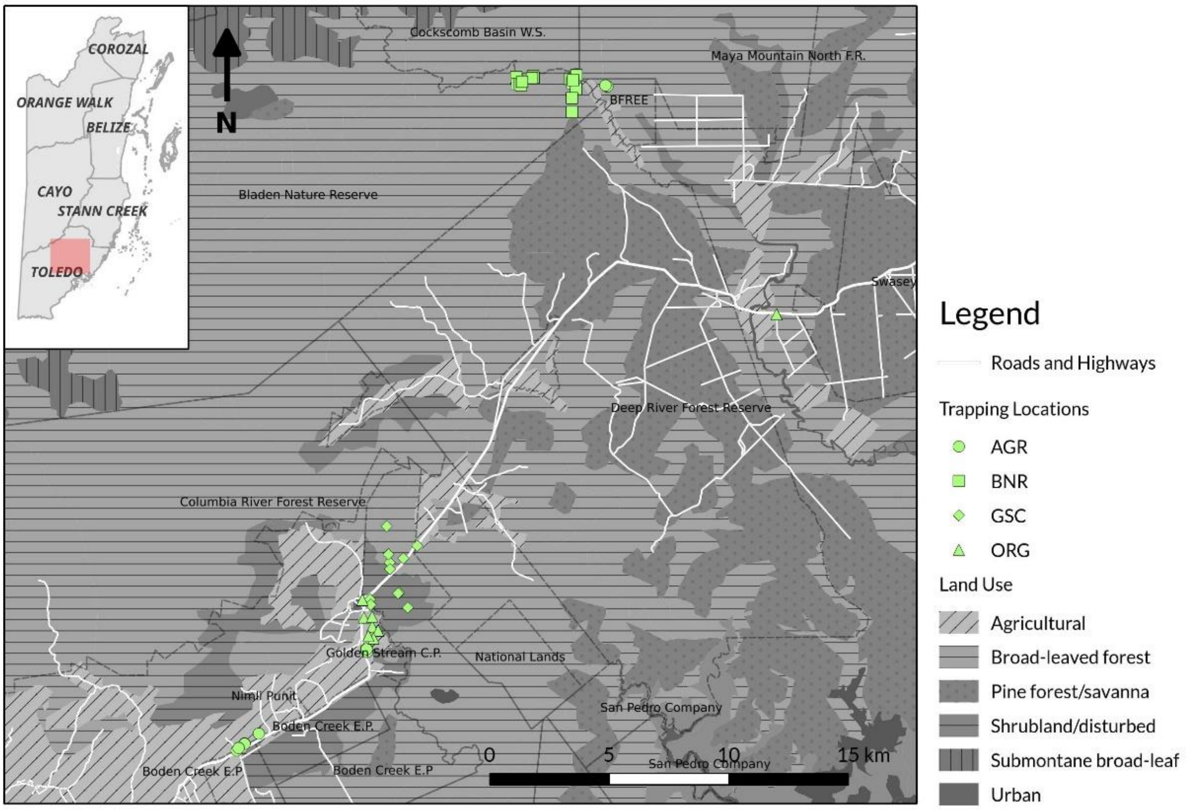


Figure 3. Bat trapping and acoustic sampling sites in

Trapping

Trapping was carried out with 2.6 x 12m and 2.6 x 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 the nets. Occasionally a high net system was used to capture bats at sub-canopy level, this comprised of three 9m nets stacked vertically using a pulley system. Ground nets were set every night at sunset and left open for four hours. Trapping was not conducted on bright nights around a full moon. Each net was attended by a trained operator at all times, bats were extracted promptly and kept in bat holding bags until processed. Biometrics (weight, forearm size and sex) were recorded, species determined and then bats were then released. Methods were standardised and sampling effort was kept as equal as possible among sites.

Some species could not be identified in the field, either because some species are identical in-hand (cryptic) or because they are of intermediate size between two species. Bats not identified to species level were either grouped by genera for analysis (*Dermanura* sp) or were not considered for analysis because their numbers were negligible (*Artibeus* sp, *Carollia* sp and *Glossophaga* sp).

We estimated capture rate for each catching method by dividing the number of bats captured by the number of mist net hours (bats/mnh) or harp-trap hours (bats/hth).

Acoustic monitoring

Whereas acoustic monitoring in previous years was carried out on transects, this year we deployed ultrasonic detectors at all trapping locations. Over the course of the year 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 we had 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 difference between these detectors is shown in Table 7.

Table 7. Differences in bat detectors used in our surveys. (*) Frequency range is one of many factors that make bat detector microphones sensitive.

	Batbox Baton	*Anabat express*	*Pettersson M500*	*Echometer EM3+*
Recording type	Frequency-division	Zero-crossing	Full spectrum	Full spectrum
Call quality	Keeps information on frequency, intensity and timing, call shape less clear	Keeps information on frequency and timing, call shape less clear	Records calls in full detail, very clear detail of call shape and structure	Records calls in full detail, clear detail of call shape and structure
*Freq. range**	20-120 kHz	10-150kHz	10-190 kHz	1-192 kHz
File size	Medium	Very small	Large	Large

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.

For the first time since Ya'axché started bat monitoring in the MGL, analysis of bat recordings was done in-house. Call parameters such as shape of call, duration, and peak frequency were compared with known species parameters from published literature. Analysis of frequency division and full spectrum recordings was carried out using Audacity, and zero-crossing calls in Analook.

To minimise variability in call quality and detection rate due to habitat structure, detectors were placed in the most open space available in each habitat. However, vegetation structure at every site was not identical and some sites were inevitably more cluttered than others. Recordings with very faint bat passes or recordings where it was not possible to identify species reliably were classified as 'unknown' (12% of 7,758 bat recordings) and were not considered for analysis. Additionally, bats of some genera are not possible to tell apart by sound alone, and as a conservative measure were grouped as one for all statistical analyses (*Eumops* gen, *Myotis* gen, *Lasiurus* gen, Vesper 50 kHz).

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. 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). To assess the differences of species diversity at each site, species richness and Shannon's and Simpson's diversity indices were calculated.

Wildlife observations

As an addition to the on-going monitoring transects of birds and large mammals, Ya'axché rangers also record significant opportunistic observations made while carrying out daily patrols in the protected areas. Only actual sightings of animals are recorded; tracks and other signs are ignored. Even though daily patrols are conducted in both GSCP and BNR, their target area and length is tailored to enforcement needs and thus very irregular and unpredictable. Therefore, no standardised indices can be derived from the observations. They merely serve as an informal indicator of presence/absence and abundance of wildlife species in the area.

Patrols done in BNR sometimes leave from the Golden Stream Field Station and cross the Columbia River Forest Reserve. A small number of sightings done in CRFR were categorised under BNR.

Tree Monitoring

In 2013, former Ya'axché botanist Gail Stott began a tree phenology monitoring program in Golden Stream Corridor Preserve in order to study the biology and ecology of *Dalbergia stevensonii* (Honduran rosewood). In 2014 monitoring was expanded to six other rare and threatened species in Bladen Nature Reserve and regular data collection has occurred since that time.

Data Collection

Tree Phenology Monitoring

Target tree species were located during surveys carried out by Gail Stott and Dr. Steven Brewer in GSCP and BNR in 2013 and 2014, respectively. Species were chosen as targets based on their known rare or threatened status, a lack of information within Belize and/or the known use as a timber species. The conservation status of the monitored species can be seen in Table 8.

Table 8. Target tree species monitored in Golden Stream Corridor Preserve and Bladen Nature Reserve.

Species	Common Name	IUCN Red List Status
Dalbergia stevensonii	Rosewood, Honduran Rosewood	Not assessed
Mortoniella pittieri	-	Not Assessed
Cymbopetalum mayanum	-	Endangered
Pouteria amygdalina	silion; silly young	Vulnerable
Chiangiodendron mexicanum	-	Endangered
Macrolobium sp.	-	Not Assessed
Platymiscium dimorphandrum	granadillo	Least Concern

One hundred individuals of *D. stevensonii* were tagged and monitored at 4 different sites ('Hope Creek', 'Behind Greenhouse', 'Opposite Field Station' and 'Downstream') within GSCP (see Figure 4). Diameter at breast height (DBH) of the main stem for each tree was measured at 1.3m. The trees were classified in size classes of the following groups: Size Class 1: 5-10cm DBH, Size Class 2: 11-20cm DBH, Size Class 3: 21-30cm DBH, Size Class 4: 31-40cm DBH and Size Class 5: 41-50cm DBH. A total of 34 individuals of the following species were tagged and monitored in BNR: *Mortoniella pittieri,* 11 individuals; *Cymbopetalum mayanum, 5; Pouteria amygdalina, 11; Chiangiodendron mexicanum, 4; Macrolobium sp.,* 1 *and Platymiscium dimorphandrum, 2* (see Figure 5).

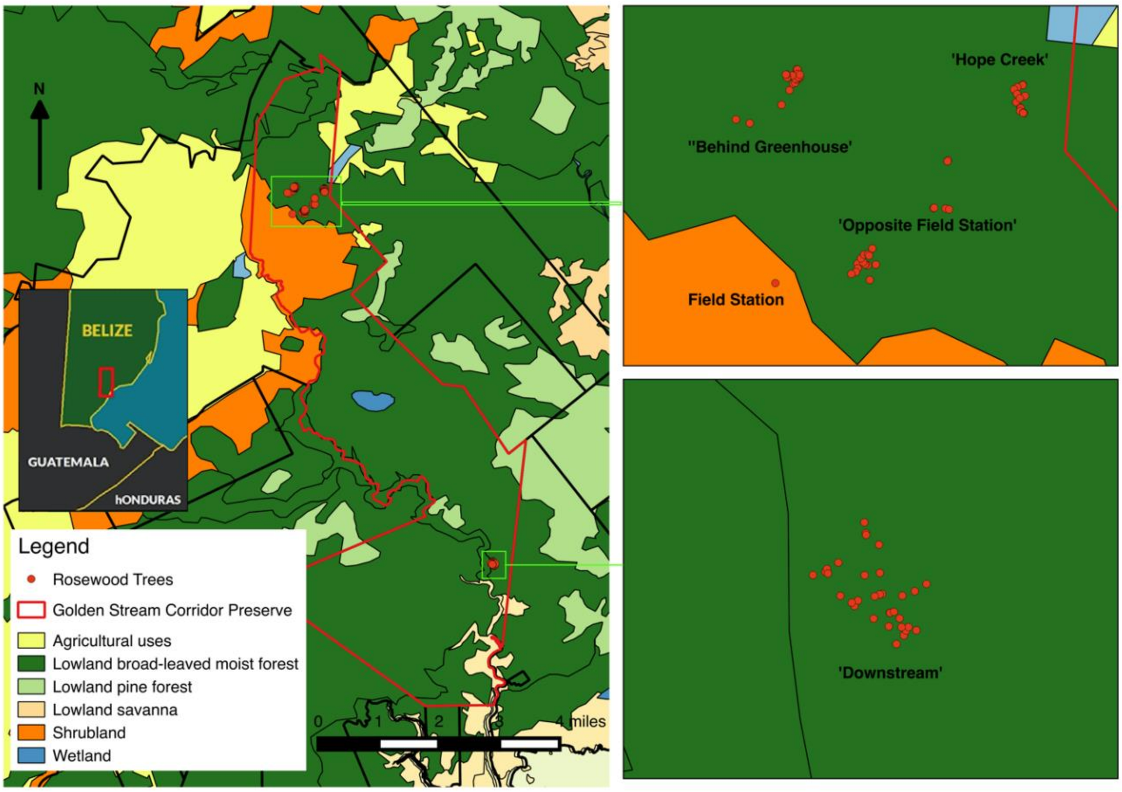


Figure 4 Location of 100 monitored individuals of *D. stevensonii* (red points excluding "Field Station") in Golden Stream Corridor Preserve.

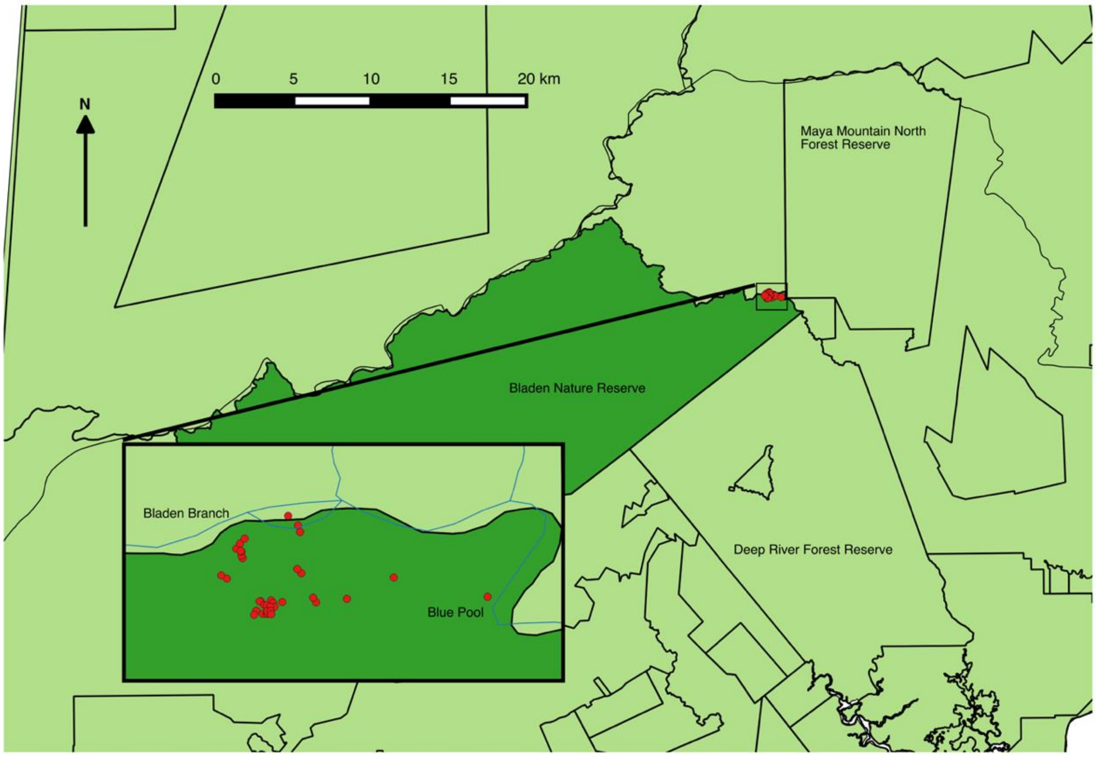


Figure 5 Location of 34 monitored individuals of *C. mayanum, M. pittieri, P. amygdalina, C. mexicanum, P. dimorophandrum, and Macrolobium sp.* (red points, excluding Blue Pool) monitored in Bladen Nature Reserve.

Monitoring began in GSCP in October 2013 and sites were visited once a week on a rotating basis. Trees at the 'Downstream' location were not monitored on the regular schedule due to the distance required for access. Therefore, these trees were only monitored 2-3 times per year during the reporting period. Monitoring in BNR began in August 2014 and the trees were monitored once every 2 weeks. During visits to both BNR and GSCP a data sheet was filled out (see Figures 6a and 6b), answering 'yes' or 'no' to questions relating to the phenological phase of each individual.

Date Monitoring Carried Out:							
Ranger Names:							
		Is the tree losing its leaves?	Does the tree have flower buds (very small, green, hanging on ends of branches)?	Does the tree have open flowers on the branches or on the ground (look for pale yellow petals)?	Does the tree have unripe pods (bright green, hanging in clusters) on the branches?	Does the tree have ripe pods (brown) on the branches?	Are there pods on the ground?
		(yes or no)	(yes or no)	(yes or no)	(yes or no)	(yes or no)	(yes or no)
	Tag #						
	1						
	2						
	3						
	4						

Figure 6a Phenology data collection sheet example for *D. stevensonii* in GSCP.

DATE MONITORING CARRIED OUT:								
RANGER NAMES:								
			Is the tree losing its leaves?	Does the tree have open flowers on the branches?	Does the tree have flowers on the ground?	Does the tree have unripe fruits hanging on the branches?	Does the tree have ripe fruits on the branches?	Are there fruits on the ground?
			(yes or no)	(yes or no)	(yes or no)	(yes or no)	(yes or no)	(yes or no)
Species	**WAYPOINT / TAG #**	**LOCATION**						
Mortoniella pittieri	1222	Main trail						
Cymbopetalum mayanum	1015	Main trail						
Cymbopetalum mayanum	1001	Main trail						
Cymbopetalum mayanum	1002	Main trail						
Cymbopetalum mayanum	1003	Main trail						
Pouteria amygdalina	1212	Slope plot						
Chiangiodendron mexicanum	1219	Slope plot						

Figure 6b Phenology data collection sheet example for species monitored in BNR.

Comparisons of the proportion of observed flowering and fruiting individuals in various class sizes of *D. stevensonii* are made. Patterns in length and frequency of annual flowering and fruiting events during the monitoring period are described for each species.

Weather

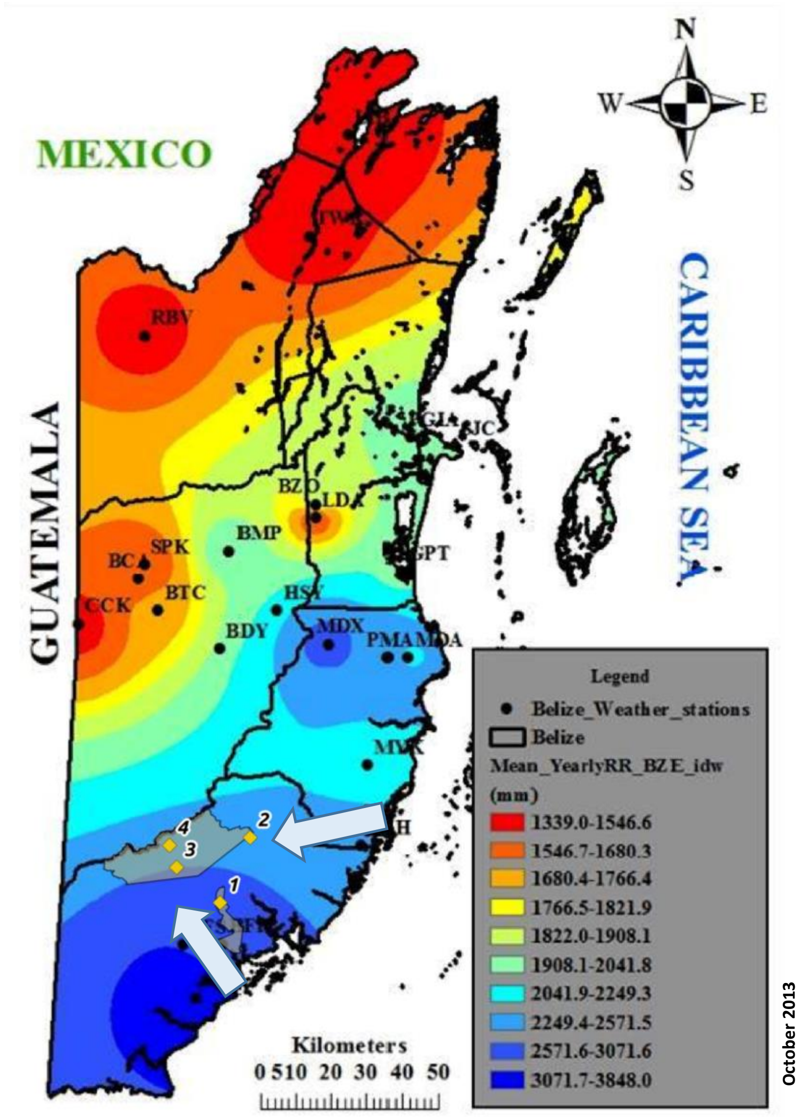
Belize’s weather is characterised by a rainfall gradient that increases roughly from north to south (see Figure 7). Long-term rainfall data are yearly averages and the countrywide coverage is extrapolated from a set of several weather stations distributed over the country, with a limited set of stations in the southern part of the country.

More detailed weather information enables a more localised picture of specific circumstances that might inform us about for example farming success or failure in certain years. Therefore, we gather rainfall data, temperature and relative humidity data at the two Ya’axché ranger bases located at Golden Stream Corridor Preserve (W088°47'13.90" N16°22'23.41" [WGS 84]) and Bladen Nature Reserve (W088°42'44.79" N16°32'07.61" [WGS 84]). Both weather stations are composed of an electronic temperature and humidity device (Digital Hygro-Thermometer, Forestry Suppliers Inc.), and a manually operated rain gauge. Data was recorded manually and entered in a digital spreadsheet.

In addition to the two manually operated weather stations, in 2012, we installed two fully automated weather stations in Bladen Nature Reserve. The systems consisted of four sensors that measure rainfall, wind speed, temperature, relative humidity and Photosynthetically Active Radiation (sunlight), and were attached to a data logger which stores measurements from all sensors every five minutes.

The two weather stations were placed to detect two rainfall gradients that are thought to exist in BNR (see arrows in Figure 7). The first rainfall gradient is expected to arise from clouds blown in with the prevailing NE-winds. The clouds hit the Maya Mountains and run along the Main Divide, dropping their rain load as they get blown up the mountains. Similarly, the increasing altitude forces moisture-loaded clouds coming from the SE to drop their load as they reach the Main Divide. With the interaction of these two gradients we would expect a local maximum (most rain) on the western end of the Main Divide.

However, one of the weather stations was stolen (presumably by Xatéros, harvesters of *Xaté* leaves – or ‘fishtail’ palm) and the other was damaged after a heavy flood in 2014. As a result, no data is available from these station for 2015.



Map prepared by Frank E. Tench

Figure 7. Mean annual rainfall across Belize since 1951, with varying number of year's data availability per weather station. Bladen Nature Reserve and the Golden Stream Corridor Preserve are indicated by transparent polygons. The four Ya'axché weather stations are Golden Stream field centre (1), BNR ranger base (2), the old Esmeralda (3) and Oak Ridge (4) . Arrows indicate expected local rainfall gradients. Map prepared by Meteorologist Frank Tench (Frutos, 2013)

Land-use change

Shifting-agriculture practices are widespread among the indigenous population of rural southern Belize. Clearings are done using two methods; slash-and-burn (more common in the dry season) and slash-and-mulch (more common in the wet season). Practices involving fire present a major threat to forests due to escaped fires as they reduce forest cover placing biodiversity at risk. For that reason both were taken into account in this report.

In order to keep track of the extent of deforestation in the Maya Golden Landscape, we make use of Geographical Information Systems (GIS) and satellite imagery to compare the status of the vegetation throughout the year. Specifically, we used satellite imagery from USGS Earth Explorer corresponding to seven specific dates in 2015: April 23rd, May 25th, July 4th, August 13th, September 14th, November 1st, and December 27th. These dates provided the most cloud free satellite images.

Through photo-interpretation of this Landsat 7 and 8 satellite imagery, we obtained the extent and number of areas that showed a clear loss in vegetative cover due to different agricultural practices. The photo-interpretation was done by Ya'axché's experienced GIS specialist, Jaume Ruscalleda.

Results

The result section follows the same sequence of monitored taxa as the methodology section. Data collected in transects are analysed separating birds and mammals, starting with general descriptive statistics on the actual number of species and followed by a more specific comparative analysis using diversity profiles and species rarefaction curves throughout transects. Data collected on other monitoring surveys are analysed and presented in an equally straightforward manner.

Birds

Transects were visited between 7 and 24 times each over the course of the year, resulting in a total of 137 km of transects completed and an average of 13.7 visits per transect (see Table 9). This was a decrease from the previous year's sampling effort, an average of 14.9 visits per transect.

Table 9. Bird monitoring effort per transect in 2015, BNR=Bladen Nature Reserve, CRFR=Columbia River Forest Reserve, GSCP=Golden Stream Corridor Preserve, IV=Indian Creek Village

Transect ID	# of visits	# of m transect	Avg. # of obs./1000m
BNR2	24	24000	10.4
BNR3	24	24000	8.4
CRFR1	10	10000	8.7
CRFR2	10	10000	11.2
CRFR3	10	10000	11.3
CRFR4	10	10000	7.7
GSCP1	7	7000	7.3
GSCP2	10	10000	8.9
GSCP9	10	10000	9.0
IV1	22	22000	9.5
MGL	**137**	**137000**	**9.2**

Of the 30 bird target species, a total of 24 species were detected, with a total of 1,646 observations recorded, resulting in an average of 9.2 observations per km of completed transect. There was a significant positive correlation between the number of visits and the number of observations per species (Spearman's ρ =0.864; p < 0.05), but no correlation between the number of visits and average number of observations per 1000m (Spearman's ρ = 0.288; p = 0.4199). There was a similar strong link between the number of visits and the number of individual birds recorded (Spearman's ρ = 0.843; $p < 0.05$). As the number of visits to transects increases, the number of individual birds also increases.

BNR2 transect consistently records the highest number of observations over all the others, but CRFR2 and CRFR3 have the highest average observations per 1000m. We will see later in this section that having a higher number of observations per 1000m does not necessarily indicate the presence of more target birds or more target species diversity.

In 2015, between 6 and 14 transect visits were conducted per month (see Figure 8). July and October had the lowest number of transect visits at 6 each while January and May had the greatest number of visits at 14 each. The average number of visits overall was 11.4 visits per month so generally transects visits were roughly even throughout most of the year.

As noted in Figure 8, the number of visits per transect was more or less even throughout the year, with dips in July and October. Logistical limitations are the main cause for these low number of visits for these two months, specifically lack of sufficient man power. The number of observations however follow a different trend; the low number of visits in October not having a significant influence on the number of observations. June and July typically record fewer target species with July having the lowest richness in 2015; mostly influenced by the absence of migrant species. More detail on migrants can be found later on in this section.

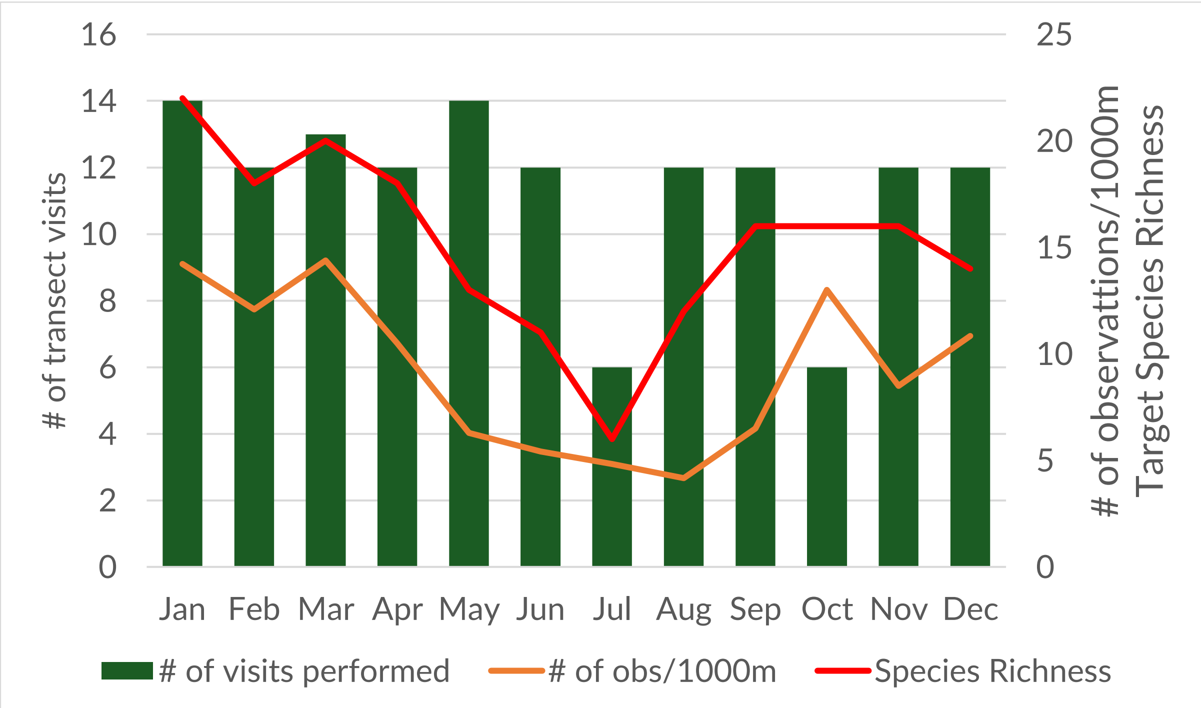


Figure 8. Bird monitoring effort in 2015

Target species richness

As explained in the methodology section, our list of target bird species is biased towards forest species, but does contain disturbance indicators and savannah species. Therefore, we are able to compare the results of the three different habitats by assembling the transects conducted in each landscape type. However, there is one important factor to consider when making comparisons, the larger proportion of forest transects relative to that of the other transect types. We therefore compare the average target species richness in 8 forest transects with a single savannah and a single village land transect; using an average value can result in a more moderate and conservative reflection of the total forest target species richness because the arithmetic average is sensitive to outlying values. On the other hand, given the openness of the savannah and village lands habitats, we would expect the visibility and sound travel distance to increase in these environments, inflating species richness estimates in these cases.

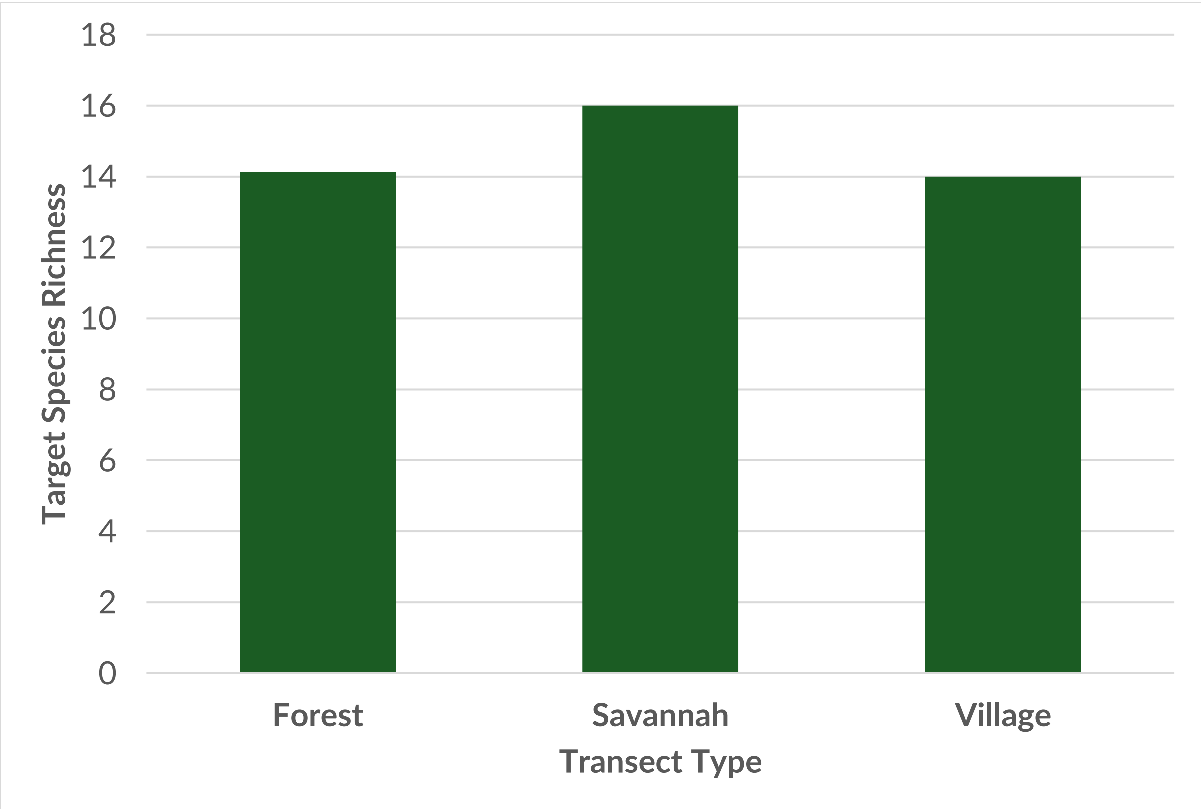


Figure 9. Total target bird species richness per habitat

Figure 9 shows an average of 14.13 target species detected on forest transects, compared with 16 target species detected in the savannah and 14 in village lands. All forest transects yielded a total of 21 target species, including all species found in the other two habitats, except three that are restricted to the pine-savannah (Blue-gray Gnatcatcher, Grace's Warbler and Yellow-headed Parrot). With this in mind we can only interpret Figure 9 as indicating a similar number of species found within all three transect types but that the species composition differs from habitat to habitat. Composition by indicator class is explored later in this section.

Sample-based species rarefaction curves

For a fair comparison, each transect should have an equal number of visits. However, logistical limitations prevent even sampling at any given point in time. Therefore, we compare all the transects' expected species accumulation at the point where the minimum sample size lays (in this case, the minimum amount of samples was 7 for GSCP1). The rarefaction analysis (explained in the methods section) results in rarefaction curves or species accumulation curves as seen in Figure 10.

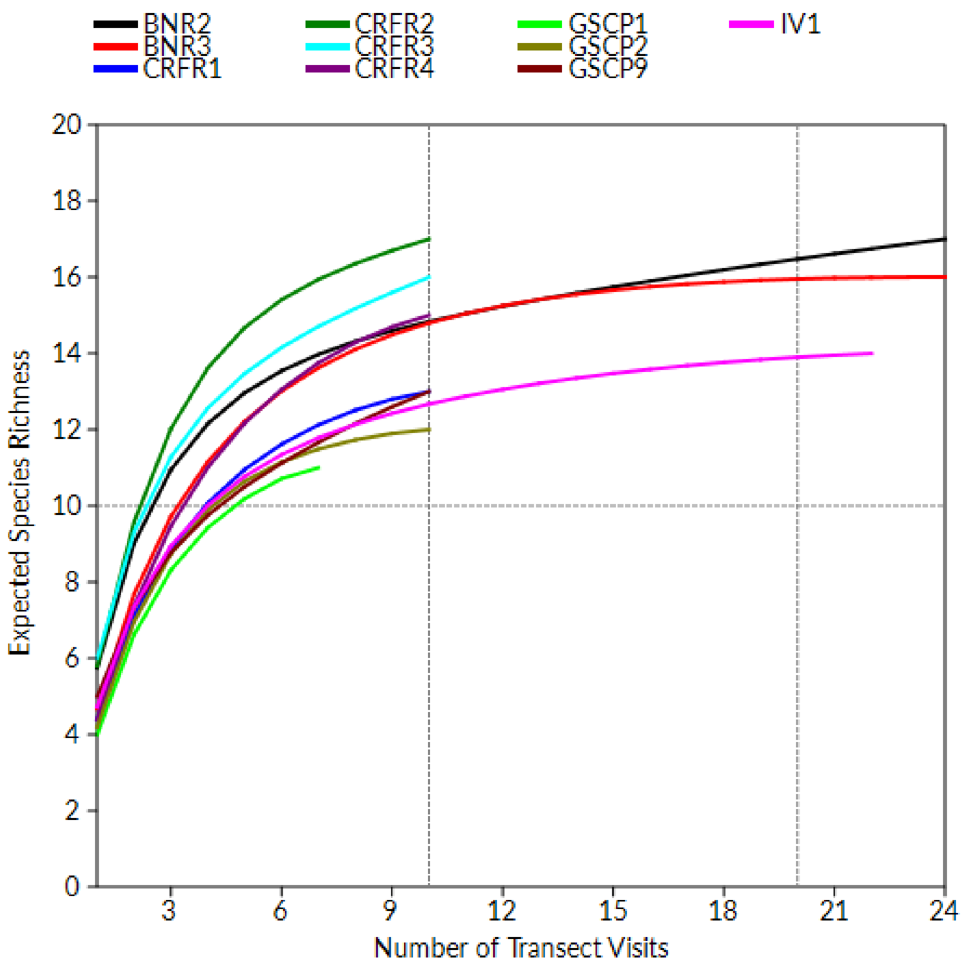


Figure 10. Sample-based rarefaction curves for all transects

Table 10. Transect ranking according to expected bird target species richness after 7 transect visits

Rank	Transect
1	CRFR2
2	CRFR3
3	BNR2
4	CRFR4
5	BNR3
6	CRFR1
7	IV1
8	GSCP9
9	GSCP2
10	GSCP1

Table 10 shows ranking in expected species richness of the transects at 7 transect visits. CRFR2 and CRFR3 transects accumulated most species at 7 visits (15.9 and 14.7 respectively); followed by BNR2 (13.9) in descending order of rank. In general, all transects in Columbia River Forest Reserve and Bladen Nature Reserve accumulate most species within 7 visits. Golden Stream Corridor Preserve transects consistently rank lower on the list. The notable change in 2015 was the village transect ranking higher than all the Golden Stream Corridor Preserve transects. We consider this to be the result of the influence of older secondary vegetation attracting a greater number of forest birds; a bias also represented within our target list. The resulting records for this transect could potentially be very variable year to year. Subsequent analyses should explore this further.

Diversity profiles

Both BNR2 and CRFR2 recorded the highest diversity but have a notable effect of dominance caused by Brown-hooded parrots and Slaty-breasted tinamous (see Figure 11). Dominance is more apparent in the savannah transect and CRFR3; both of which have high target species diversity but are dominated by two species (Yellow-headed Parrots and Plain Chachalacas). All Golden Stream Corridor Preserve transects recorded show lower species richness in comparison to the rest; but they are the sites least affected by species dominance making them the transects with more species evenness. Although the village transect (IV1) recorded a higher diversity than the Golden Stream transects, and in fact higher than the previous year, it has a steep influence of dominance attributed to the abundance of plain chachalacas in the area.

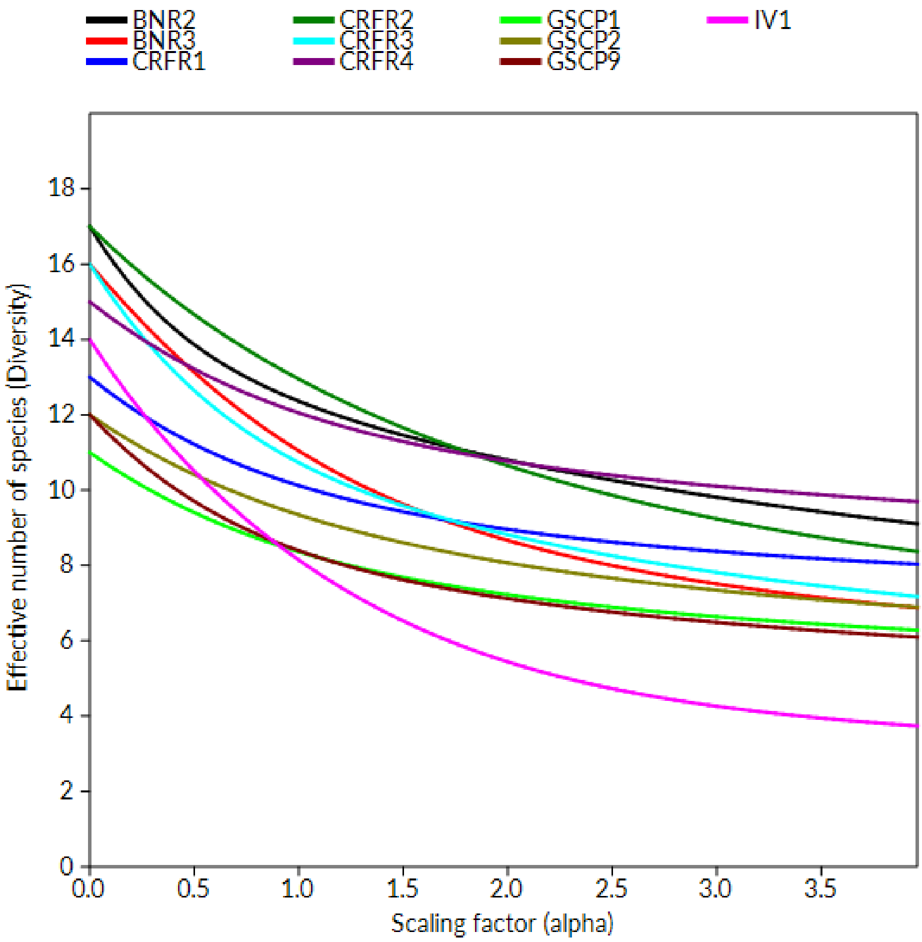


Figure 11. Bird diversity profiles

Migratory birds

To detect bird migratory patterns throughout the year we compare encounter rates per month of migrant target bird species only. Encounter rates are calculated as the number of individuals recorded per 1000m of walked transect. There was no significant correlation between the number of individuals per 1000m and the number of transect visits per month (Spearman's ρ = 0.28; p = 0.37), which enables us to compare between months without controlling for the number of visits conducted in these months.

The pattern of migration can be clearly seen as the peak of the season is marked from October to March (see Figure 12). Like previous years, species richness follows a similar pattern with encounter rates plummeting to low numbers or none at all in the summer months. Contrary to 2014's findings, species richness was highest in January 2015 but coincides with the pattern at the end of 2014. Species richness was also lower at the end of 2015 than it was at the end of 2014.

The species that were present the longest during 2015 were the American Redstart and Black and White Warblers. The former was absent only between mid-June and early

August; and the latter being absent between May and July. The presence of the Blue-gray Gnatcatcher in the savannah was consistent with last year's records, which was the first time it was recorded in our transects.

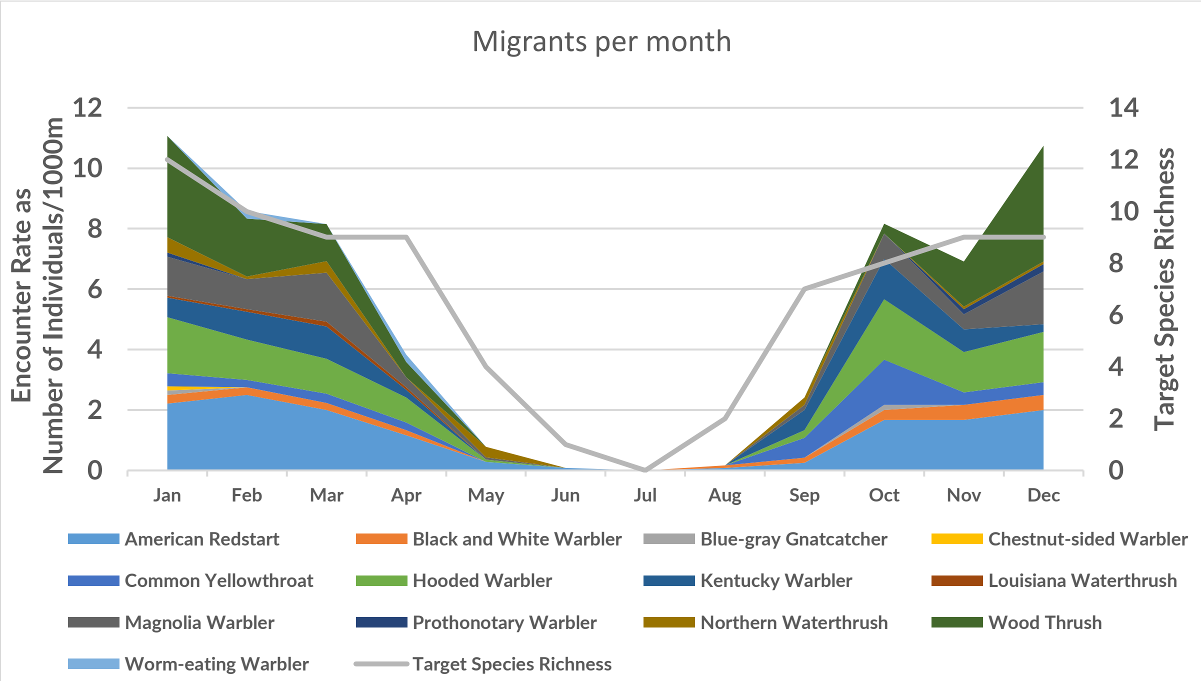


Figure 12. Migrant encounter rate and species richness throughout the year

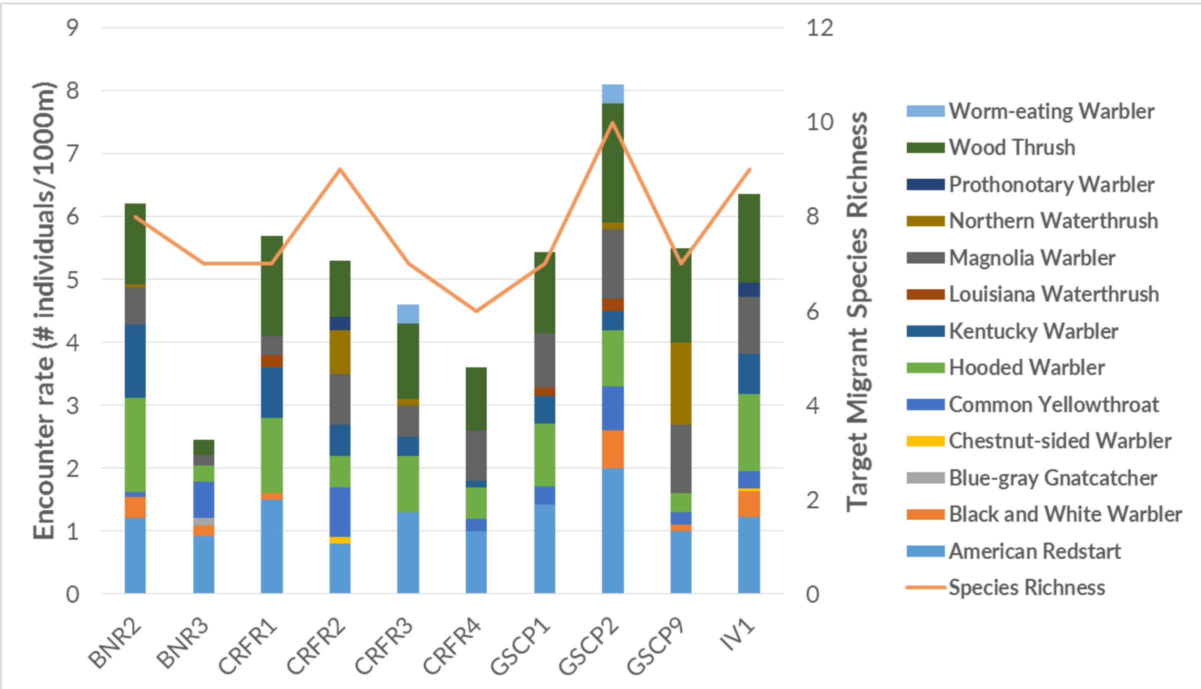


Figure 13 Encounter rate and species richness of migrants per transect

Migrant species richness fluctuated across transects but there was a notable dip in richness for CRFR4 (Figure 13). This transect also has a low encounter rate, although not the lowest. The lowest encounter rate can be seen for BNR3, the savannah transect, although this transect has a higher species richness than CRFR4. Both of these transects had displayed evidence of dominance in the previous section and is evident to a lesser extent with the migrants. The village transect shows high species richness and high encounter rates indicating a more even distribution of abundances of migrant species. A similar pattern was observed for BNR3, although the species composition differs to that of IV1. The dominant migrants are clearly evident across transects, singling out Wood Thrush, Hooded Warbler and American Redstart.

Indicator groups

Indicator groups give us information about the health of an ecosystem. When comparing different ecosystems, we need to take into account the number of visits done in each habitat. As explained earlier, statistical analysis determined a positive correlation between the number of observations and number of transects. There were 91 transect visits done in the forest habitat, only 24 in the savannah and 22 in village lands habitat. The higher sample size of transect visits explains why more individuals and species were observed in the forest than on the transects in the savannah and village lands. To take these visit differences into account, we standardized the results using percentages rather than standardizing per distance (i.e., encounter rate – the number of individuals per 1000m), to avoid the difference in observed number of species affecting the summed encounter rates per indicator group. In Figure 14, the total number of individuals encountered in each habitat is shown in brackets.

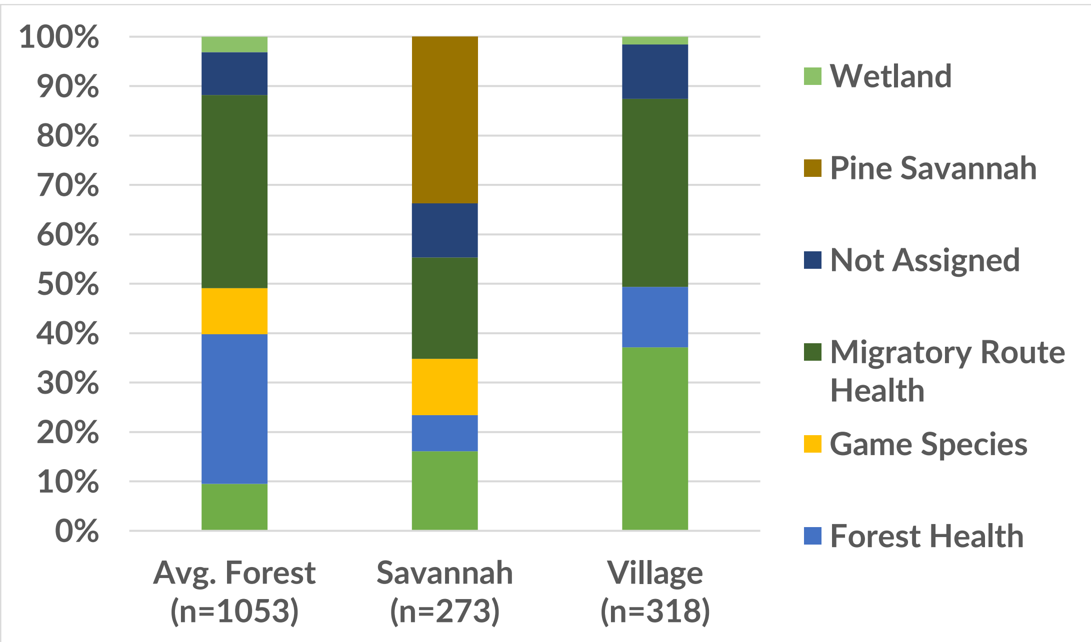


Figure 14. Distribution of individuals among Indicator Groups

Migratory route health indicators made up 39% of the individuals recorded in all forest transects combined. Forest health indicators made up a similar proportion at 30% of the individuals recorded in all forest transects combined. Disturbance indicators, notably one species (Plain Chachalaca), made up 9.5% of the total number of individuals. Similarly, game species made up 9.4% of the total number of individuals in forest transects (see Figure 14).

In the savannah, a third (33.7%) of all individuals detected were pine savannah indicators. As in the previous year's data, a significant percentage (25%) of the individuals were migratory route health indicators and is a smaller proportion than is seen in the other two habitats. In addition, game indicators are greater in the savannah than in the other two habitats; but these are all recordings from the nearby forested foothills.

In village lands, considerably less forest health, game and pine-savannah indicator species were detected. 37.1% of individuals were indicators of disturbance, significantly higher than that seen in the other two habitats. Migratory route health indicators made up 38% of the individuals in the village lands and game birds were conspicuously absent.

To compare the distribution of indicator groups across transects, we arranged the transects in a roughly defined disturbance gradient in forest transects originally defined by Hofman et. al., 2013. Figure 15 presents the proportions of individuals belonging to each indicator group for all forest transects and compares them side by side with the village transect and savannah transects. As this is a coarse gradient of disturbance it should be taken conservatively considering that there may be other factors affecting any patterns in the indicator groups (weather, monitoring effort, population fluctuations etc.).

The most notable trend is a decrease of forest indicators as the disturbance gradient increases. On the other hand, disturbance indicators increase as the disturbance increases. Migratory indicators have an affinity to forested areas and are less abundant in the savannah. As expected, the savannah transect (BNR3) has a very different composition than all other transects. The number of individuals detected in the different transects is shown in brackets. BNR2, BNR3 had 24 transect visits each, IV1 had 22 visits, GSCP1 had 7 visits and all other transects had 10 visits over the course of the year (see Table 9).

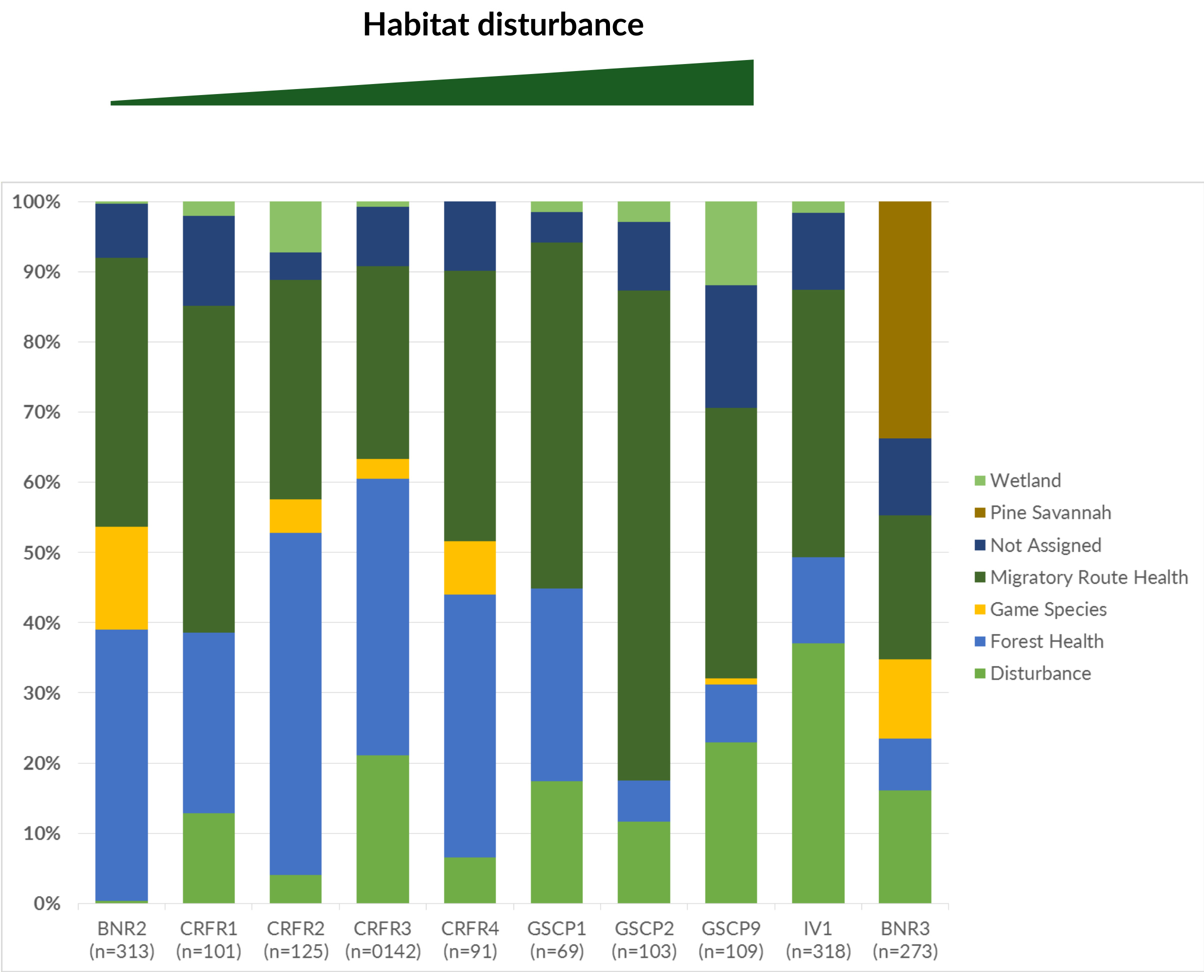


Figure 15. Distribution of individuals among Indicator Groups, looked at per transect. From the left, the first 8 transects indicate a habitat disturbance gradient in the forest. The next transect is on village lands, the last one in savannah.

Large mammals

As with previous years, the number of mammal transect visits remained approximately half that of birds. For 2015 a total of 69 mammal transects were carried out, covering a total of 69km (see Table 11). This was similar to 2014's total of 70km. The number of transect visits per general location (i.e. all transects in Bladen) was more consistent than in previous years with a minimum of 4 visits, a maximum of 12 visits and an average of 4.2 observations per 1000m transect in the MGL.

Table 11. Mammal monitoring effort per transect in 2015, BNR=Bladen Nature Reserve, CRFR=Columbia River Forest Reserve, GSCP=Golden Stream Corridor Preserve, IV=Indian Creek Village

Transect ID	# of visits	# of m transects	Avg. # of obs/1000m
BNR2	12	12000	6.1
BNR3	12	12000	2.8
CRFR1	5	5000	5.4
CRFR2	5	5000	3.8
CRFR3	5	5000	3.4
CRFR4	5	5000	3.0
GSCP1	4	4000	5.8
GSCP2	5	5000	4.4
GSCP9	5	5000	4.0
IV1	11	11000	3.5
MGL	**69**	**69000**	**4.2**

Of the 19 target species of mammals, 16 were recorded, with a total of 289 observations made and 568 individuals counted. The Neo-tropical River Otter, Brown Brocket Deer and White Nosed Coatis were not recorded over the course of the year. The largest number of mammal observations per km was recorded for BNR2, GSCP1 and CRFR1. BNR2 and GSCP1 have consistently been on the top of the list for number of observations per km as reported in Gartzia and Gutierrez 2015 and Gartzia 2014. This is largely due to dominant species within these transects (e.g., white-lipped peccary in BNR2). Transects with the least number of mammal observations per km were IV1, CRFR3, CRFR4 and BNR3, the last one showing a significant decline in the number of observations as compared with 2014. Once again this was influenced heavily by the absence of 2014's dominant species, the white lipped peccary, that favoured the general area of that transect in that year but not in 2015.

A marginally strong positive correlation between the number of transect visits and the number of observations was seen in the data (Spearman's, $\rho = 0.62$; $p = 0.054$) indicating that a larger number of observations could have resulted from additional transect visits. There was also a significant positive correlation between the number of visits and the number of individuals recorded (Spearman's, $\rho = 0.65$; $p = 0.042$) partly owing to the inflated number of highly social species recorded in some transects. However, even after removing the influence of this species (white-lipped peccary) there is still a significant positive correlation between the number of visits and the number of individuals recorded (Spearman's $\rho = 0.72$; $p<0.05$). The average number of individuals per transect did not appear to differ greatly among transects and there was no significant relationship between the number of visits and the average number of individuals per 1000m (Spearman's, $\rho = 0.26$; $p = 0.46$).

Transect visits were variable, as in previous years, with a minimum of three visits per month and maximum of seven visits per month. January, March and June had the most transect visits at seven each, and July and October had the least transect visits at three each (see Figure 16). Under normal conditions the dry season does not offer very favourable conditions for recording tracks. However tracks were recorded throughout the year in similar numbers with low records only in the months of July and October when transect visits were at their lowest. 2015 was an El Niño year with weather patterns not fitting the norm and likely affecting the excess rains that were recorded during the dry season (see Weather section for information on El Niño). This meant that there was no obvious marked decline in the number of observations during the dry season as in previous years.

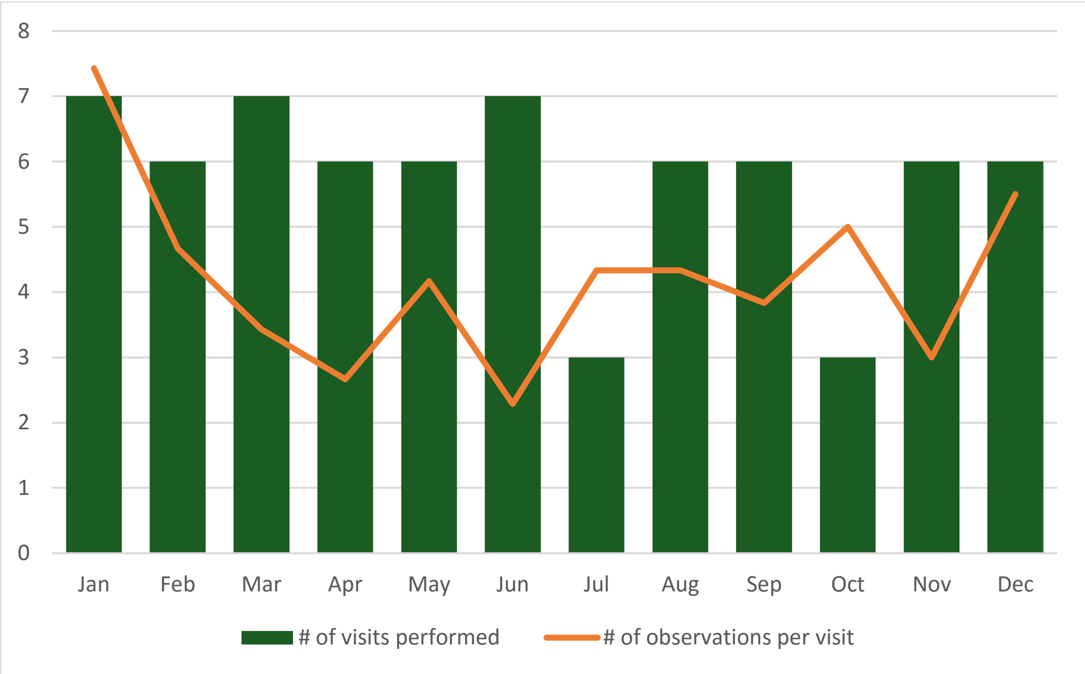


Figure 16. Mammal monitoring effort in 2015.

Target species richness

There are three broad habitats that we can compare from the data collected under the monitoring program. Forest habitat is represented in far more transects than the savannah and village lands transects. The latter two are represented in only one transect each. With differing numbers of transects per habitat, the forest transects were pooled and the averages used for comparisons with the other two habitats. Although there was a total of 14 target species recorded within forest transects, the average target species richness within forest habitats was comparatively similar to the target species richness in the other two habitats (see Figure 17). Increased accuracy of distance estimates has led to significant improvements in the data particularly when recording species heard at a distance from the savannah transect. As a result, the savannah transect recorded fewer species as compared with previous years; ruling out the presence of species likely to be within the forest's edge rather than within the savannah habitat. The savannah and village transects both recorded 7 target species. BNR2 and CRFR1, both forest transects, recorded the highest richness at 12 and 10 species respectively.

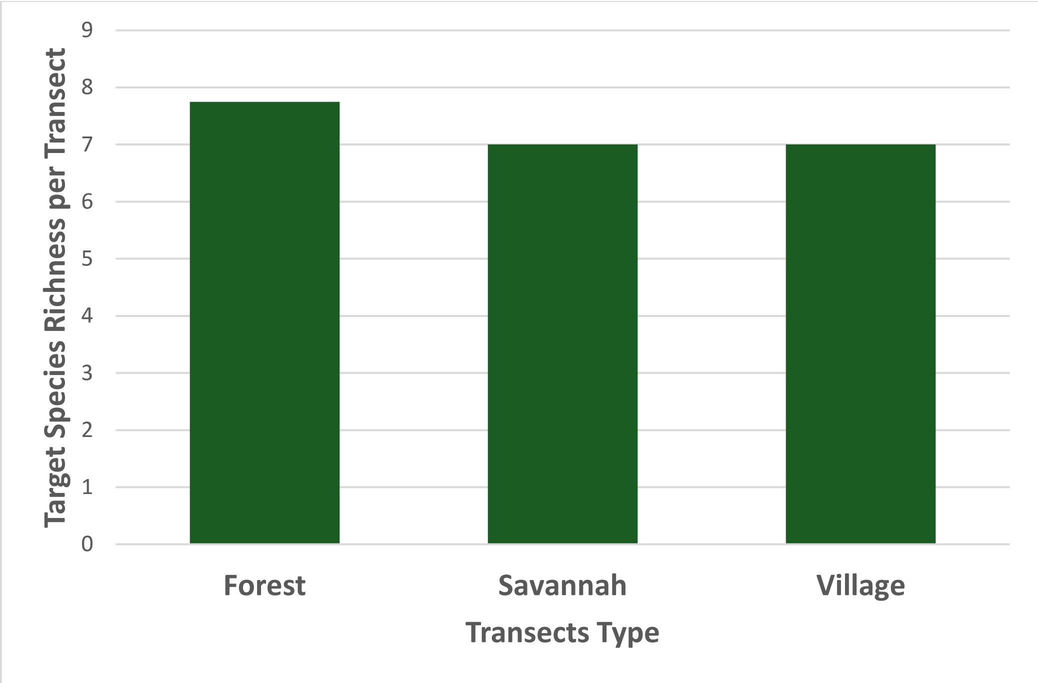


Figure 17. Target mammal species richness per habitat type. “Forest” shows the average target species richness for that particular habitat.

Species accumulation and rarefaction curves

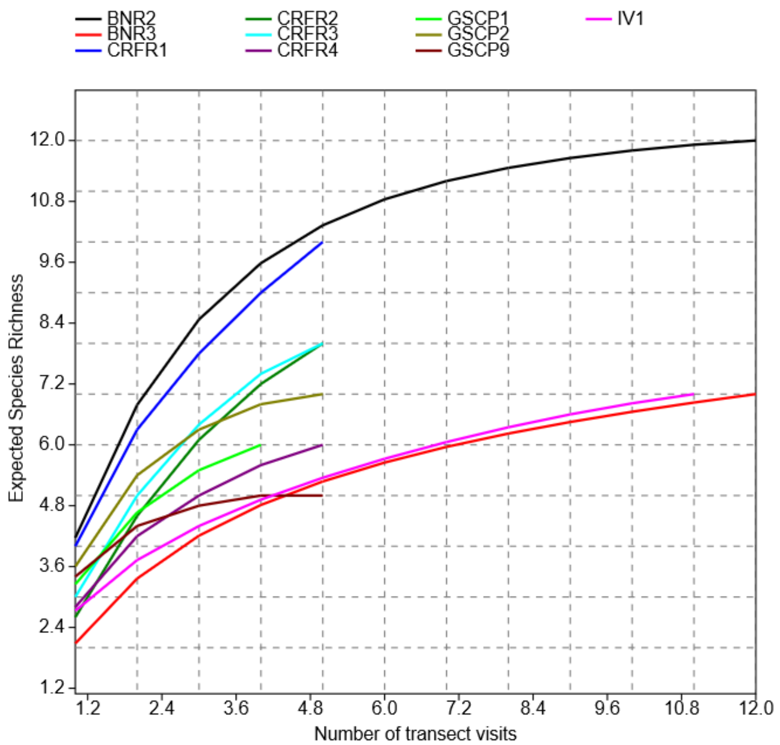


Figure 18. Sample-based rarefaction curves for large mammals

We calculated the expected species richness for each transect and produced rarefaction curves (see Figure 18). This allows the comparison of transects with different sampling efforts, as in the total number of visits per transect. Transect visits ranges from a minimum of 4 to a maximum of 12.

Table 12. Transect ranking according to expected mammal target species richness after 4 transect visits

Ranking	Transect
1	BNR2
2	CRFR1
3	CRFR3
4	CRFR2
5	GSCP2
6	GSCP1
7	CRFR4
8	GSCP9
9	IV1
10	BNR3

Table 12 shows the ranking of transects based on their expected species richness after the minimum number of visits. BNR2, CRFR1 and CRFR3 recorded between 7 and 10 species after just 4 visits. The village transect IV1 and the savannah transect BNR3 had similar richness at 4.9 and 4.8 respectively and represent the lowest target species richness.

Diversity profile

Dominant species in some of the transects can create an "uneven" distribution of relative abundance. This is most apparent in transects BNR2 and CRFR3 (see Figure 19). This pattern can be year to year or transect to transect; but it has always been due to one species that seems to dominate in certain areas at different times of the year. So, although BNR2 has the highest target species richness, the unevenness in relative abundance is quite noticeable for this transect. White-lipped Peccaries are the primary cause for this effect on the profiles for both BNR2 and CRFR3 where we can see that as the scaling factor α increases, the dominance of that one species reduces the effective number of mammal species. CRFR1 was the second highest for target species richness with little influence of dominant species and more even relative species abundance compared with BNR2. All other transects showed more even abundances but at lower target species richness.

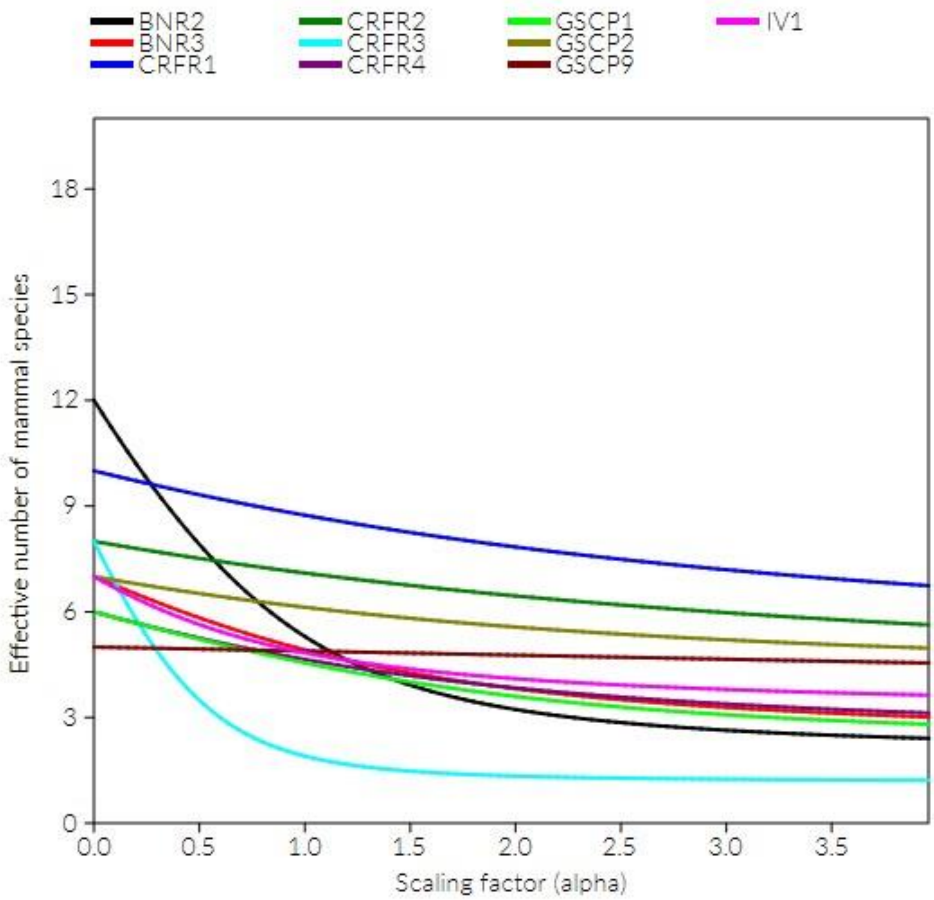


Figure 19. Mammal diversity profiles 2015

Indicator groups

The savannah transect BNR3 had as many forest indicator species as the forest transect BNR2 likely due to its proximity to the broadleaf forest habitat on the boundary line of the Bladen Nature Reserve and the Deep River Forest Reserve. However, the average forest indicator species for all the forest transects provided a much lower figure when compared to the savannah transect (Table 13). More game species were recorded in the village transect and the most diverse forest transect BNR2 as compared with 2014 data. The only wetland species, the Baird's Tapir, was only recorded in forest transects in 2015.

Table 13. Average number of species per transect

Indicator species	Average Forest (n=8)	Savannah (n=1)	Village (n=1)
D	0.125	0	0
F	2.375	5	1
G	4.25	2	5
W	1	0	0
NA	0	0	1

Game species seemed to be the dominant group within the village transects and similarly within the forest transects. However, the forest transects were more diverse with more groups represented. The savannah transect seemed to attract quite a high percentage of forest species as shown in Figure 20.

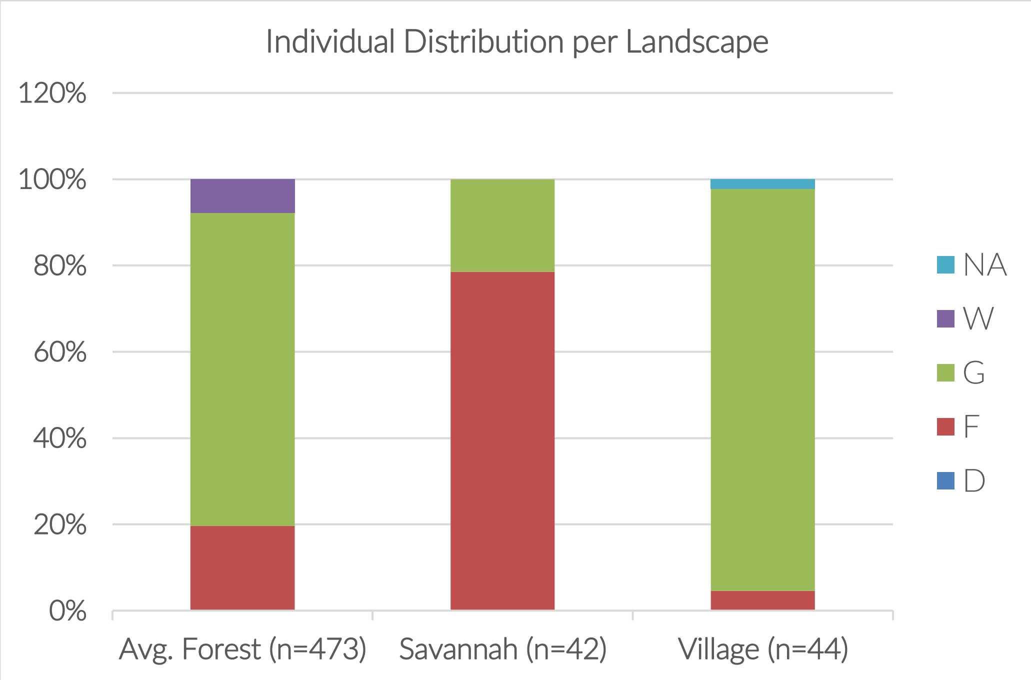


Figure 20. Distribution of individuals among Indicator Groups

To get a clearer understanding of species composition we assessed the encounter rate of individual forest indicator species per 1000m (see Figure 21). Diversity of forest species between forest transects and the savannah transect were notably similar. However, more individuals were recorded within the savannah transect. Howler monkey vocalizations are recorded more often within the savannah, largely due to the openness of the habitat. The village transect recorded only jaguars as forest indicator species but not as often as in the forest transects.

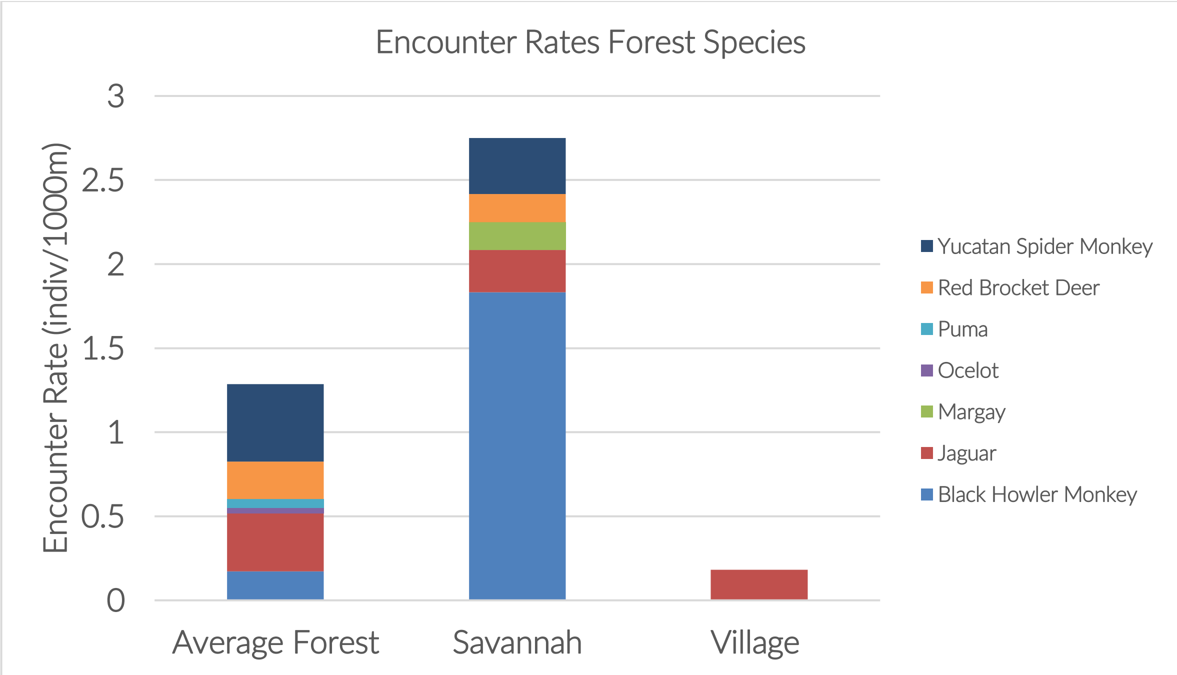


Figure 21. Encounter rate of all forest health indicator species

The encounter rate for game species was assessed in a similar manner (Figure 22). The village transect shows a higher encounter rate for pacas than the average forest encounter rate. Both pacas and nine-banded armadillos seem to be encountered in similar numbers within the village transect and the forest transect. As in previous years the likelihood of encountering armadillo tracks in the savannah transect was rather high; as it seems to be the species most frequently encountered and its encounter rate is rather similar across transects types. The only wetland indicator species, the Baird's Tapir was only recorded within forest transects in 2015. In 2014 it was recorded within the savannah transect in addition to forest transects.

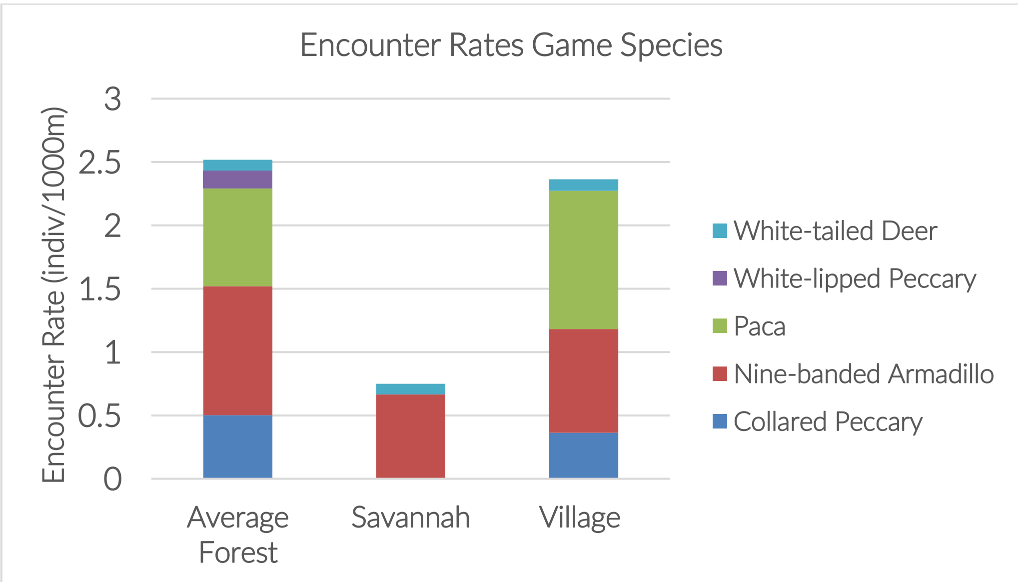


Figure 22. Encounter rate of all Game indicator species

Bats

Over the course of the year a total of 576 mist net hours and 72 harp trap hours of data collection were conducted, and 187 hours of recording were analysed (see Table 14). This is a great increase in sampling effort for both acoustic and trapping methods compared with
previous years.

Overall, 39 bat species were trapped and 19 species were positively identified in recordings, giving a total of 51 species found with both methods (Table 15, at the end of this section). There were also four phonic types of bats recorded that could not be identified to species level, as each type could represent 2-3 species that cannot be distinguished by acoustics alone.

Table 14. Bat sampling effort in 2015

	Nights	*Net (h)*	*Detector (h)*	*Harp-trap (h)*
Agroforestry	12	136.5	56.23	15.5
BNR	16	157.2	43	25.17
GSCP	16	146.3	44.75	20.67
Orange	13	135.7	43.17	10.27
Grand Total	**58**	**575.7**	**187.2**	**71.6**

Trapping

A total of 1,639 individual bats were captured at all sites (507 at agroforestry, 500 at BNR, 339 at GSCP and 293 at orange monocultures). Mist netting yielded a total of 1,578 bats captured while the harp-trap captured 61 bats. In total 9 species were identified, 29 of which were not logged on the detectors. Species recorded belonged to the families Emballonuridae, Mormoopidae, Natalidae, Noctilionidae, Phyllostomidae and Vespertilionidae. The number of bats caught by mist netting relative to trapping effort is shown in Figure 23.

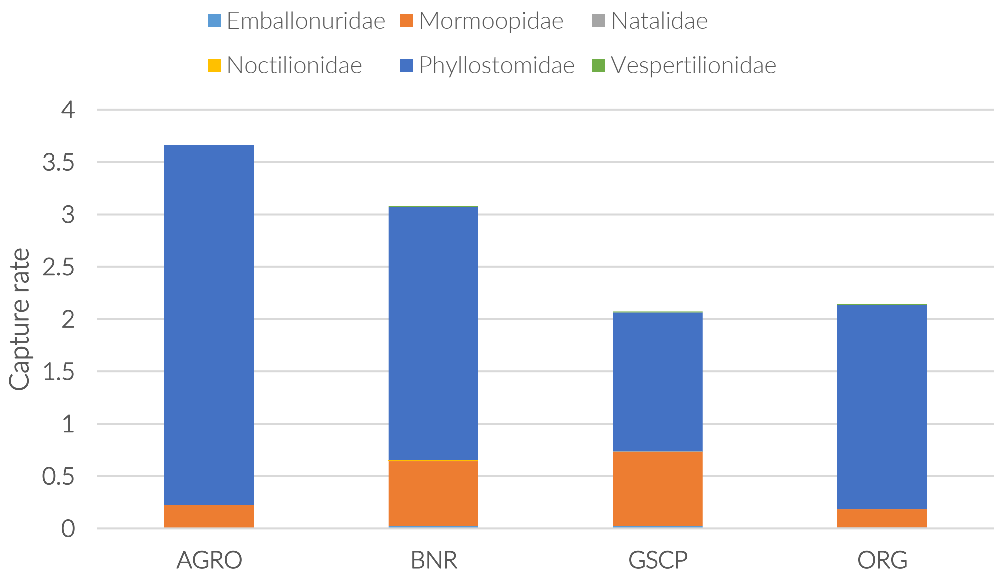


Figure 23. Bat capture rate in mist nets, per family. Vespertilionidae, Natalidae. Emballonuridae, and Noctilionidae have extremely low capture

We found that the results were particularly biased towards phyllostomid bats – this is because phyllostomids are more likely to be captured by mist nets due to their sensory ecology (Kalko & Handley 2001). 79.8% of the individuals sampled belonged to the Phyllostomidae family and 15.6% to the Mormoopidae family. Figure 23 also shows that members of the Mormoopidae family were more commonly captured at forested sites (BNR and GSCP).

Individual capture rate in mist nets was highest in agroforestry plots with 3.66 bats/mnh, followed by BNR with 3.1 bats/mnh, orange monocultures with 2.1 bats/mnh and finally GSCP with 2.05 bats/mnh. Conversely, harp trap capture rate was highest in GSCP, followed by BNR, agroforestry and orange monoculture with 1.7, 0.64, 0.45 and 0.2 bats/hth respectively. The harp trap was particularly successful at capturing bats in well-established trails in forested sites.

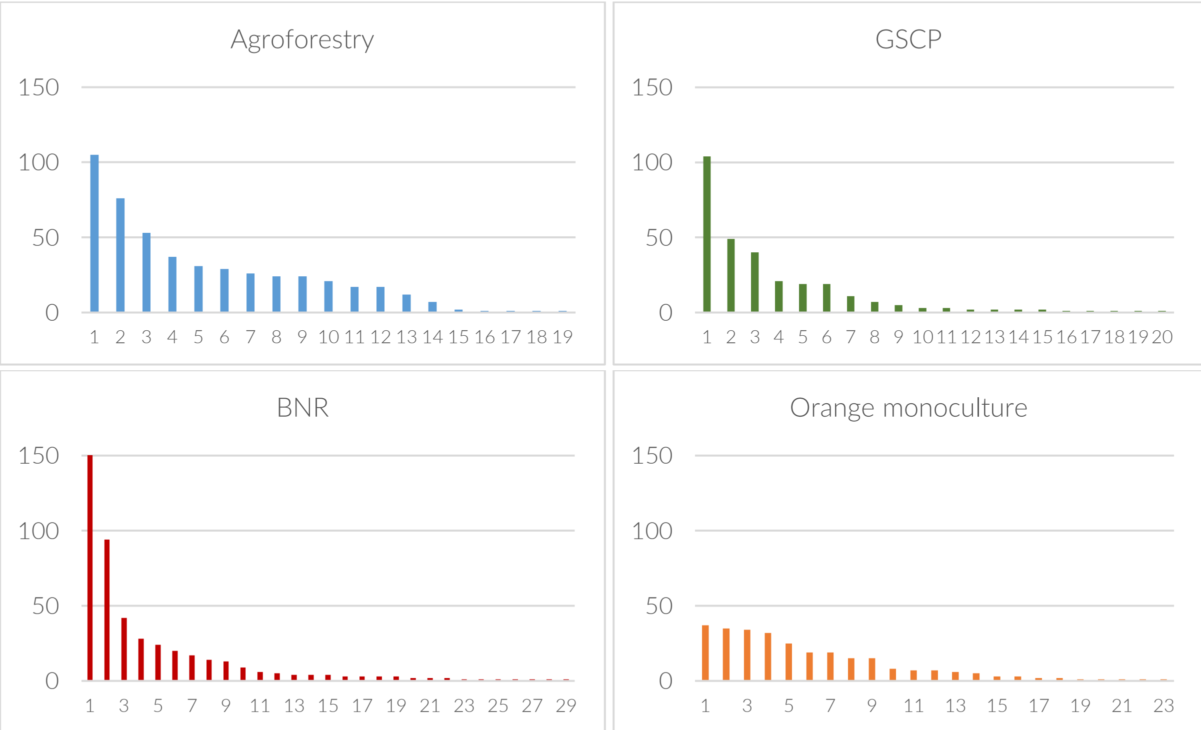


Figure 24. Abundance of bat species for mist net data in 2015

Regarding species diversity, we found that the most species rich site was BNR with 29 species recorded, followed by the orange orchards with 23 species, and agroforestry and GSCP both with 19 species. Species diversity indices like Shannon's and Simpson's showed that orange monocultures had the most species evenness (H=2.64, λ=0.91) while BNR and GSCP were most affected by species dominance (H=2.3, λ=0.83 and H=2.1, λ=0.82, respectively). Using the diversity indices in isolation might therefore suggest that the orange monoculture is a good habitat, however the bats found were largely species that are associated with disturbed areas, and the capture rate at this site was low compared with BNR and agroforestry. Figure 24 shows the abundance of species in each trapping location.

In the Figure 24 we can see a disproportionate number of two species recorded in BNR, these were *Artibeus jamaicensis* and *Pteronotus mesoamericanus*. This is likely due to the proximity of a known cave with a large *A. jamaicensis* colony to our trapping locations. High abundance of these species in forests has been found in previous studies (Schulze *et al*, 2000). *P. mesoamericanus* was to a lesser extent the dominant species in GSCP, followed by small frugivorous bats like bats of *Carolliinae* subfamily. We observed a similar bat community structure in both agroforestry and orange monoculture habitats, with dominance of the nectar feeding bat *Glossophaga soricina*, and other small frugivorous bats like *Carollia perspicillata* and *Sturnira parvidens*. Other studies have shown that the dominance of small frugivorous bats increases with disturbance (Schulze *et al*, 2000).

Acoustic monitoring

In the 187 hours of recording a total of 8,402 bat call events were logged. The 19 species identified belonged to the families Emballonuridae, Molossidae, Mormoopidae, Noctilionidae and Vespertilionidae (see Table 15, page below). In addition, one sonotype belonging to the Molossidae family and three to Vespertilionidae were recorded, and a member of the family Natalidae was recorded outside of the standard surveys. The analysis of sound data revealed the presence of 12 confirmed species that were not recorded using capture methods alone.

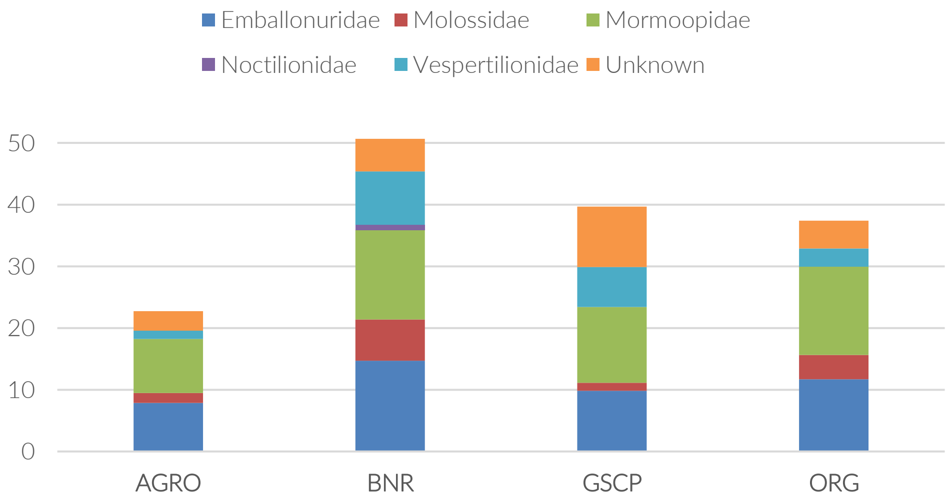


Figure 25. Acoustic activity index on each site, per family.

Figure 25 shows that the highest level of activity was recorded in BNR, and the lowest levels were in agroforestry, despite the extra hours recorded in this habitat. Individuals of the Mormoopidae family were the most frequently recorded in the MGL, in particular *Pteronotus mesoamericanus* and *Pteronotus davyi*. Members of the Vesper family were more often recorded in forested sites. Additionally, an increase of unidentified species is observed in BNR and particularly in GSCP. As explained above, habitat structure can impact call detection by the ultrasonic recorder and the forests in GSCP are the most cluttered of the four habitats surveyed; hence resulting in a decrease and distortion of calls being recorded in this habitat.

Regarding species diversity, the conservative count of species was highest in BNR, followed by agroforestry farms and citrus monoculture. The lowest number of species were recorded in GSCP. When weighting species dominance with Shannon's and

Simpson's diversity indices, BNR showed the highest level of evenness (H=2.49, λ=0.89), followed by orange monocultures (H=2.24, λ=0.87), agroforestry (H=2.18, λ=0.85) and GSCP (H=2.09, λ=0.85).

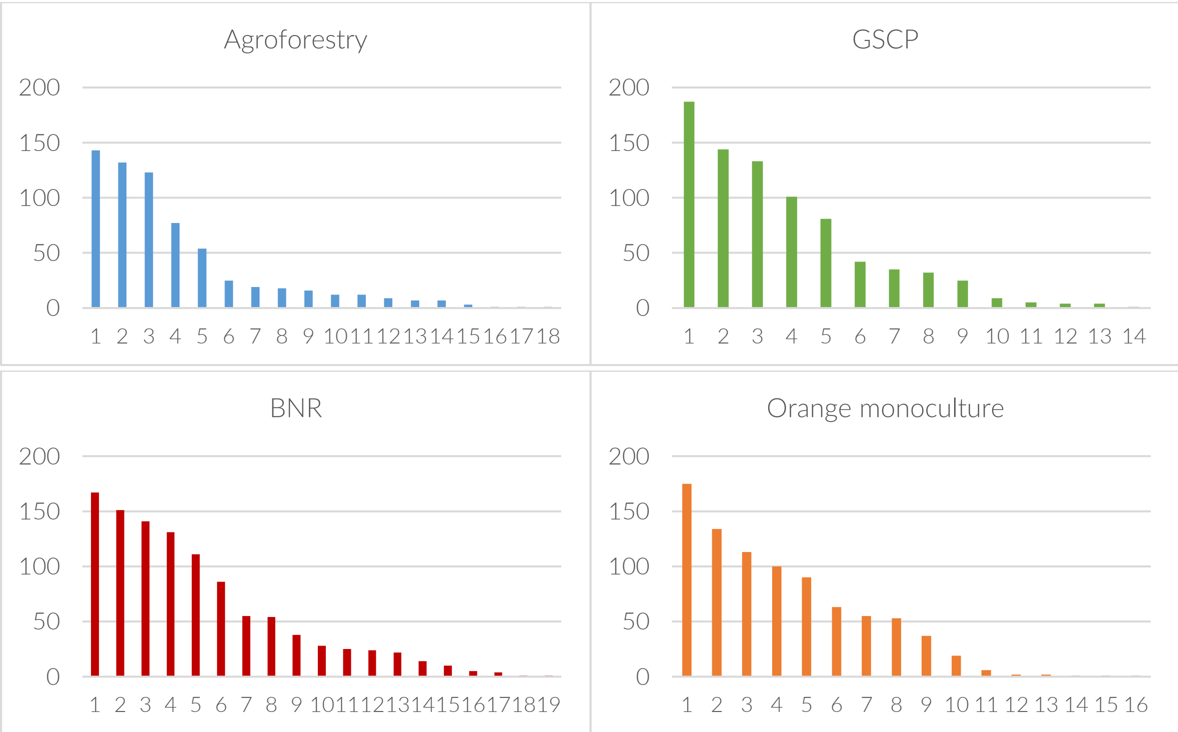


Figure 26. Abundance in minutes present of bat species for acoustic data in 2015

Regarding species composition, *Pteronotus mesoamericanus* appeared as one of the dominant species in agroforestry, BNR and GSCP. The prevailing species in orange orchards were species that prefer flying in open habitats such as *Pteronotus davyi, Mormoops megalophylla* (Mormoopidae) and *Peropteryx macrotix* (Emballonuridae). We also noted a noticeable presence of a 50 kHz Vespertillinoid in BNR and species of the *Myotis* genera in GSCP.

Nevertheless, as observed in previous years, bat detectors tend to be biased towards open habitats – the increase in clutter (vegetation density) could buffer sounds and therefore affect bat detectability. In addition, acoustic detectors are often biased towards the detection of species with higher intensity calls (Duffy *et al.*, 2000) which tend to be fast-flying bats characteristic of open landscapes (Broders *et al.*, 2004).

Table 15. Checklist of species recorded in the Maya Golden Landscape, by ground or sub-canopy nets (N) harp-traps (H) and acoustic methods (A). * Species recorded exclusively by acoustic methods. *ɣ Grouping that can compose more than one species but are cryptic in detectors. **trapped or recorded outside of standard surveys*

Taxon	Agroforestry	BNR	GSCP	Citrus monoculture
Emballonuridae				
*Centronycteris centralis**		A		
*Peropteryx kappleri**	A	A	A	A
*Peropteryx macrotis**	A	A	A	A
Rhynchonycteris naso		N,A	N	
Saccopteryx bilineata	A	A	A	N,A
*Saccopteryx leptura**	A	A	A	
Molossidae				
*Cynomops mexicanus**	A			
*Eumops sp*ɣ*	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	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	N
Artibeus lituratus	N	N	N	N
Artibeus sp		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 sp	N	N		
Desmodus rotundus	N	N	N	N
Diphylla ecaudata		N		
Glossophaga commisarisi	N	N	N,H	N
Glossophaga soricina	N	N	N	N,H
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
Vespertillionidae				
_Eptesicus furinalis_*	A	A	A	A
_Lasiurus blossevillii_*				A
_Lasiurus sp_*ˠ	A	A	A	A
Myotis keaysi	A	A	N,H,A	A
_Myotis sp_*ˠ	A	A	A	A
Rhogeessa aeneus**		N**		
Rhogeessa sp				N
_Vesper 50kHz_*,ˠ	A	A	A	A

Wildlife observations

As mentioned in the methodology section, the purpose of recording opportunistic sightings during ranger patrols is to complement the transect data, rather than including them in any form of analysis of general biodiversity. Table 16 summarises the sightings recorded in both BNR and GSCP.

Patrol effort differs between the protected areas and may influence the frequency of observations of some species. Yet there is still a marked difference in the number of observations between BNR and GSCP and their corresponding species richness from opportunistic data. In previous years the Harpy Eagle was an important sighting, but it was not spotted in 2015 in BNR. However, another equally important forest species, the Ornate Hawk-Eagle was spotted in BNR. Like the Harpy Eagle, Ornate Hawk-Eagles require large areas of relatively undisturbed forests for survival.

Table 16. Species sighted in 2015 during patrolling activities

	Species	BNR		GSCP	
		# of observations	Avg. group size	# of observations	Avg. group size
Birds	Crested guan	20	2.7	1	1
	Great curassow	19	1.9	2	1.5
	Great tinamou	7	1.0	3	1
Mammals	Howler monkey	10	4.7	1	11
	Nine-banded armadillo	2	1.0		
	Ornate hawk-eagle	1	1.0		
	Puma	1	1.0		
	Red brocket deer	1	1.0		
	Spider monkey	44	3.8		
	Tapir	1	1.0		
	White-lipped peccary*	3	76.7		
	White-tailed deer	1	1.0		
	Agouti	3	1.0	4	1
	Collared peccary	1	4.0		
	Total # of observations	114		14	
	Species Richness	14		5	

* = *instances of species seen are provided as # of observations; averages are based on rough estimates of herd size*

Mammal observations are conspicuously absent from GSCP and it could be that these species are avoiding trail systems in the recovering secondary forests of the preserve. It is encouraging that there are still, albeit few, encounters of Howler Monkeys in GSCP. Howler Monkeys were first observed in 2013, more than 10 years after Hurricane Iris severely damaged the forest in GSCP in 2001. Game birds are occasionally seen or heard in GSCP but their numbers are low.

Tree Monitoring

GSCP Monitoring

The *Dalbergia stevensonii* trees were monitored for a total of 100 days between October 2013 and December 2015. A total of 62 of the 100 trees were observed to flower and/or fruit at least once during the period of monitoring. The number of trees monitored in each class size are shown in Table 17. The proportion of trees in each size class observed to fruit and/or flower increased with size class (see Figure 27).

Table 17. Number of *D. stevensonii* trees monitored in each size class.

Size Class (DBH)	5-10cm	11-20cm	21-30cm	31-40cm	41-50cm
Number of Trees	9	41	35	11	4

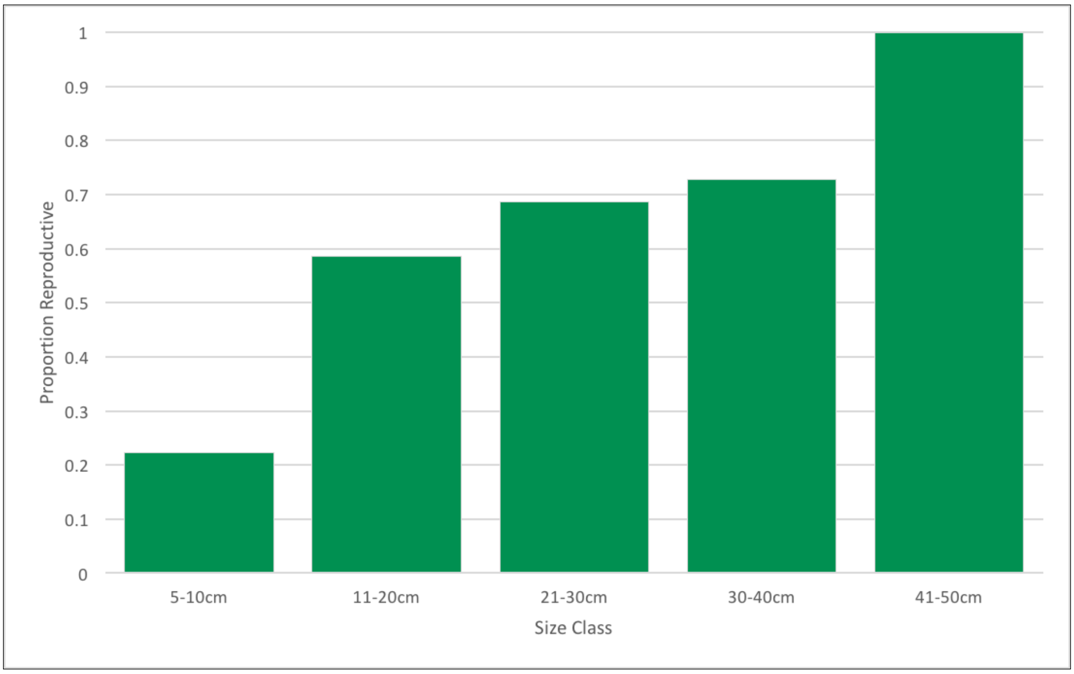


Figure 27 Proportion of individuals in each class size observed to flower or fruit between October 2013 and December 2015.

The *D. stevensonii* trees were observed to have a relatively narrow flowering period during the year. Leaves were observed to fall in April and May, with flower buds appearing in May or June. Unripe fruits first appear in July and seeds may fall in September through November. The main flowering event was observed in May and June during the monitoring period and the trees were observed fruiting July through December (see Table 18). This is consistent with other species in the genus, which exhibit mass flowering events, but also exhibit high amounts of seed abortion, meaning that immature seeds/fruits would be rejected, and may not be observed (e.g. Bawa & Webb, 1984).

Table 18 Number of *D. stevensonii* trees observed in flowering and fruiting phases during each month.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2013	Flowering	-	-	-	-	-	-	-	-	-	0	0	0
	Fruiting	-	-	-	-	-	-	-	-	-	0	11	13
2014	Flowering	0	0	0	0	23	6	12	1	1	0	0	0
	Fruiting	0	0	0	0	0	4	17	3	7	7	16	14
2015	Flowering	0	0	3	0	0	21	3	1	0	0	0	0
	Fruiting	4	3	6	1	1	0	7	6	2	3	3	3

BNR Monitoring

The trees in BNR were monitored for a total of 45 days between August 2014 and December 2015.

Mortoniella pittieri

All 11 M. *pittieri* trees monitored were found flowering and fruiting at least once during the monitoring period. Flowers were observed from March to October and fruits were observed in July to October (see Table 19). This may indicate multiple flowering events throughout the year.

Table 19 Number of M. pittieri trees observed fruiting or flowering between August 2014 and Dec. 2015.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2014	Flowering								1	7	6	4	6
	Fruiting								0	0	5	4	4
2015	Flowering	1	1	9	10	10	9	11	9	5	11	4	3
	Fruiting	0	0	0	0	1	2	6	2	1	11	3	0

Cymbopetalum mayanum

Five of the *C. mayanum* trees were found to be fruiting or flowering at least once during the monitoring period. The sixth tree died during the course of monitoring and was removed from the monitoring trail in July 2015. *C. mayanum* was observed to flower most prominently between April and August and fruit throughout the rest of the year with a dip in May and June (see Table 20).

Table 20. Number of *C. mayanum* trees flowering and fruiting between August 2014 and December 2015.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2014	Flowering								0	1	0	0	0
	Fruiting								4	4	5	5	5
2015	Flowering	0	0	1	5	5	5	5	5	0	3	1	0
	Fruiting	5	5	5	4	1	1	4	4	5	5	5	5

Pouteria amygdalina

Five of the eleven *P. amygdalina* trees were found fruiting and/or flowering at least once during the monitoring period. *P. amygdalina* was observed to have a very narrow period of flowering and fruiting during the year. Observations of flowering were largely confined to March through May and fruiting was observed from April to June (see Table 21). This is similar to observations and herbarium collections made of this species in other nearby Central American countries (Stott, 2014a).

Table 21. Number of *P. amygdalina* trees flowering and fruiting between August 1014 and December 2015.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2014	Flowering								0	0	0	0	0
	Fruiting								0	0	0	0	0
2015	Flowering	0	0	1	0	2	0	0	0	0	0	0	0
	Fruiting	0	0	0	2	2	3	0	0	0	0	0	0

Chiangiodendron mexicanum, Macrolobium sp. and *Platymiscium dimorphandrum*

None of the monitored individuals of *C. mexicanum or Macrolobium sp.* were observed to either flower or fruit between August 2014 and December 2015. The two individuals of *P. dimorphandrum* were also not observed to flower or fruit, however these individuals were added to the phenology trail in July 2015, therefore, only 6 months of data is reported for this species.

Weather

Weather data in 2015 was nearly as complete as 2014's records. Bladen Ranger Base and Golden Stream Field Station had a yearly data coverage of 96.2% and 93.2% respectively. There is an increasing effort in keeping consistency in data collection by the ranger team. For 2015 we report only data gathered from these two stations. Raw weather data is available upon request.

The National Oceanic and Atmospheric Administration in the US declared 2015 as an El Niño year back in February of the same year (Thompson 2015). For Belize and the Caribbean Coast of Central America this means a significant increase in precipitation throughout the year. This causes a rain shadow over the Pacific Coast of Central America where drought conditions intensify. Temperatures in an El Niño year are expected to be generally higher than normal in Belize. The perceived pattern for 2015 was a wet start to the year with higher rainfall than the previous year. The dry season was particularly short but intense. The rainy season was seen as an extremely wet one causing flood events that had not been seen in over a decade by affected community members (personal coms).

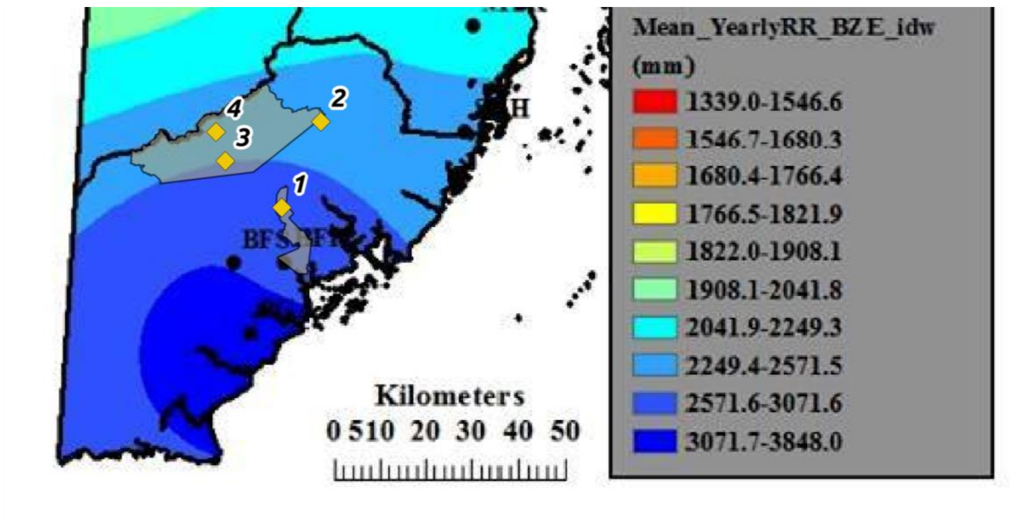
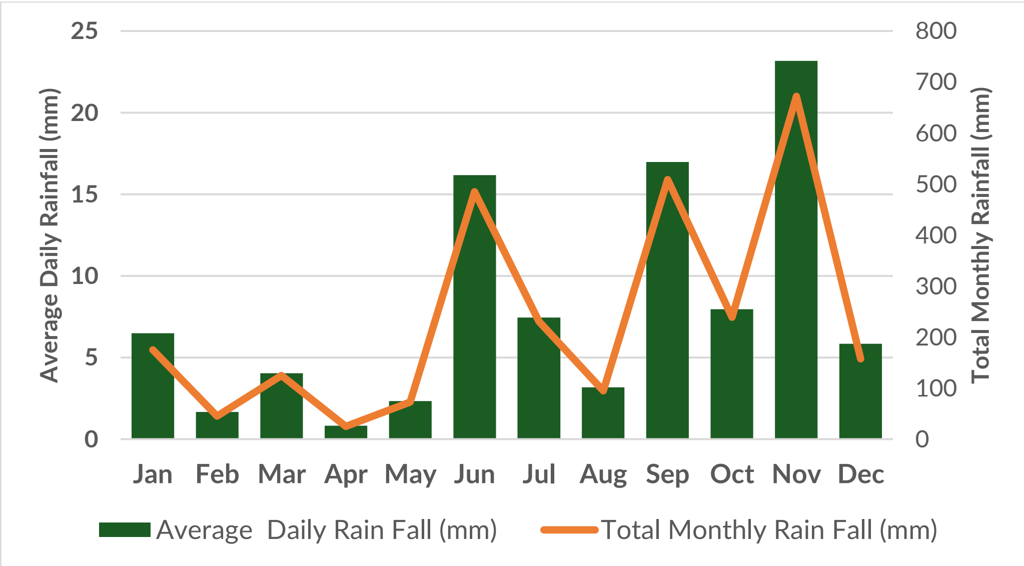


Figure 27. Detail of the mean rainfall map presented in the methodology section (Figure 7 on p24)

Bladen Nature Reserve Ranger Base

A total of 14 days have missing data from the Bladen Ranger Base, making a total of 351days (96.2% of the year) of recorded weather data; a slight decrease from 2014. This yielded an annual rainfall of 2831.06mm, which is above the expected values for that area (see Figure 28A&B). In fact, Balden recorded an impressive 463mm in excess of the 2014 record of 2368mm; making it a particularly wet year. Data collected showed a prolonged dry season with very low precipitation. The bulk of the rains fell between June and November with most of it falling in the month of November. The average daily rainfall follows the increasing pattern of rainfall from the dry season into the rainy season. Monthly high temperatures were similar month to month on average, ranging between 98.9 °F and 108.7 °F. Monthly low temperatures followed a similar pattern of eveness ranging from 67.1°F and 79.8°F. The average monthly maximum humidity remained constant throughout the year ranging from 72% to 83%. Monthly average minimum humidity ranged from 33% to 49%. With humidity being constantly high, it means that average day time temperatures had a feel of at least 2 degrees higher than the average maximum temperatures recorded. The recorded figures for rainfall and temperatures coincide with the expected influence of El Niño on our region.

A



B

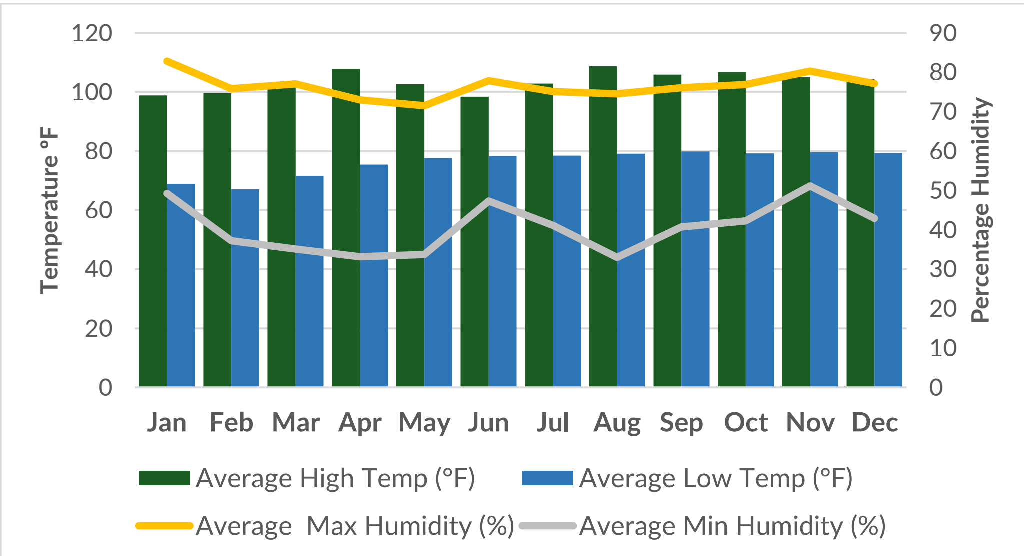


Figure 28. BNR ranger base rainfall (A) average daily and total monthly (B) patterns throughout 2015

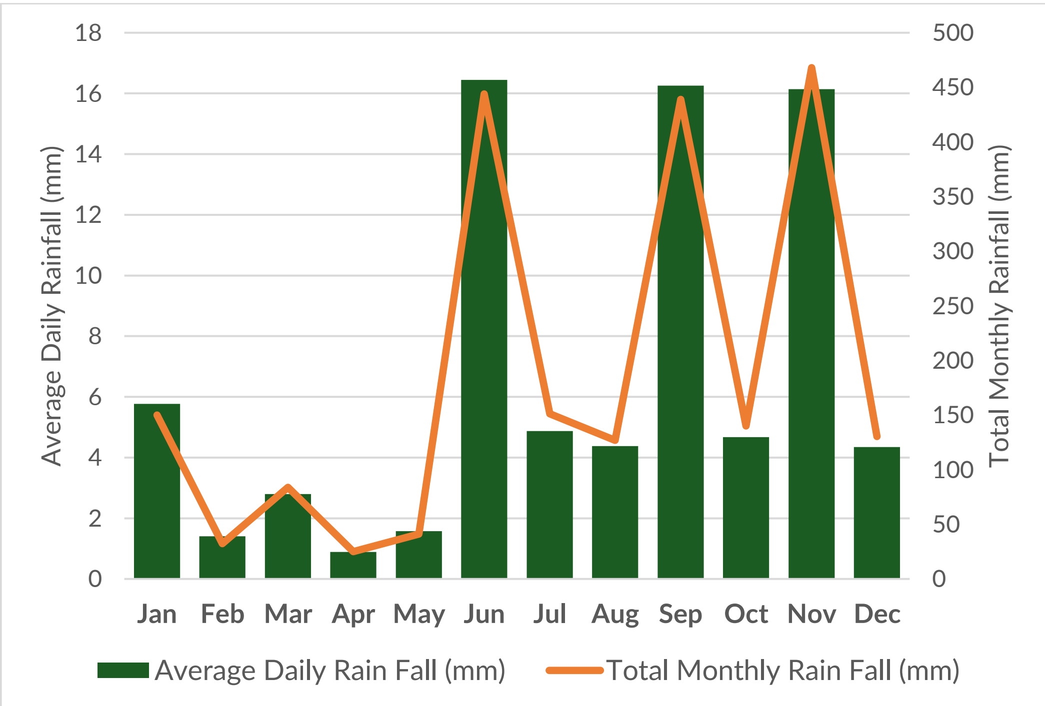
Golden Stream Corridor Preserve Field Station

There were 25 days of data missing for the Golden Stream Corridor Preserve Field Station, which gives us a very reliable data with 93.2% of the year covered. A total of 2231.9mm of rain was registered at the Golden Stream Field Centre in 2015. However, this is below the expected rainfall trend registered in the last 60 years. This could be an artefact of the 25 days of missing data and actual total rainfall could have been well over the 2014's record, as reflected at the Bladen base. It is nonetheless an accurate representation of the trends in precipitation over the preserve.

Similar to the Bladen Ranger Base weather station, the monthly rainfall pattern roughly follows the expected dry-wet seasons trend (see Figure 29A&B). When comparing Golden Stream Field Station with Bladen Ranger Base, both show a similar significant drought during the dry season and a more erratic rainfall pattern during the wet season. Golden Stream recorded a lower annual rainfall than Bladen, which was unexpected considering the expected precipitation gradient seen in Figure 27.

Average monthly high temperatures fluctuated more than at the Bladen base ranging from 78.3 °F to 96.7 °F. A similar pattern was observed for the average monthly low temperatures which ranged from 64.7 °F to 80.7 °F. The average monthly maximum humidity ranged from 76% to 92% and the average monthly minimum humidity ranged from 40% to 66%. Despite less rainfall recorded at the Golden Stream station than at the Bladen base, humidity was notably higher througout the year.

A



B

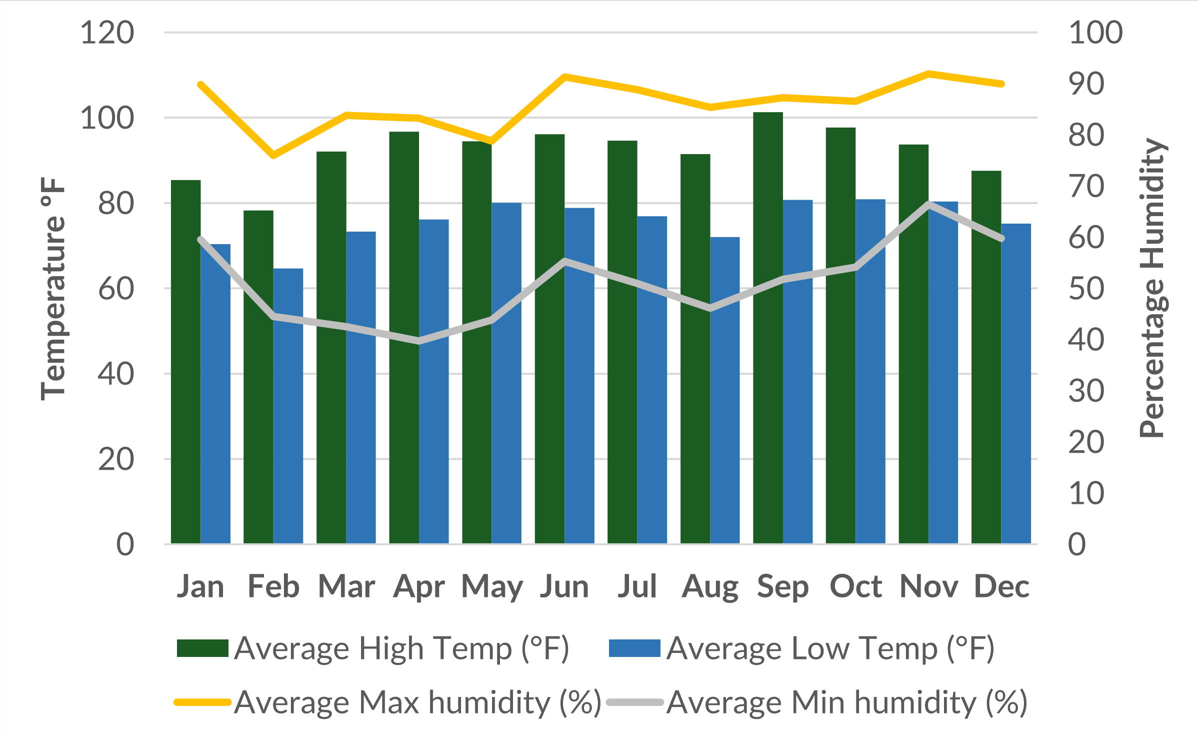


Figure 29. Golden Stream field centre rainfall (A) and temperature and humidity (B) patterns throughout 2014

Land-use change

There is a clear trend of an advancing agriculture frontier into forested lands within the last 3 years (see Table 22). Clearings within protected areas are also a trend, specifically in Maya Mountain North Forest Reserve, Deep River Forest Reserve and Columbia River Forest Reserve. Deforestation rates are lower than the national average (around 1%) but this is due to the proportionally larger area of forested land in the MGL (509367.6 acres, 76% of its terrestrial part), compared with forested land in Belize (60.3% in 2014), which is also more affected by large scale agricultural clearings, the major contributor to deforestation in Belize.

Tambran and Medina Bank

These communities are located along the highway within the Southern Belize Biological Corridor. Tambran has been developing at a very high pace since 2012, and from 2013 to 2015, Medina Bank has seen new clearings in the Deep River Forest Reserve area as well as in La Sierra. The trend is that plots being cleared for agriculture run parallel to the highway, and as more land is cleared in this northeast to southwest direction, the corridor is being bisected.

Chun Bank

The Chun Bank is located in the DRFR and has been farmed by people from Bladen village since 2013. Joint patrols have been conducted in the area by Ya'axché and FD but no further action has been taken. Of special concern is the use of fire in this area, which is adjacent to the Bladen Nature Reserve.

Waha Leaf area

The Waha Leaf area is located within the MMNFR to the northeast of the current agricultural concession. This area saw a decrease in activity from 2013 to 2015, but in 2016 the area was used again (data to be incorporated into the 2016 report). It seems that the San Pablo community might have an impact in the area, as well as the Waha Leaf group that seems to have re-activated. The area is flat and has good soil, so chances are it will be developed for agriculture, which makes it a suitable area for another controlled agricultural concession.

Red Bank and Roseville communities

The communities of Red Bank and Roseville are situated east of MMNFR and south of CBWS. This area has seen extensive development between 2013 and 2015. The Roseville community was established between 2012 and 2013, and has grown along the west bank of the Swasey River, which has appropriate topography for farming (being mostly flat) and also has fertile soils. These factors point toward future expansion of this settlement closer to the MMNFR boundary (it is 1.3 km away as of 2016). The Red Bank community has developed extensively on the east bank of the Swasey River approaching the southern boundary of CBWS (1.2 km away as of 2016), and there are still some flatlands appropriate for agriculture left to use in that area.

Farmers' road from San Pedro Columbia

A farmers' road leading from San Pedro Columbia into CRFR has provided access to an area that is being increasingly used for agriculture. Since the road was created, the presence of humans in the area has increased, and this trend is continuing in early 2016 (to be incorporated into 2016 report).

Guatemalan border

On the western boundary of CRFR, where the reserve adjoins the Guatemalan border, small clearings are continuously being cut. It appears that residents of Guatemala, where most natural resources have already been exploited, are coming into Belize to utilize the relatively untouched land for farming, cattle ranching, and production of marijuana.

The above mentioned areas were assessed more in detail in regards to acreage cleared between 2013 and 2015 (see Table 21).

Table 21. Acres cleared in areas of special concern

Location	2013	2014	2015
Tambran	228*	62	69
Medina Bank	556*	69	65
Chun Bank	77	49	67
Waha Leaf	72	22	9
Roseville/Red Bank	712	34	487
CRFR/San Pedro Columbia	34	25.5	89
CRFR-Guatemala border	140	11	71

Table 22. Land clearance in the MGL between 2013 and 2015 by landscape type

	2013	2014	2015
Clearings in Historical Agricultural Areas (ac)	2912.95	1796.47	2554.56
Advance of Agricultural Frontier (ac) (Clearings in forested areas not used for agriculture in the past)	2897.27	1528.97	1879.59
Clearings in Historical Escaped fires (ac)	32.71	69.00	125.48
Clearings in Riparian Area (66ft)	186.81	130.14	184.12
Clearings in Protected Areas (ac)	638.43	255.04	612.38
Clearings In Matrix (%)	49.85	52.92	57.61
Clearings Out of Matrix (%)	50.15	47.08	42.39
Proportion of clearings in PA's (%)	10.93	7.51	13.81

Deforestation rate 2013 (%)*	0.73
Deforestation rate 2014 (%)*	0.30
Deforestation rate 2015 (%)*	0.37

*With respect to the forest cover in the MGL (does not include regrowth forest)

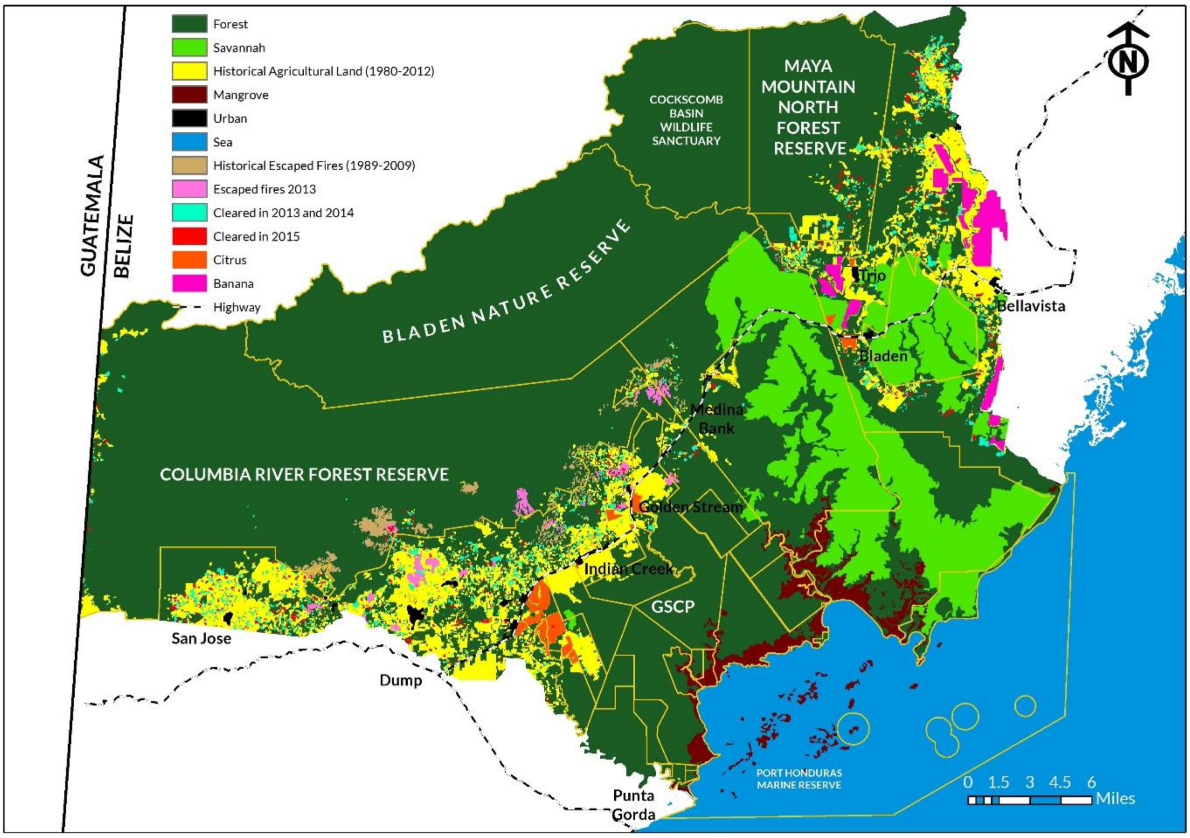


Figure 30. Location and size of agricultural clearings in the MGL during 2015

Conclusions

Our data collection efforts continue to be consistent in both quality and quantity, despite the many limitations that we are faced througout the year. Although we had a slight decrease in effort as compared with 2014 our data has provided valuable information for our conservation and community program areas. The transect data once again provided us with a landscape-wide view of the status of target indicator species and the status of their environments. Our bat monitoring was turned into a species inventory and we now have an improved understanding of the bat fauna of the MGL. We were able to report on the long term tree phenology monitoring that started in late 2013 which has increased our knowledge of some of Belize's most rare and important tree species. Overall Bladen Nature Reserve provides the highest diversity of species but edged closely by Columbia River Forest Reserve. Golden Stream Corridor Preserve has the least diversity but not significantly less than the Village transect.

As Ya'axché's geographical scope grows within the Toledo district, so does the programs it has established. Although 2015 followed a similar trend as the past three years for data collection, it was also a year for development and planned expansion of the biodiversity monitoring program. Much of the information gathered in 2015 has been useful information for the expansion of data collection, particulary where data is deficient. We expect the expansion to be reflected in the 2016 Biodiversity Synthesis Report.

Birds – BNR2 recorded the highest number of bird species but was followed closely by CRFR2. Overall species richness was relatively high for all forest transects with the lowest being GSCP1, the transect with fewer visits, which means that it could have recorded more species because of more visits. Consistent with previous years the savannah transect recorded a high number of species, partly due to its relative closeness to the broadleaf forest. This transect attracts many forest species that have an afinity to the edge effect and also three target species that are exclusive to the savannah habitat were recorded. This trend was expected for the savannah transect and we will continue monitoring its status in the coming years. All transects showed evidence of dominance of one or two species. The transects less affected by species dominance were all three Golden Stream Corridor Preserve transects GSCP1, GSCP2 and GSCP9 with more even distribution of relative abundances but with notably lower species richness.

When looking at indicator species, the transect with the most interesting trend was the village transect IV1. In previous years it recorded generally fewer species than the other transects; but in 2015 it recorded an increase in the number of target species. Of interest was that all but 4 of the target migratory species were recorded for the village transect. The habitat within the area seems to be attracting many of the migrants. On the other hand, game birds were completely absent from this transect; which was expected given the prevalence of hunting within village lands. CRFR3 recorded all forest health indicators, followed by BNR2, CRFR1, CRFR2, CRFR4. The GSCP transects recorded low numbers for forest health indicators which gives us a rough idea that the forests of GSCP are still recovering from the extensive damage of Hurricane Iris in 2001.

Overall the forest transects in BNR and CRFR appear to be in good standing with a high diversity of indicator target species. The forests in Golden Stream Corridor Preserve are consistent with species richness recorded in previous years and is yet to show a marked increase in richness that signals an equally marked healthier forest recovery. The habitat around the village land transect appears to be in good shape as indicated by the prevalence of many forest and migratory species; but it still shows the effect of close proximity to humans by the lack of game birds.

Large mammals –BNR2 recorded the highest species richness for target mammal species. It also showed evidence of dominance by white-lipped peccaries, a species that is of great importance as an indicator of forest health due to its requirement of large areas of forested land for survival. A similar pattern of dominance was observed in CRFR3 where white-lipped peccaries were also detected in large herds. The village transect and the GSCP transects had lower species richness than the other transects with abundances leaning towards the smaller game species like pacas and armadillos that appear to thrive in areas adjacent to farms from the communities. The larger game species seem to avoid these areas or are likely hunted to exhaustion in community lands. Tapirs were present only in the forest transects and completely absent from the village land and the savannah transects. Since 2015 was a very wet year it could be that tapirs were less likely to move to areas that had a more permanent water body during the dry season as many seasonal water bodies would retain much of their volume throughout the year. Jaguars appear to be present across the landscape with similar frequency of observations across habitat types although more observations were made in the forest transects. As in previous years armadillos have been recorded across the landscape and in similar abundances. Its worth noting that armadillos have been documented to be a favorite prey species for jaguars (Foster et. al., 2010)

Bats – As a result of expanded monitoring and the introduction of a new sampling method, this year a total of 51 bat species were identified, a much higher count than the three years previous where only 20 species were recorded in total. In addition, we found 3 families that were not recorded in previous years. The combined approach taken this year has been effective. Using passive acoustic methods alone is biased to open areas and certain families. For both methods, BNR had the highest species richness, while GSCP had the lowest. Looking at mist netting data we observed that bat communities changed in different habitats - in more disturbed areas there was an increase in dominance of small frugivorous bats, as has been found in previous studies.

Acoustic data cannot be used to draw any firm conclusions, but does highlight the difficulties of comparing habitats with different vegetation structure. Data from acoustic monitoring in the neotropics are still few and far between. It is important to continue collecting acoustic data, as in the long-term non-phyllostomid bats could prove to be especially vulnerable to disturbance.

Vegetation – Tree Phenology- The individuals monitored provide valuable insight into the ecology of rare and threatened tree species in Belize. *D. stevensonii* appears to have strong phenological patterning, indicating that annual changes in weather patterns may play a role in determining the timing (and potentially the success) of reproduction. It should be noted that issues such as genetic compatibility of ovule and pollen also play a role in successful seed set in this species; therefore an understanding of the reproductive success needs to take multiple factors into account. A higher proportion of the larger size classes were observed flowering and fruiting, which highlights the importance of larger trees as seed producers.

M. pittieri may have multiple flowering events during the year and based on surveys appears to have narrow habitat and recruitment preferences (Brewer & Stott, 2014). C. *mayanum* is a common species within BNR (Brewer & Stott, 2014) and appears to also flower throughout multiple months during the year. This species is an important food source for migratory birds in Mexico (Foster 2007), and may play a similar role in BNR as fruiting appears to coincide with increased migratory bird visits to BNR and GSCP from January through March and September through December (see results on bird transect data). *P. amygdalina* is observed to be frequent in the limestone areas of BNR and future years of monitoring are required to assess if the narrow window of flowering and fruiting is consistent between years in this species (Brewer, 2015). The flowers of

C. mexicanum are very small (less than half a centimetre in length), and therefore may be difficult to distinguish on the branches when observing from the ground. The trees' size and condition should be compared to observations of flowering and fruiting individuals in other parts of Central America. The currently unidentified *Macrolobium sp.* requires continued monitoring to observe fruiting and flowering of this emergent canopy tree. At the end of the reported monitoring period (December 2015) the *P. dimorphandrum* trees were observed to be losing their leaves, a phenological phase often observed before trees flower. Therefore, the trees may flower and fruit in early 2016 (March - May), timing which would align with observations made from herbarium collections in other Central American countries (Stott, 2014b).

Weather –The most important conclusion from our analysis was that 2015 was indeed a very wet year. The dry season was short but very intense. The year started with an increased pattern of precipitation that was more pronounced toward the end of the rainy season. Bladen acounted for more rainfall than Golden Stream, a pattern that was not normal. In fact, Bladen recorded an excess of rainfall when compared to 2014. An excess of rainfall was not evident in Golden Stream and recorded below the 2014 record, perhaps owing to the number of days with missing data makeing our conclusions very conservative ones. The paterns in rainfall and temperature fluctuations could be interpreted as the influence of the El Niño phenomena that was declared early in 2015. This pattern is expected to last into 2016.

Land-use change – Toledo finds itself in a very important moment of its history. The recent court ruling (April 2015) that recognized ancestral land rights of the Maya of Toledo and the increased connectivity of the district through the completion of the new highway to Guatemala have the potential to have a powerful effect on the fate of Toledo's forests. It is still not clear how the court ruling will translate into land tenure and community boundary delineation, and it might take a few years until that is concreted. In any case, land use will be one of the main factors to consider when establishing those rights.

Currently, in southern Belize (as well as in most tropical developing countries in the world where slash and burn is the main farming method), we have conditions of increasing populations, decreasing fallow periods and increased demand for farmland. According to our results in the MGL this translates to an advance of agriculture frontier to the detriment of untouched forests.

Although Ya'axché focuses its work within Maya communities, we also acknowledge the contribution to Land Use/Land Cover Change in the MGL by other stakeholders. The banana and citrus plantations that have been established in Toledo (with a total of 9,223 acres of forest cleared since 1980) and the Mennonite communities of Pine Hill and Roseville (which have cleared 1,821 acres of forest since 1994) have contributed extensively to deforestation. The latter is developing very rapidly in an important water catchment area. In recent years we have approached the banana industry to push for certified production, and it remains a challenge for us to encourage traditionally closed Mennonite communities into adopting more sustainable practices.

Communities rely on their environment for farmland and for the ecosystem services provided by forested areas. Through sustainable land use, based on long-term land use planning approaches (which Ya'axché has attempted but not been able to implement successfully at the community level as of yet), future generations of MGL inhabitants will be able to feed from the land, extract resources (including timber and non-timber forest products) in a planned and sustainable way, and conserve the forests, which are some of the most important in Mesoamerica. Through its COL and PAM programs, Ya'axché is pushing both communities and government agencies towards this road to a sustainable future for all.

Recommendations

This section includes suggestions to improve data collection and analysis in the biodiversity monitoring program. Priority species or taxa for conservation, field methods or financial resources are subject to continuous change, and as a result so are our monitoring activities. However, at Ya'axché we have the determination and commitment to obtain long-term biodiversity data of the best quality, and so we keep learning and adapting from the challenges we face in the field.

The revision of the Biodiversity Research, Inventory and Monitoring Program will need to align with many aspects of the National Biodiversity Monitoring Program that will be finalized in 2016. As a working document it will be the new guiding document for the improvement of Ya'axché's program while keeping up with national goals and targets. Ya'axché should aim to be involved in as many aspects of Belize's conservation movements as possible, in particular keeping an eye out for the health of our environment.

Birds and large mammals – With the recent turnover of staff there should be an increased emphasis in training new staff and building their capacity for monitoring. With the expansion of the monitoring program to include more areas within the MGL it will also be necessary to ensure that the team responsible for data collection has the most up to date information needed to carry out their duties.

The program has now amassed more than six years of data which can produce a more robust analysis of trends within the MGL over that time period. With that, more advanced methods of analysis will be required in addition to the descriptive statistics presented in this and previous years' reports.

Bats – This year's survey effort has been markedly increased, adding different methodologies and standardising acoustic data collection; resulting in a substantial increase of bat species being recorded. In previous years, monitoring bats using the Anabat system has proven to be cost and labour efficient, however the system is unable to detect many species such as leaf-nosed bats (*Phyllostomidae*). Phyllostomid bats have previously been used as indicators of habitat disruption (Fenton *et al.*, 1992; Castro-luna *et al.*, 2007). Therefore, it is more informative to include supplementary survey methods to acoustic monitoring such as mist-netting and harp-trapping.

The soon-to-be-drafted National Monitoring Protocol will include a bat chapter and Ya'axché should help in its implementation. To continue improving biodiversity data collection, Ya'axché should seek funding to have a full time national member of staff dedicated to research and monitoring activities and this person's work should include bat data collection and analysis.

Vegetation – The initial phenology monitoring in GSCP and BNR provides a valuable baseline of information about the reproductive patterning and success of rare and threatened trees in the MGL. As only one or two complete years of data have been collected for these species, monitoring should continue to examine between-year changes in phenology as well as confirm annual patterns seen in species only monitored for a single complete year. The DBH of the *D. stevensonii* trees will be re-measured in 2016 and an understanding of the growth rate of various size classes can improve knowledge of the ecology of this species.

Weather – The ranger team needs to have refresher training sessions on the importance of data collection particularly with weather data. Although they do receive training on the different data they collect, having a team that fully understands the importance of regular and efficient data collection will ensure consistency in quality. In order to understand how weather patterns affect the environment, Ya'axché should reinstall the weather stations at Bladen Nature Reserve and make an investment in the establishment of additional weather stations across the MGL. This could benefit implementation of our sustainable agroforestry and other alternative agricultural practices by providing accurate localized weather information for planned development.

Land-use change – Ya'axché should continue extension work in communities, implementing smart agricultural practices (inga alley cropping, agroforestry, backyard gardening). This should include new farmers adopting these practices and farmers we have worked with in the past taking on full management of their farms without our active support through a graduation scheme. As an achievable target, a total of 40 to 80 acres should be added each year into sustainably managed land in the MGL. This will include both new and graduated farmers' land. That increase should be focused in areas under current use (plots under cultivation in the present, wamil or young secondary forest in fallow land) more than in high forest (with the exception of the agroforestry concession in MMNFR).

Where possible, extension work should focus in the communities around the Southern Belize Biological Corridor: Golden Stream, Tambran and Medina Bank. An aim should be to increase farmers' capacity to improve management and increase yield per acre in areas under current use, in order to prevent expansion of agricultural lands into forest areas of the corridor. In this context, the COL program should be moved toward the farmer field school approach as the main training technique, with training, exchange visits and follow-up visits from extension officers as part of the field school.

Freshwater monitoring - In 2016 Ya'axché needs to structure freshwater invertebrate monitoring in the MGL using the tools that have already been developed by the freshwater ecologist, Dr Rachael Carrie. The baseline study of macroinvertebrates in 2016 will need to provide an adequate frequency for data collection at multiple sites.

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We are looking forward to keep developing collaborations and partnerships in the future.

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