Biodiversity Synthesis Report

2016

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Front Cover photo: White-tailed Deer in an Agroforestry Farm in the Toledo district

Back Cover photo: Ranger conducting rosewood phenological monitoring. Photo by Maximiliano Caal.

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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
MCD	Minimum Cutting Diameter
MGL	Maya Golden Landscape – Ya'axché's working area
MMNFR	Maya Mountain North Forest Reserve
NGO	Non-Governmental Organization
NOAA	National Oceanic and Atmospheric Administration
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 2016, transect monitoring remained variable as in the previous year. Village lands recorded similar species richness than in 2015, with a particularly high number of migrant bird species and was comparable to that of forested lands and savannah. Dominant species like the chachalaca tend to show prominently in the counts. Game bird species were completely absent from village lands but game mammal species were present in higher number than the previous year. The forest transect BNR2, considered the least disturbed of the transects, exhibited high species richness for both bird and mammal target species with dominant species being the two monkey species in our list. Overall the forest transects in Bladen Nature Reserve and Columbia River Forest Reserve recorded higher target species richness than transects in Golden Stream Corridor Preserve.

This year, we report on the phenology and growth of the threatened rosewood species, *Dalbergia stevensonii*. Monitoring data collected between 2013 and 2016 show that *D. stevensonii* reproductive timing is closely tied to seasonal weather patterns. In addition, preliminary growth rate analyses show that the hardwood species is indeed slow-growing, as presumed, though growth rates vary between size classes. These studies provide valuable life-cycle data for the species, which are necessary to develop sustainable harvest and management plans.

Data collection from the weather station at the Golden Stream field station remained consistent throughout the year. Data collection at the Bladen ranger base was variable, but the data in combination with the Golden Stream data show that the wet-dry seasonal patterns experienced by Belize were exaggerated for the MGL in 2016. As in 2015, 2016 experienced an intense dry season. Rainfall peaked in Golden Stream in August, which is

likely due to the arrival of category 1 hurricane Earl to Belize. Overall, 2016 was wetter for Golden Stream than the previous two years.

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.

Over the past eight years Ya'axché has been implementing a biodiversity monitoring program 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 faces when managing and co-managing protected areas, and recommends a number of target groups (e.g. birds and mammals, freshwater invertebrates, and vegetation) to be monitored in order to answer 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. This document is undergoing an update to include other research and monitoring areas and will be reflected in the 2017 report.

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 7 species of rare, data deficient and threatened trees. Due to logistical constraints and feasibility not all program areas are conducted every year.

This report continues the efforts made throughout the past 8 years to ensure the fulfilment of the BRIM strategy requirement to report major findings annually. This year we present the results from bird and mammal transects, farm monitoring, tree monitoring, and weather stations. Camera trap survey data will be explored in detail combining 2016 and 2017 data in the 2017 report. Freshwater monitoring data analysis is also on hold pending the return of freshwater ecologist Devina Bol, and as such this has also been omitted from this year's report.

This report has a few important sections including the Introduction with general information on the report; Methodology, which consists of an in-depth description of the methods 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.

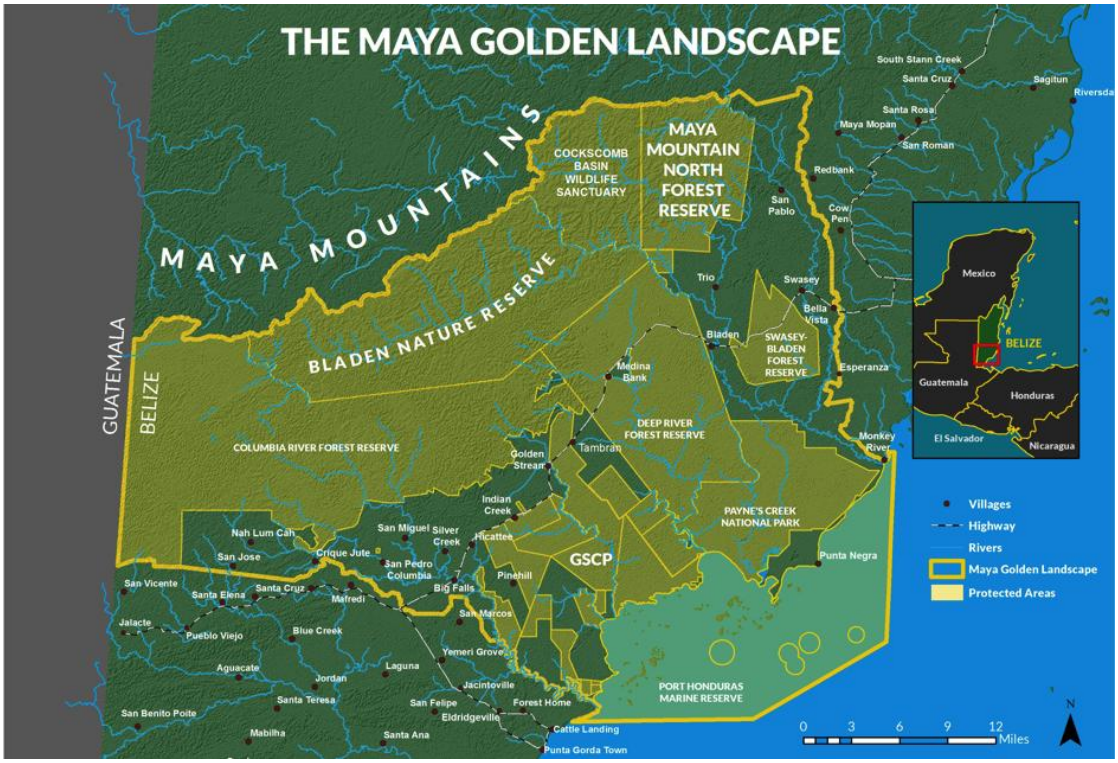


Figure 1. Location of the Maya Golden Landscape and its protected areas in the Toledo District.

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 2 for birds and Table 3 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

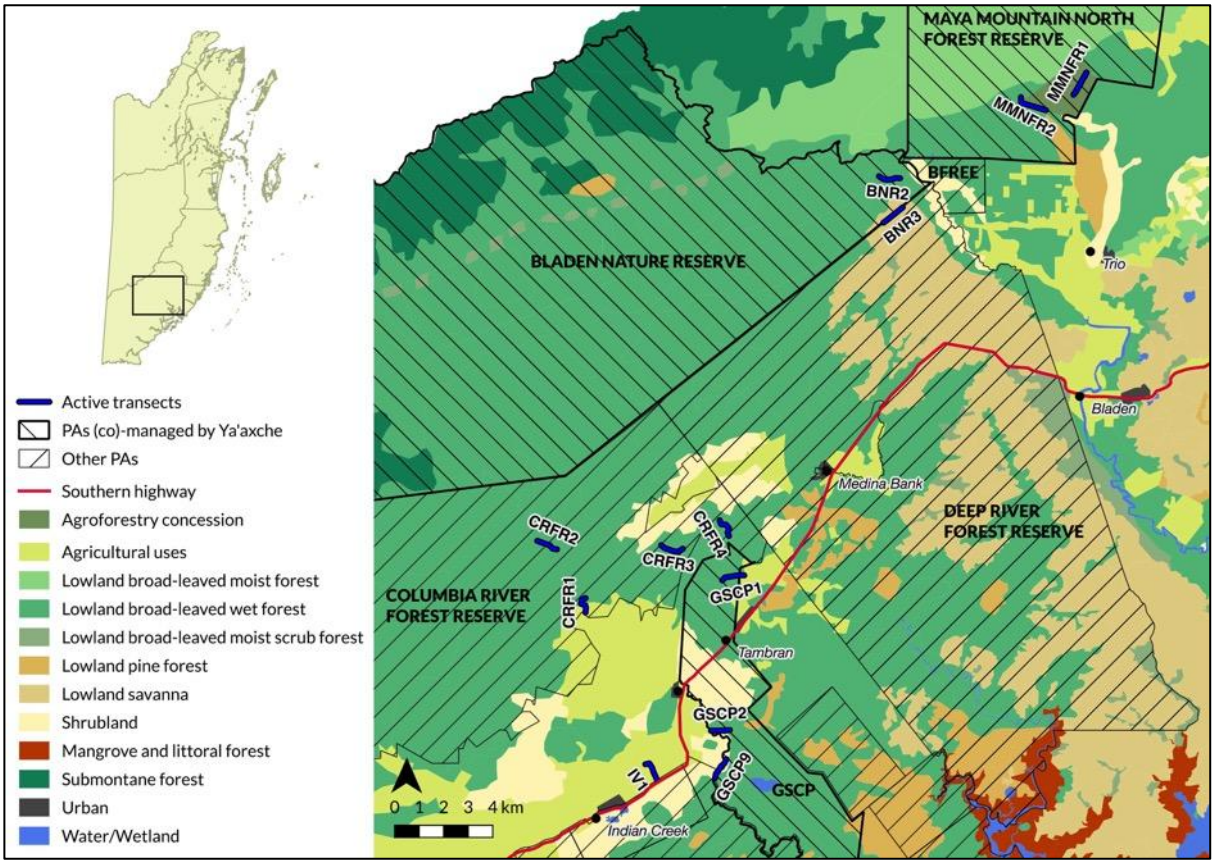


Figure 2. Location of 2016 biodiversity monitoring transects within the MGL

Table 2. 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 3. 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

Table 4. 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%

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 4). The Tables 2 and 3 in the previous page present a more detailed species list and their corresponding indicator group.

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. Four transects were monitored 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). Two transects were implemented and monitored in Maya Mountain North Forest Reserve (MMNFR 1 and 2), but these data will first be presented in next year's synthesis report. 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 5. Description of the currently active transects, their locations, levels of human disturbance and general ecosystem types 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 but deviated from that due to logistical limitations (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 or other research activities) interfering.

For bird monitoring, the transects were visited twice daily: early morning and late afternoon as much as possible. Any differences to this default schedule are reflected in the results section for birds and mammals. 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 for mammals 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 6. Transect visits in 2016; shaded areas indicate periods of inaccessibility or scheduling limitations

	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	6
	Feb	1	1		1				1	1	1	6
	Mar	1	1	1		1	1	1			2	8
	Apr		1		1				1	1		4
	May	1	1	1		1	1	1			1	7
	Jun		1		1					1	1	4
Wet season	Jul	1	1			1	1	1			1	6
	Aug		1		1				1	1	1	5
	Sep	1	1	1							1	4
	Oct		1	1					1		1	4
	Nov		1			1	1	1				4
	Dec	1	1						1	1	1	5
Total		**7**	**12**	**5**	**4**	**4**	**5**	**5**	**5**	**5**	**11**	**63**

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 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. Due to staff turnover, Ya'axché has continued running 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 names for birds and mammals, and observations that lacked number of individuals in the database were set conservatively to '1'.

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 four biodiversity reports (Gutierrez 2016; 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 2 and Table 3), hence the name Target Species Richness.

Diversity profiles

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 [$\boldsymbol{\lambda}$]).

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 ($\boldsymbol{\alpha}$), 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 $\boldsymbol{\alpha}$, p_i indicates the relative abundance of species i, and S stands for the total number of species. When $\boldsymbol{\alpha}$ equals zero, we obtain the target species richness. When $\boldsymbol{\alpha}$ equals 1, we obtain the Effective Number of Species that corresponds to the exponential of the Shannon's index (e^H). And when $\boldsymbol{\alpha}$ 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 $\boldsymbol{\alpha}$, 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 as 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.

Farm monitoring

Study area

The area covered under the farm monitoring was approximately 500km^2 within the MGL. The area is a mosaic of farmlands, forest patches and community lands (Figure 1). Farmland is dominated by slash and burn producing staple crops such as corn for the most part. Cacao farms are typically found within this same landscape oftentimes forming islands of forested land within clear-cut areas under cultivation for corn. Fallow land is under various degrees of succession with many patches having been cultivated in the last 5 years. Community lands are small and much of the land surrounding the communities is set aside for farming. Some forest patches are connected through the mosaic of fallow lands and land under cultivation. A network of gravel roads spans the area connecting to the Southern Highway. The highway is the major artery connecting the south to the rest of the country and bisects the conceptual area of the proposed Southern Belize Corridor. Five cacao farms were chosen out of a total of nine potential farms that include cacao and

clear-cut land. Farm sizes ranges from 6 to 12 acres, with the smallest area under cacao being 1.5 acres and the largest at 8 acres. All farms were at least 2km apart and spread across five different communities (Table 7). These five cacao farms are adjacent to or in close proximity to patches of forest that are connected via the many areas of land in fallow.

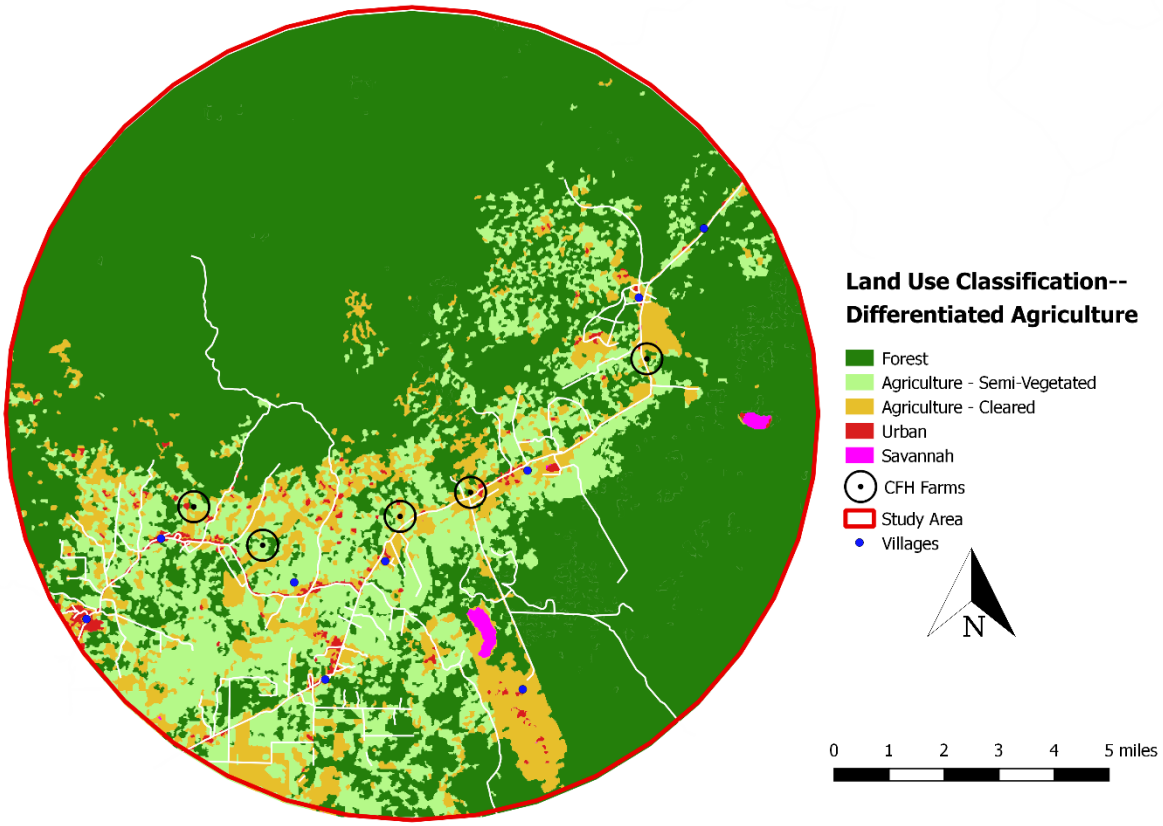


Figure 3. Study area showing differing densities of vegetation within the landscape. Dark green represents healthy, unaltered forest. Light green represents land with varying degrees of regeneration no more than 10 years old. Light orange represents areas under current cultivation of corn and other crops. Black dots represent the selected farm locations.

Table 7. Characteristics of five farms chosen within several community lands in the MGL

	FARM 1	FARM 2	FARM 3	FARM 4	FARM 5
Area (Acres)	6	8	6.5	6	12
Area Under Cacao Production (Acres)	4	6	5.5	4	1.5
General Location	Golden Stream Village	Indian Creek Village	Hickatee Village	Silver Creek Village	San Miguel Village
Age (Years)	20	20	8	5	25
Canopy Cover	90%	40%	50%	30%	80%
Canopy Height	~ 4 m	~ 8 m	~ 4 m	~ 5 m	~ 6 m
Distance From Roads	~ 100 m	~ 70 m	~ 20 m	~1 km	~ 20 m
Adjacent To Forest Patch	Yes	Yes	Yes	Yes	No

Mammal surveys

One camera trap was place on the perimeter of each farm, facing towards the centre of the farm. Where possible, cameras were placed in close proximity to game trails and under canopy. Cameras were moved only once to another location within the farms in order to maximize the probability of detecting more species. Number of cameras and location changes were subject to resource limitations. In contrast to the bird surveys, the mammal surveys aimed at documenting all the mammal species that may occur in the farms although indicator species under the BRIM strategy were considered as another important layer of information for reference in this study. Cameras were checked twice every month to change the batteries and retrieve the data collected. Species were identified following Reid (2009). All photographs were sorted by farm and the data entered into a database and prepared for analysis.

Remote sensing analysis

A Landsat 8 OLI image of southern Belize taken on November 19, 2016 was used to assess vegetation cover within the study area. Spatial resolution for the imagery was 30m on Path 19 Row 49. Ya'axché's GIS officer Caitlin Furio did the photo-interpretation and classification. For more information on Landsat 8 OLI imagery visit https://lta.cr.usgs.gov/L8.

Data analysis

Diversity profiles were produced allowing a combination of relative abundances, individual farm diversity and effective number of species in a graphic format. These profiles provides an overview of dominance within the farms and effective number of species calculated through the two main diversity indices (Species richness [R], Shannon's index [H] and Simpson's index [$\boldsymbol{\lambda}$]). All diversity analysis was conducted using PAST 3.14.

Farm visits were subject to human resource availability and weather conditions and as such sampling effort varied from farm to farm. To account for differences in sampling effort and to make viable comparisons among farms, sample rarefaction curves were produced. Comparisons were made at the minimum number months (sample period) surveyed for mammals. Rarefaction calculations provide the expected number of species out of a random number of visits and plots the average number of species as a function of the number of visits/sample period. Plotting the curves allows another graphic representation of richness with species accumulation over time/effort allowing for modifications in effort for future surveys.

Tree monitoring

Study area

In 2013, Ya'axché began a monitoring program for 100 rosewood (*Dalbergia stevensonii*) trees in Golden Stream Corridor Preserve. GSCP is primarily comprised of the preferred habitat of *D. stevensonii*, "broken ridge" forest on inner coastal plain alluvium, and is likely one of the last strongholds of the species in Belize. The monitored individuals were tagged at 4 different sites in GSCP: Hope Creek, Behind Greenhouse, Opposite Field Station, and Downstream (HC, BGH, OFS, and DS, respectively). These sites are mapped in Figure 4.

Data collection

In May 2013, initial size measurements of the trees were taken. Ocular height in meters was recorded for each tree. The same researcher estimated ocular height within each site (though not necessarily between sites) to minimize discrepancies in measurements. Diameter at breast height (DBH) of the main stem for each tree was measured at 1.3m with diameter tape. The trees were classified into size classes of the following groups: 5-10cm DBH, 11-20cm DBH, 21-30cm DBH, 31-40cm DBH and 41-50cm DBH. In June of this year, Ya'axché conducted the first re-measurement of height and DBH of the trees in order to assess their growth rates.

As the established sites are located along regular patrol routes in GSCP, Ya'axché's rangers have carried out monthly phenological monitoring (i.e. timing of flowering and fruiting periods) of these trees since October 2013. Trees were visited at least once every three months at the less accessible Downstream site and once per month at each of the other three sites. When a tree was determined to be dead, a suitable nearby replacement tree was identified and size measurements taken.

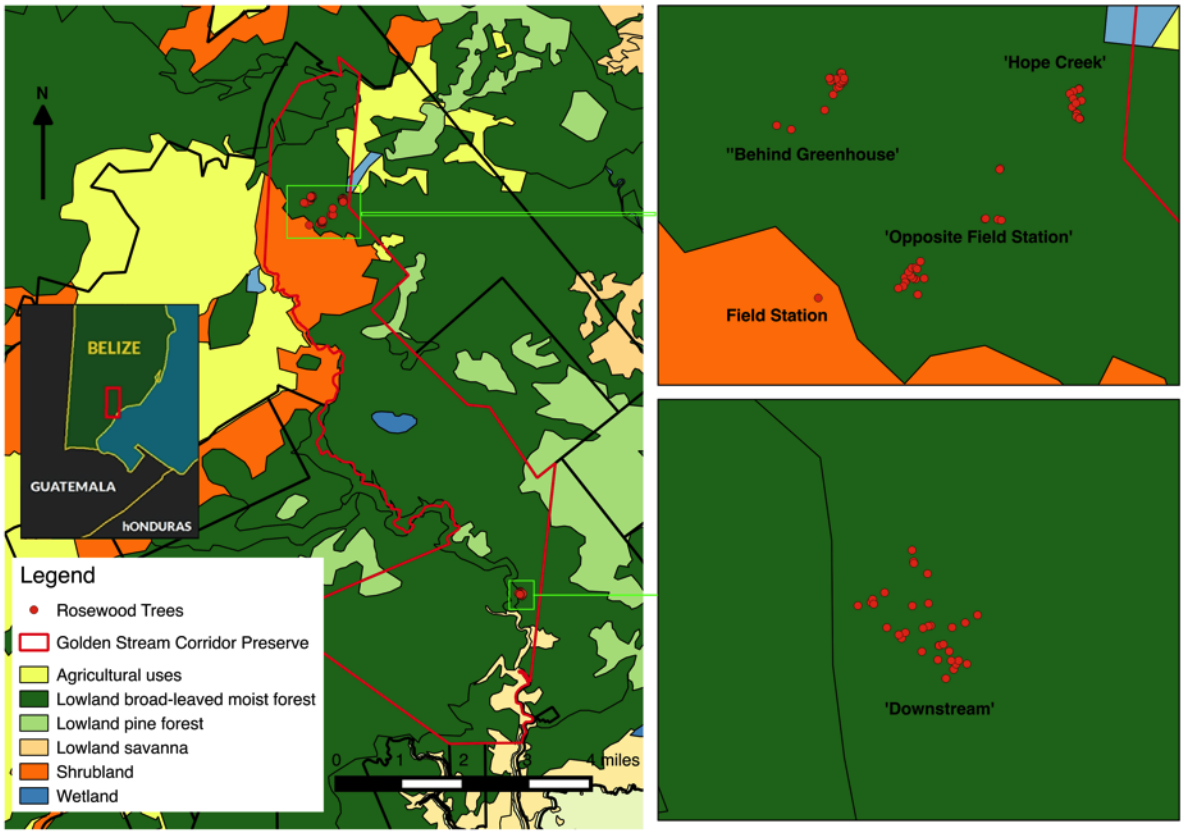


Figure 4. Location of 100 *D. stevensonii* trees used in analysis (Golden Stream Corridor Preserve, Toledo District, Belize)

Data analysis

Growth rates were calculated overall and for each diameter size class of *D. stevensonii*. Comparisons of the proportion of observed flowering and fruiting individuals between size classes of *D. stevensonii* were made. Patterns in the length and frequency of annual flowering and fruiting events during the monitoring period were described.

In combination with growth rate data, information on tree phenology contributes valuable information on long-term reproductive patterns and population processes that are still undetermined for this hardwood species.

Weather

Belize's weather is characterized by a rainfall gradient that increases roughly from north to south (Figure 5). The countrywide coverage is extrapolated from several weather stations distributed across the country, with a limited set of stations in the southern part of the country. In addition to the countrywide gradient that exists, several localized rainfall gradients are expected along the central mountain range. However, like southern Belize, inland and higher elevation regions in the Maya Mountain massif are also underrepresented with weather data collection sites; therefore, gradients in these regions are not well defined.

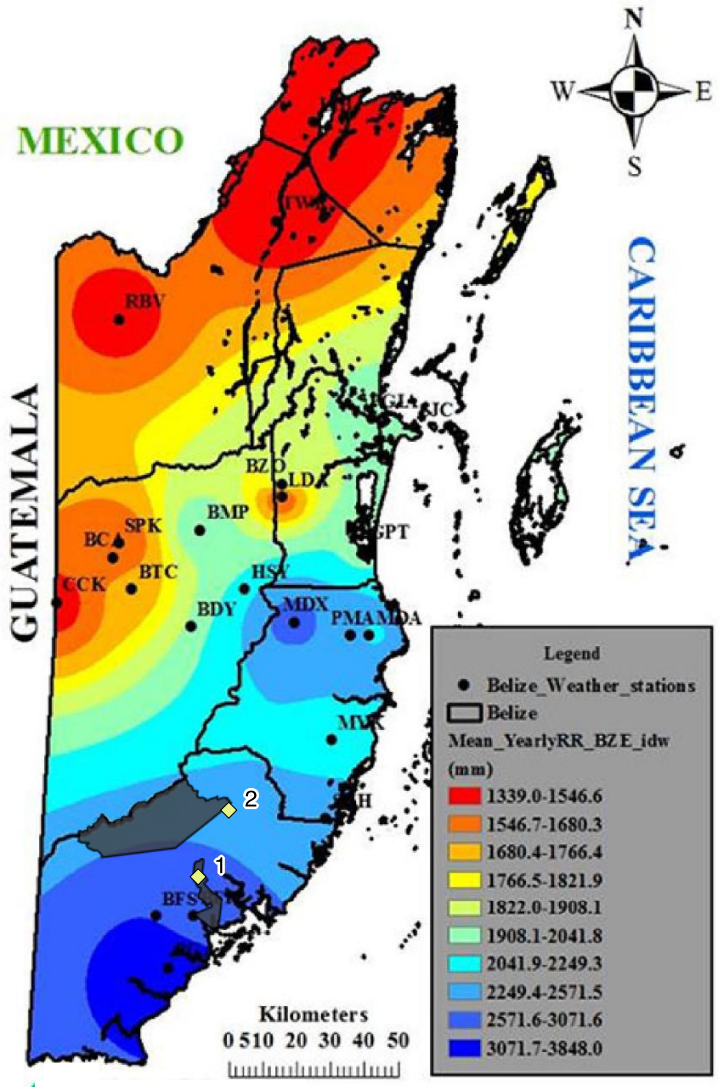


Figure 5. Mean annual rainfall across Belize since 1951, with varying years of data available per weather station. Bladen Nature Reserve and the Golden Stream Corridor Preserve are indicated by transparent polygons. The two Ya'axché weather stations are Golden Stream field station (1) and BNR ranger base (2). Map prepared by Meteorologist Frank Tench (Frutos, 2013).

Sampling weather data in these areas enables us to better understand where the rainfall gradients lie, and it gives us a more localized of specific circumstances that could, among other things, inform us about farming success or failure in certain years. Therefore, we gather rainfall, 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 were recorded manually and entered in a digital spreadsheet.

Land-use change

The land use change section for 2016 is not included in this year's report. Information on Land Use Change will be made available upon request.

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 21 times each over the course of the year, resulting in a total of 117 km of transects completed and an average of 11.7 visits per transect (see Table 8). There was a decrease in sampling effort, compared to the previous two years with averages 13.7 visits per transect in 2015 and 14.9 visits per transect in 2014.

Of the 30 bird target species, a total of 23 species were detected, with a total of 1,442 observations recorded, resulting in an average of 8.9 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 =0.862; $p < 0.05$), and an equally significant positive correlation between the number of visits and the number of individuals (Spearman's ρ = 0.84; $p < 0.05$). As the number of visits to transects increases, the number of individual birds seen also increases.

Table 8. Bird monitoring effort per transect in 2016, where 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	13	13000	9.7
BNR3	20	20000	7.1
CRFR1	10	10000	7.9
CRFR2	10	10000	7.8
CRFR3	10	10000	11.6
CRFR4	9	9000	11.4
GSCP1	9	9000	10.2
GSCP2	7	7000	5.6
GSCP9	8	8000	9.5
IV1	21	21000	9.0
MGL	**117**	**117000**	**9.0**

Over the years BNR2 transect has recorded the highest number of observations over all the others, but in 2016 the decrease in sampling is evident in the decreased in observations for this transect. CRFR3 and CRFR4 had the highest average observations per 1000 m in 2016. IV1 had the highest number of observations with and the highest number of individuals recorded over all. We will see later in this section that having a higher number of observations per 1000 m does not necessarily indicate the presence of more target birds or more target species diversity.

In 2016, between 6 and 14 transect visits were conducted per month (see Figure 6). September had the lowest number of transect visits at 6 and March had the greatest number of visits at 14. The average number of visits overall was 9.7 visits per month making 2016 the year with the highest level of fluctuation in sampling effort.

As noted in Figure 6, the number of visits per transect peaked during the dry months and dipped considerably during the peak of the rainy months. Logistical limitations are the main cause for the decrease in number of visits and are primarily due to rains. The number of observations follow a similar pattern overall. However, observations peak in the month of December even though the number of visits peaked in the month of March. June and July recorded the lowest number of target species with June recording 9 species and July recording 10. Migrant species have a clear influence in the numbers recorded in these two months of the year. More detail on migrants can be found later on in this section.

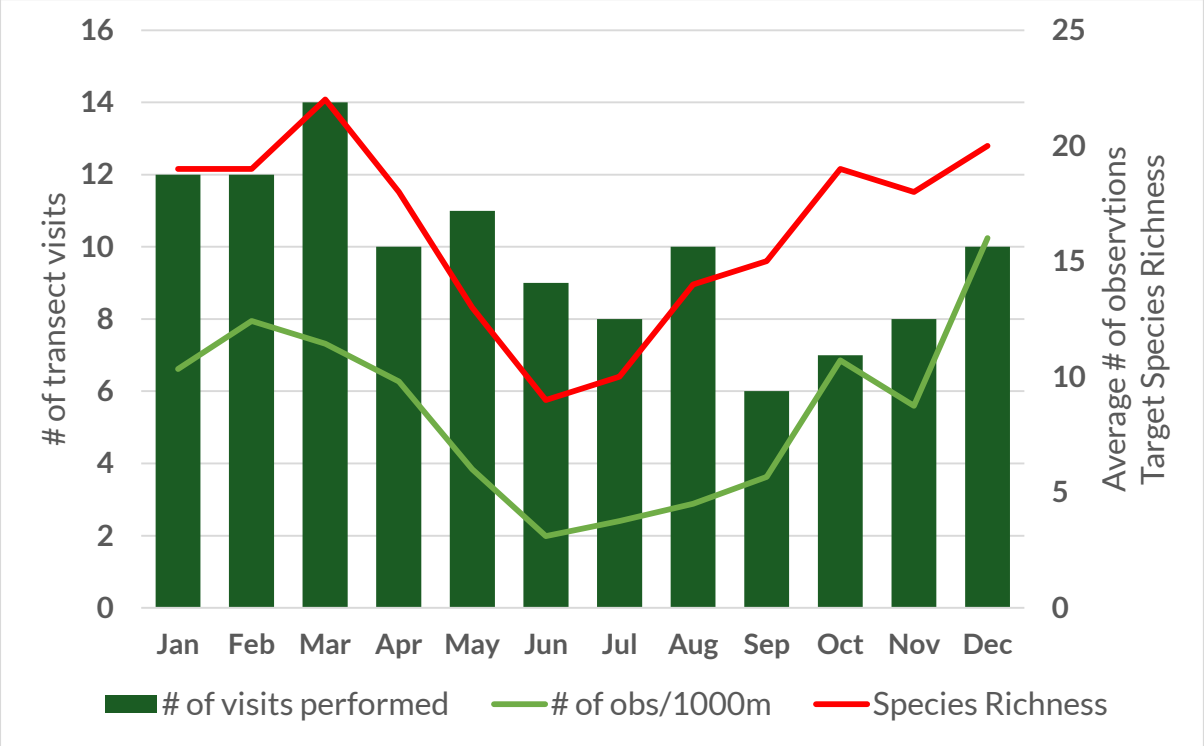


Figure 6. Bird monitoring effort in 2016

Target species richness

Forest habitat transects have a higher representation in comparison to disturbance and savannah habitat. To make a general visual comparison among the habitat types the average of all forest transects is used along with the totals for disturbance and savannah transects. Using an average value results in a 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, potentially inflating species richness estimates in these cases.

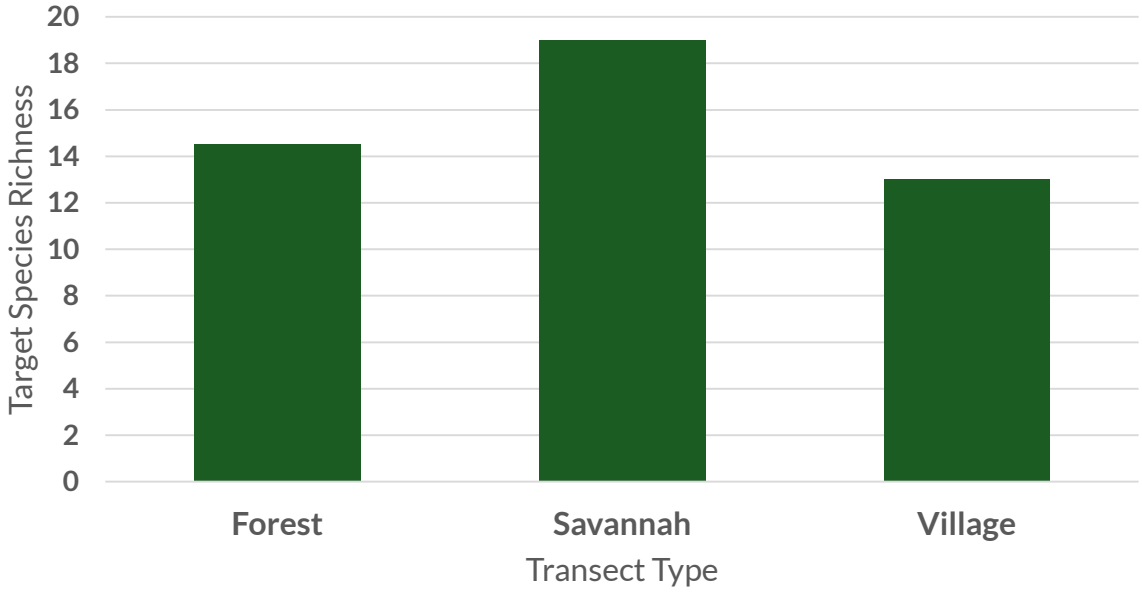


Figure 7. Total target bird species richness per habitat

An average of 14.5 target species was detected on forest transects, compared with 19 target species detected in the savannah and 13 in village lands (Figure 7). All forest transects yielded a total of 21 target species, almost the total number of species recorded over all except two that are restricted to the pine-savannah (Blue-gray Gnatcatcher, Grace's Warbler). Similar number of species are found within all three transect types but species composition differs from habitat to habitat. Composition by indicator class is explored later in this section.

Sample-based species rarefaction curves

Comparing transects with differing sampling effort can lead to biased and inadequate interpretations of the data. Therefore, we compare all the transects' expected species accumulation at the point of the lowest number of transect visits (in this case, the minimum number of visits was 7 for GSCP2). The rarefaction analysis (explained in the methods section) results in rarefaction curves or species accumulation curves as seen in Figure 8.

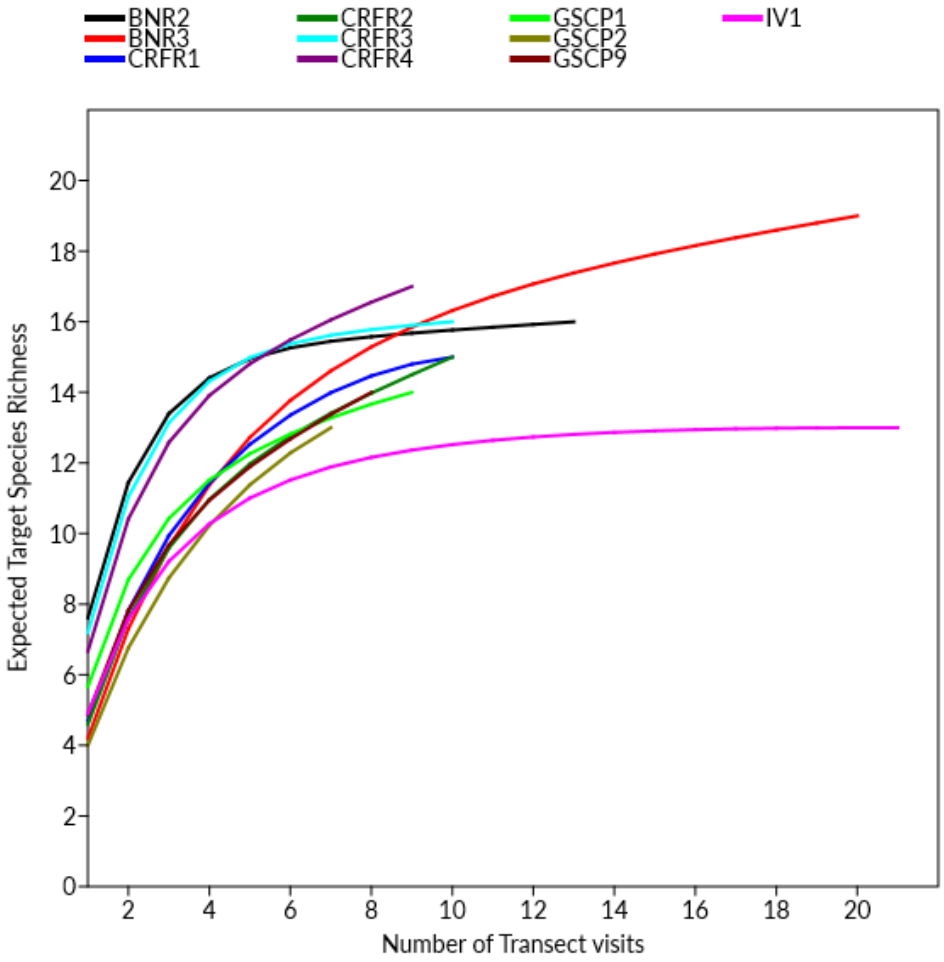


Figure 8. Sample-based rarefaction curves for all transects

In Table 9 we can see the ranking in expected species richness of the transects at 7 transect visits. CRFR4 and CRFR3 transects accumulated most species at 7 visits (16.1 and 15.6 respectively); followed by BNR2 and BNR3 (15.4 and 14.6 respectively) in descending order of rank. In general, all transects in Columbia River Forest Reserve and Bladen Nature Reserve accumulate at least 60% of target species within 7 visits. Golden Stream Corridor Preserve transects consistently rank lower on the list but not by a large margin.

Table 9. Transect ranking according to expected bird target species richness after 7 transect visits

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

Diversity profiles

The highest diversity was recorded for BNR3. However, in this transect there is a major effect of dominance, with an uneven distribution of number of individuals per species, caused by a high number of Yellow-headed Parrots recorded (see Figure 9). The second highest diversity was recorded in CRFR4 where the dominant target species was the Chachalaca, a species associated with disturbances but not uncommon to find in forested areas near human habitation. The Columbia River Forest Reserve transects usually rank lower in diversity in comparison to the Bladen Nature Reserve transects but numbers of individuals recorded are more evenly distributed. Golden Stream Corridor Preserve transects recorded lower species richness in comparison to the rest. The BNR2 transect is consistently identified as the most diverse of all transects, but in 2016 it fell behind slightly. Species numbers were most even in this transect with many forest species being recorded in similar numbers.

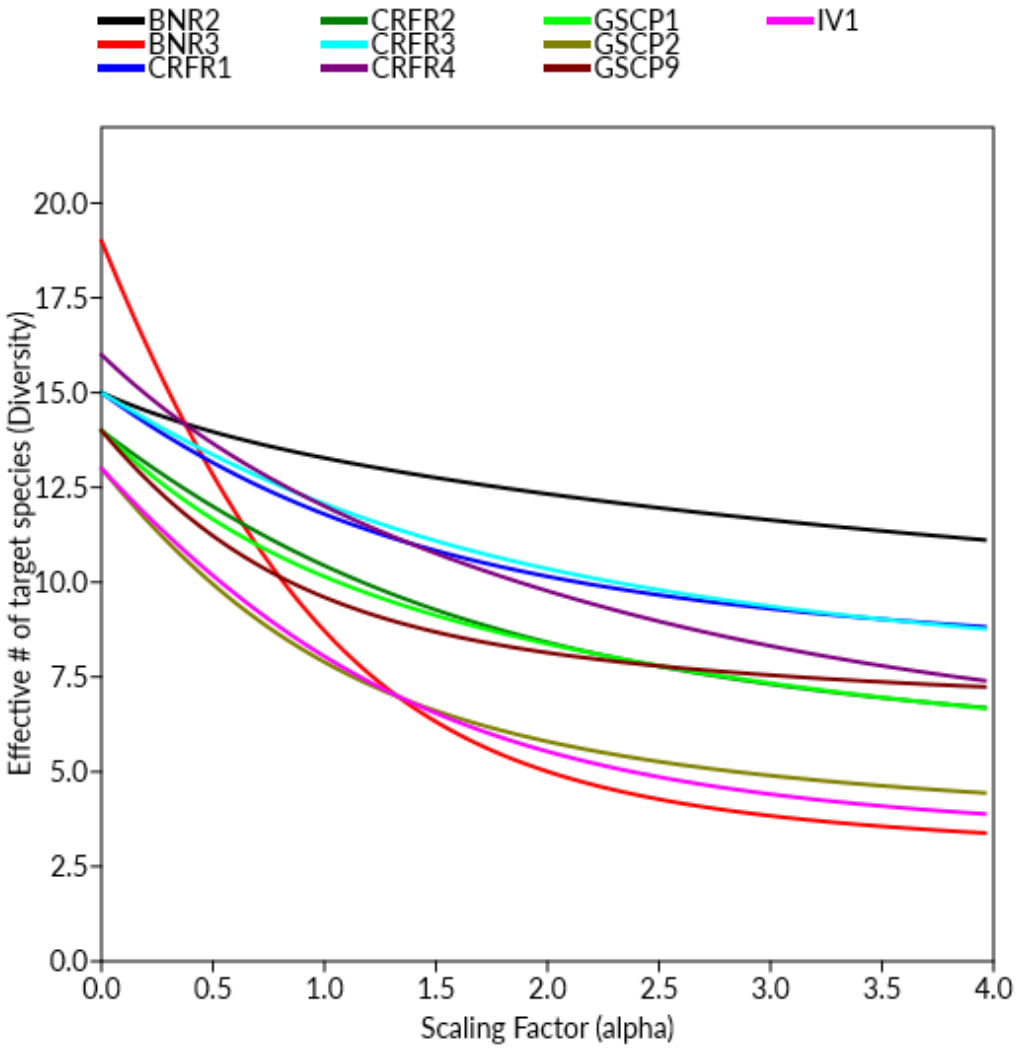


Figure 9. Bird diversity profiles

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 month per transect. There was no significant correlation between the number of migrant individuals per month and the number of transect visits per month (Spearman's ρ > 0.05; p = -0.378), which enables us to compare between months without controlling for the number of visits conducted in these months.

The pattern of migration is clearly evident and depicted by a peak season marked from October to March (see Figure 10). Like previous years, species richness follows a similar pattern with encounter rates declining to low numbers during the late spring and late summer months and no migrant detection in the month of June. Migratory target species richness peaked twice, once in March and again in October with both records at 11 migratory target species. This pattern, while different to last year's it is not entirely dissimilar and could reflect the migratory patterns of birds that winter south of Belize.

The American Redstart was detected throughout the year except for the month of June. The next early arrival late departure species was the Common Yellowthroat which was only absent in the months of June and July. All other species follow the same pattern of increasing numbers as the peaks of March and October approached.

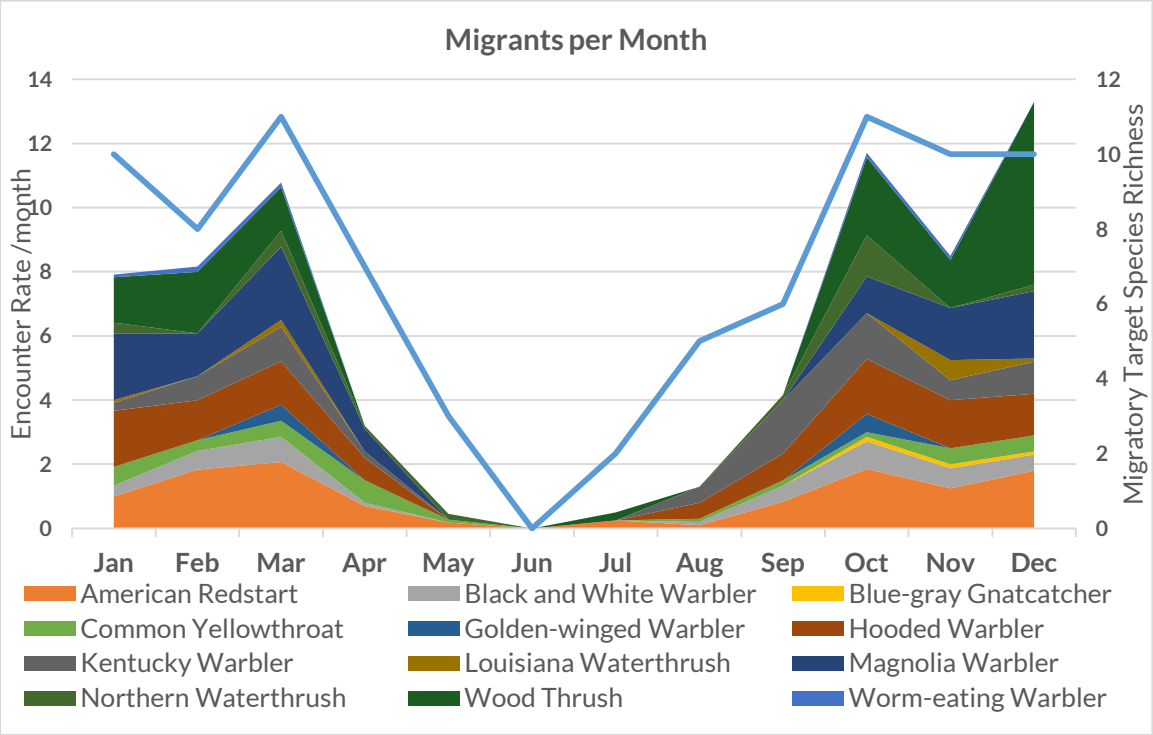


Figure 10. Migrant encounter rate and species richness throughout the year

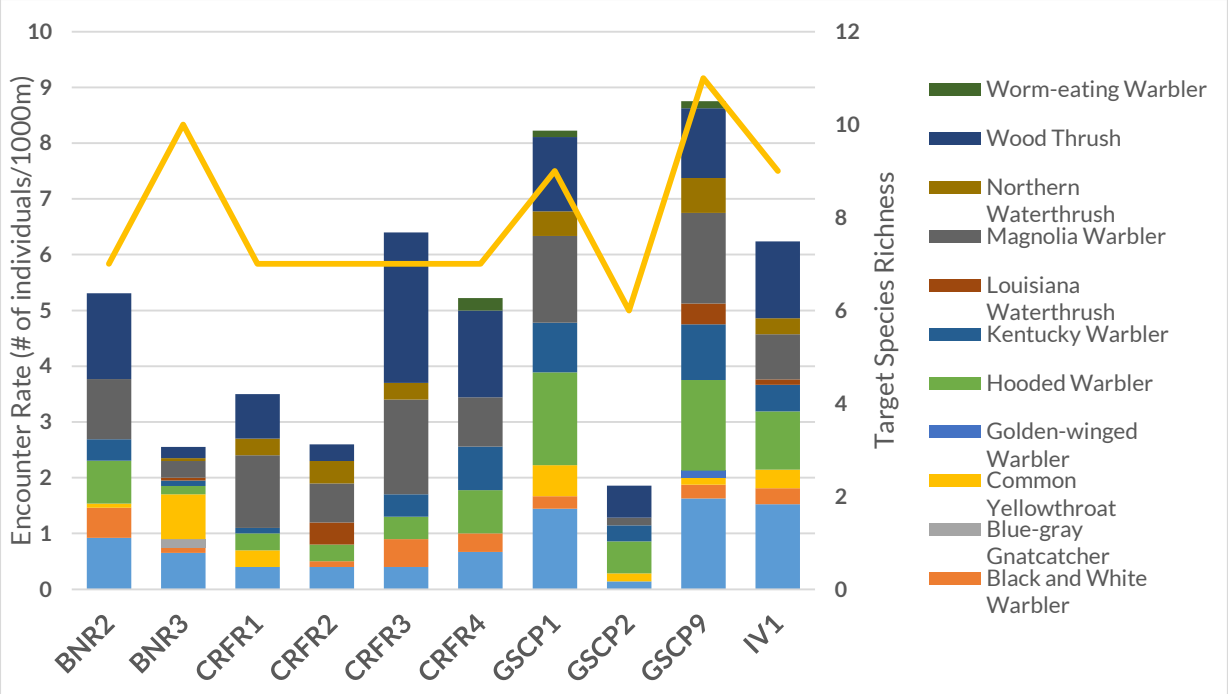


Figure 11. Encounter rate and species richness of migrants per transect

Migrant species richness fluctuated across transects but there was a notable dip in richness for GSCP2 (Figure 11). This transect also had the lowest encounter rate for migrants. IV1 has a visibly higher encounter rate than some of the forest transects including GSCP2. The openness of the IV1 transect could be leading to a higher detection than in forested areas. In the diversity section, IV1 had displayed evidence of dominance by a few species and also had the lowest target species richness along with GSCP2. While BNR3 had a low encounter rate for migrant species, it recorded the second highest number of migrant species after GSCP9. Dominant migrants throughout the transects were Wood Thrush, Magnolia Warbler, Hooded Warbler and American Red Start.

Indicator groups

Ecosystem health can be gauged by looking at the wildlife in an ecosystem. In order to do that we document indicator bird species based on the ecosystem and habitats they prefer and whether they are sensitive to changes within those ecosystems/habitats. 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 76 transect visits done in the forest habitat, only 20 in the savannah and 21 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 12, the total number of individuals encountered in each habitat is shown in brackets.

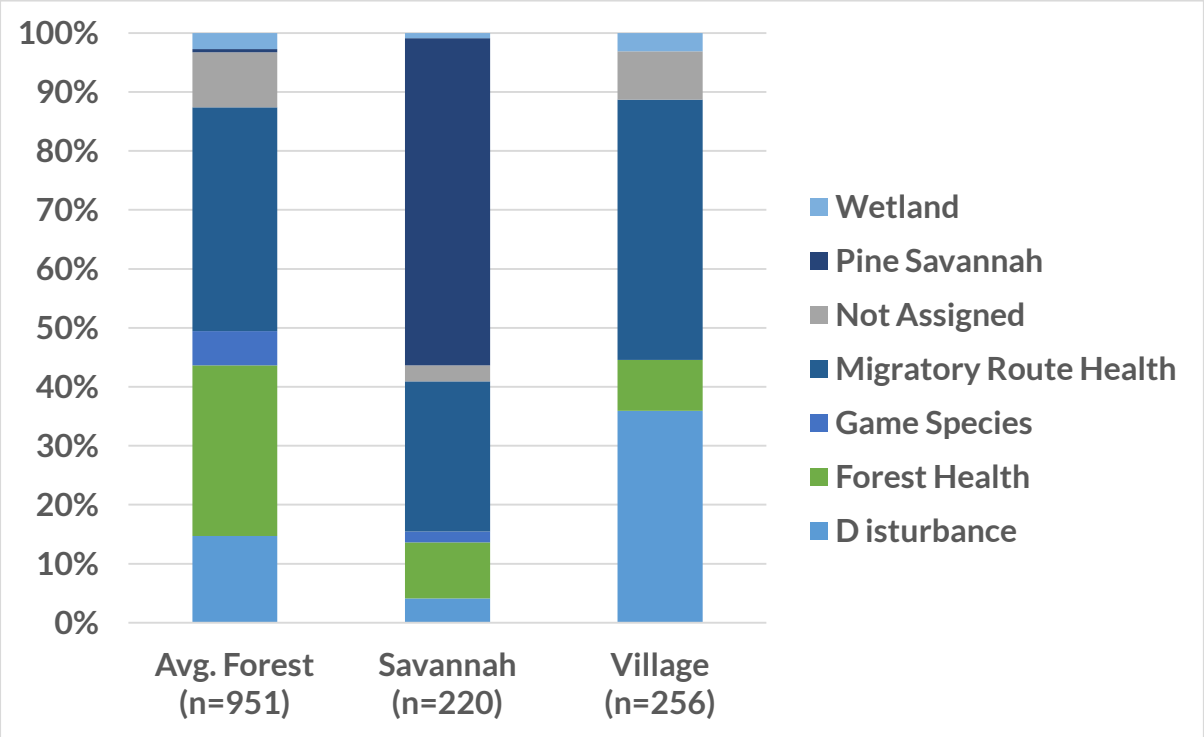


Figure 12. Distribution of individuals among Indicator Groups

Migratory route health indicators made up 37.96% of the individuals recorded in all forest transects combined. Forest health indicators made up a similar proportion at 28.92% of the individuals recorded in all forest transects combined. Disturbance indicators, notably one species (Plain Chachalaca), had an increase to 14.72% in 2016 from 9.5% in 2015 with these numbers being driven by the numbers in the CRFR and GSCP transects. Game species made up 5.78% of the total number of individuals in forest transects (see Figure 12).

In the savannah, 55.45% of all individuals detected were pine savannah indicators. As in the previous year's data, a significant percentage (25.45%) of the individuals were migratory route health indicators and is a smaller proportion than is seen in the other two habitats. Game bird numbers were significantly lower than in 2015 down from 11.36% to 1.82% in 2016. In general, game birds were down across the different habitat and ecosystem types.

In village lands, game and pine-savannah indicator species were completely absent and forest indicators only made up 8.59% of all individuals recorded. Disturbance indicators made up 35.94%, significantly higher than that seen in the other two habitats. Migratory route health indicators made up the highest numbers with 44.14% of the individuals.

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 13 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 trends are a decrease of forest indicators as the disturbance gradient increases and an increase in disturbance indicators as the disturbance gradient increases. Migratory indicators showed similar numbers across the transects. The savannah transect had a very different composition than all other transects with a great proportion of individuals being the dominant savannah indicator species. The number of individuals detected in the different transects is shown in brackets.

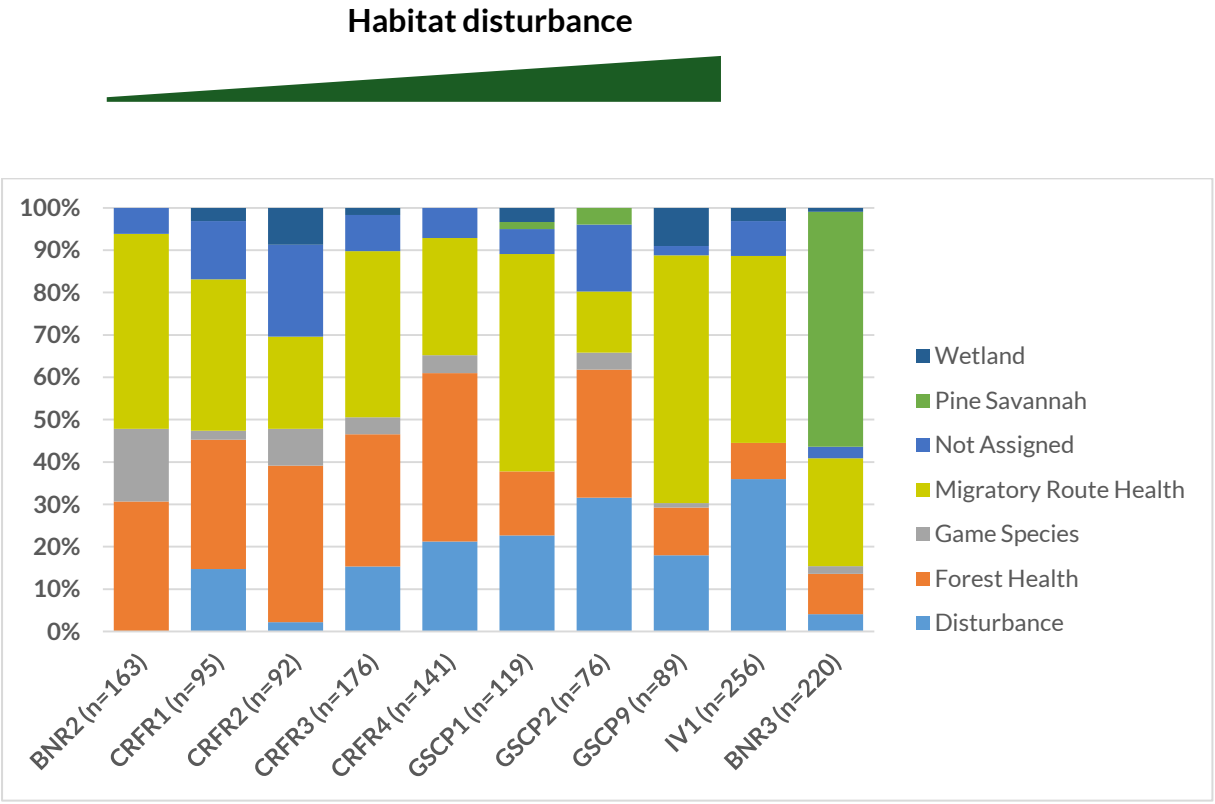


Figure 13. Distribution of individuals among Indicator Groups, looked at per transect. From the left, the first 8 transects indicate a habitat disturbance gradient in the forest. The next transect is on village lands, the last one in savannah.

Large mammals

Similarly to the bird transects, the number of mammal transect visits decreased slightly from the previous year and are generally half the frequency of bird transects. For 2016, a total of 63 mammal transects were carried out, covering a total of 63km (see Table 10). This was down from 69km in 2015. The number of transect visits per general location was more variable than in previous years with a minimum of 4 visits, a maximum of 12 visits and an average of 3.8 observations per 1000m transect in the MGL.

Table 10. Mammal monitoring effort per transect in 2016, where 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	7	7000	6.3
BNR3	12	12000	3.2
CRFR1	5	5000	2.6
CRFR2	5	5000	2.6
CRFR3	5	5000	4.2
CRFR4	5	5000	3.8
GSCP1	5	5000	4.4
GSCP2	4	4000	4.3
GSCP9	4	4000	3.5
IV1	11	11000	3.1
MGL	63	63000	3.8

Of the 19 target species of mammals, 16 were recorded, with a total of 235 observations made and 375 individuals counted. The Neo-tropical River Otter, Brown Brocket Deer and Margay were not recorded over the course of the year. The largest number of mammal observations per km was recorded for BNR2 as with previous years. GSCP1 and GSCP2 were right behind in descending order. BNR2 and GSCP1 have consistently been on the top of the list for number of observations per km as reported in Gutierrez 2016, Gartzia and Gutierrez 2015 and Gartzia 2014. This is largely due to dominant species such as Yucatan Spider Monkey in BNR2. Transects with the least number of mammal observations per km were CRFR1, CRFR2 and IV1, the first two showing a significant decline in the number of observations as compared with 2015. White lipped peccaries were not detected in any of the Bladen transects but their presence has now shifted to the Columbia River Forest Reserve transects.

There was a significant correlation between the number of visits and the number of observations recorded (Spearman's $\rho = 0.569$; $p < 0.05$) indicating that a larger number of observations could have resulted from additional transect visits. Unlike previous years, there was no significant correlation between the number of visits and the number of individuals recorded (Spearman's $\rho = 0.571$; $p = 0.09$). 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 $\rho = 0.09$; $p = 0.8$).

Transect visits per month were less consistent than in previous years, with a minimum of four visits per month and maximum of eight visits per month. March had the most transect visits at eight followed by May at seven and January, February and July with six. April, June, September, October and November has the lowest number of visits at four each (see Figure 14). Under normal conditions, the dry season does not offer very favourable conditions as can be seen in Figure 14. Fluctuations in observations throughout the rainy season reflect the effort and detectability of tracks due to logistical problems particularly at the peak of the dry season in April.

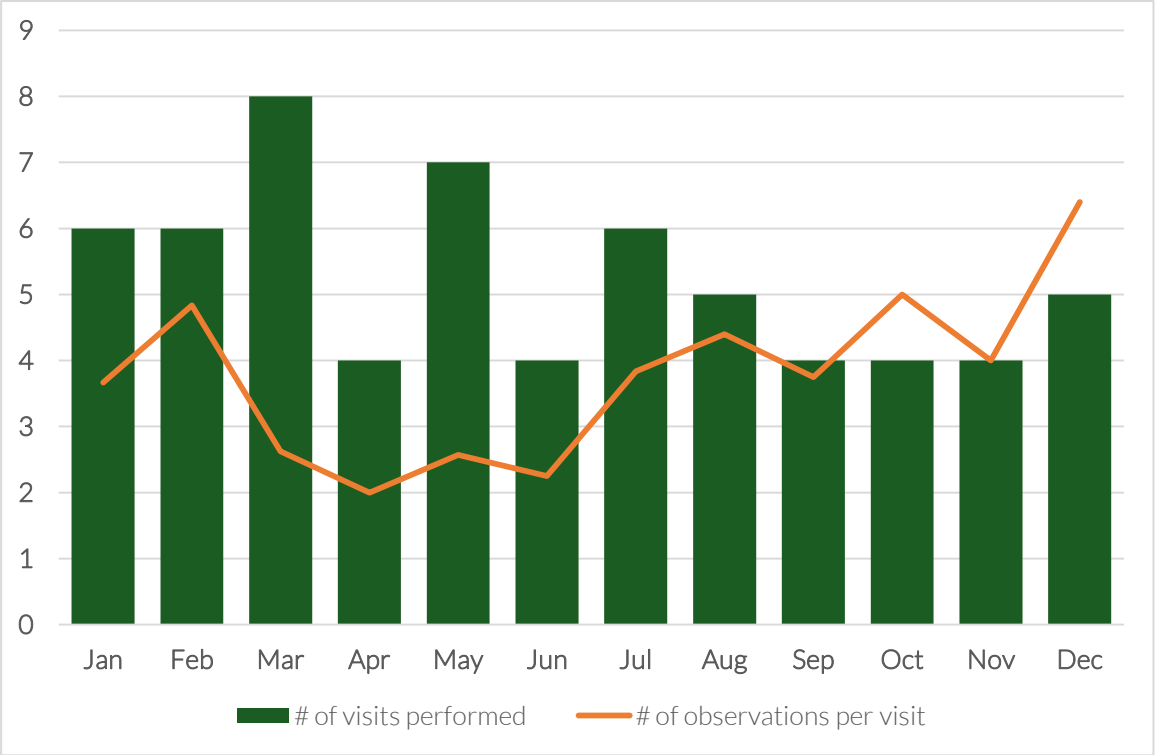


Figure 14. Mammal monitoring effort in 2015

Target species richness

We can make conservative comparisons between Forest habitats and the other two habitats types. Forest habitats are represented in far more transects than the savannah and village lands transects. The latter two are represented in only one transect each. With an uneven representation of transects per habitat, the forest transects were pooled and the averages used for comparisons with the other two habitats. Fifteen target species were recorded within forest transects and the average target species richness within this habitats was less when compared to the savannah which had more species.

However it was more similar to the number of species recorded in the village transect (see Figure 15). The savannah transect is on the transition area of broadleaf and pine savannah. The savannah transect recorded nine target species and the village transect recorded six target species. CRFR3 also recorded nine species followed by BNR2 and are both forest transects.

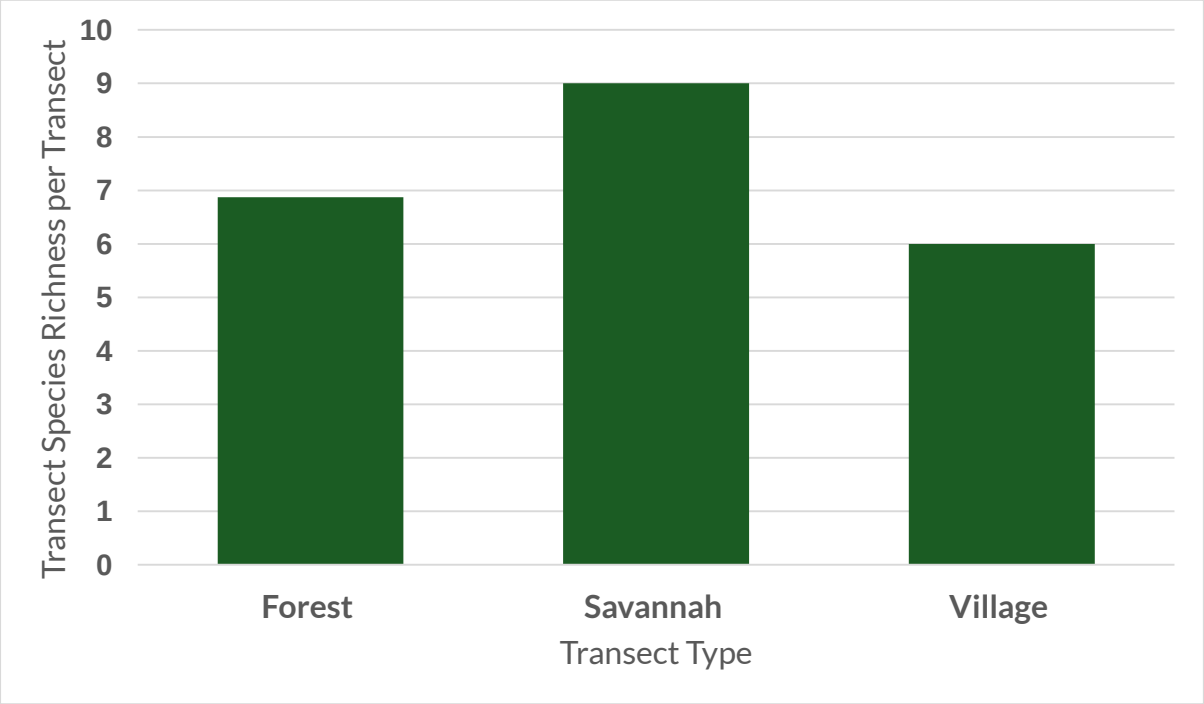


Figure 15. Target mammal species richness per habitat type. "Forest" shows the average target species richness for that particular habitat.

Species accumulation and rarefaction curves

We calculated the expected species richness for each transect and produced rarefaction curves (see Figure 16). This allows the comparison of transects with different sampling efforts, by looking at the number of species recorded after the minimum number of transect visits. Transect visits ranges from a minimum of 4 to a maximum of 12.

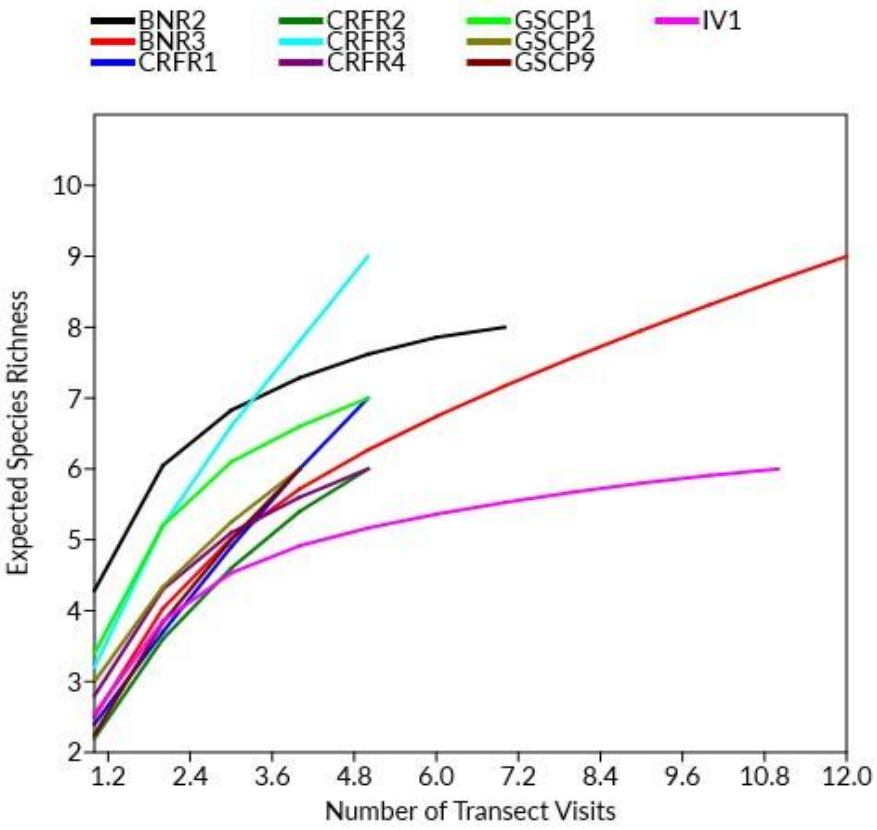


Figure 16. Sample-based rarefaction curves for large mammals

Table 11 shows the ranking of transects based on their expected species richness after the minimum number of visits. CRFR3, BNR2 and GSCP1 recorded between 6 and 8 species after just 4 visits with CRFR3 recording the higher number. 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.

Table 11. Transect ranking according to expected mammal target species richness after 4 transect visits

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

Diversity profile

Dominance by one species in some of the transects has often created an "uneven" distribution of relative abundance. The effect can be seen in CRFR2 and CRFR3 (see Figure 17). Note the steep downward curves representing these two transects. This pattern had consistently been observed for BNR2 but in 2016 the pattern changes to the CRFR transects where White-lipped Peccaries were more dominant. BNR2 displays a lesser effect of dominance but for 2016 it was largely due to an increase in the detection rate of Yucatan Spider Monkeys on this transect. The savannah transect BNR3 and CRFR3 recorded the highest species richness but we can see that abundances are not evenly distributed. In general over the last few years the transects with the most even distributions tend to also have lower species richness. For 2016, CRFR4, GSCP2, GSCP9 and IV1 recorded the lowest species richness with IV1 being the most even with numbers per species.

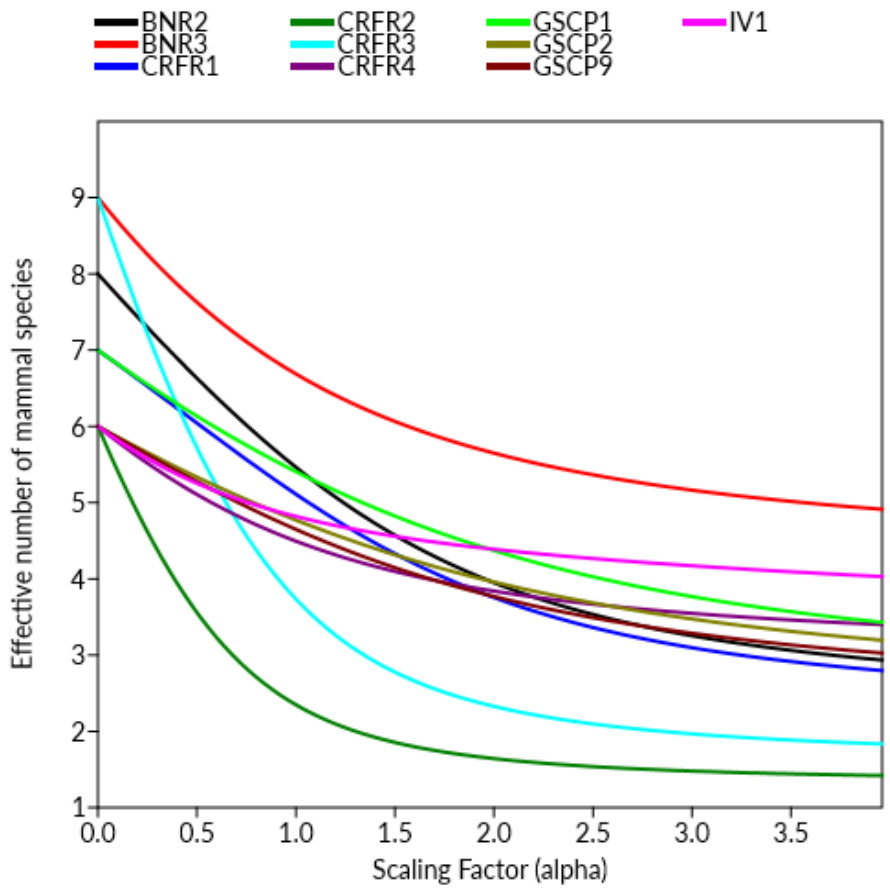


Figure 17. Mammal diversity profiles 2016

Indicator groups

BNR2 and BNR3 have consistently recorded similar numbers of forest species even though BNR3 is within savannah habitat. Its proximity to the broadleaf forest habitat on the boundary line of the Bladen Nature Reserve and the Deep River Forest Reserve places the transect in a transition zone where it still attracts forest species in addition to other indicators. However, the average number of forest indicator for all eight forest transects yield a lower number than the savannah transect (Table 12). Game indicators were the most evenly distributed of the groups across transects. The only wetland species, the Baird's Tapir, was recorded in most transects except for CRFR4 (a forest transect) and IV1 the village transect.

Table 12. Average number of species per transect

Indicator species	Average Forest (n=8)	Savannah (n=1)	Village (n=1)
D	0.125	0	0
F	2.125	4	2
G	3.5	4	4
NA	0.25	0	0
W	0.875	1	0

Even though the savannah contains a high number of forest and game indicator, over all the forest transects contain more species all together and have a higher abundance for all indicator groups. What is more interesting is the large proportion of species belonging to game indicator group being very dominant within the village transect as seen in Figure 18.

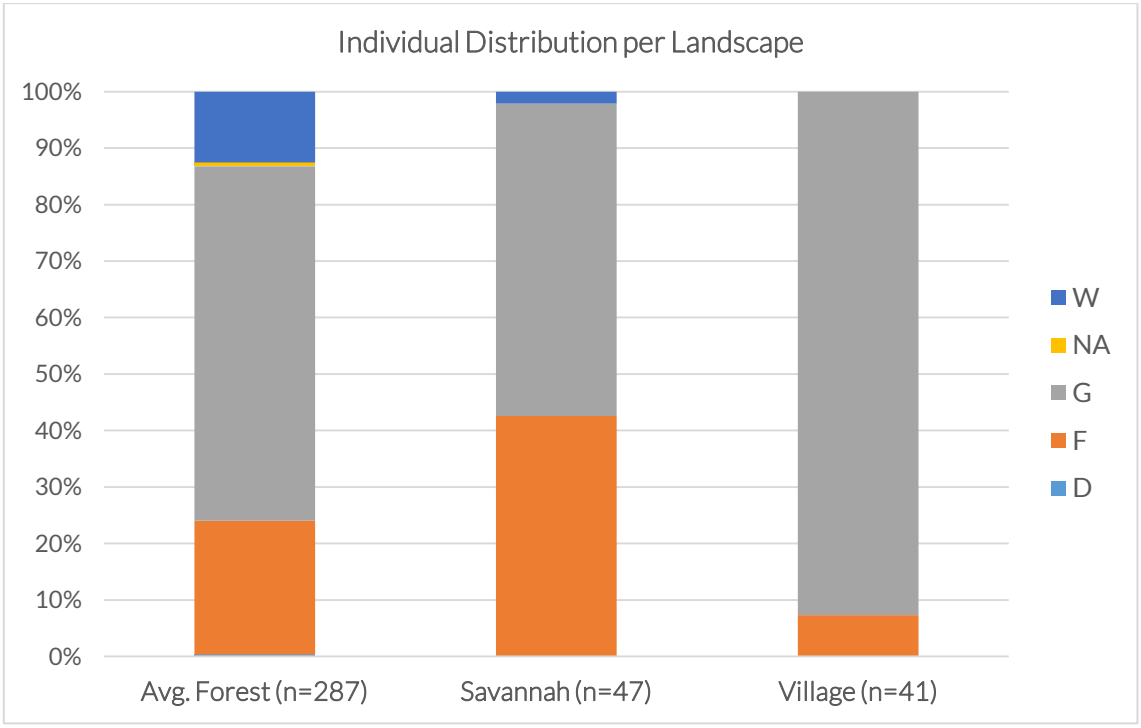


Figure 18. Distribution of individuals among Indicator Groups

To get a clear understanding of species composition we assessed the encounter rate of individual forest indicator species per 1000m (see Figure 19). The average encounter rate per transect for all eight forest transects was use to compare with the savannah and the village transect. As expected, the forest transects had more forest indicator species than the other two transect types. Yucatan Spider Monkeys were more abundant on average with the forest transects while Howler Monkey vocalizations are recorded more often within the savannah transect, largely due to the openness and proximity of the forest. Jaguars were recorded evenly throughout all transects including the village transect.

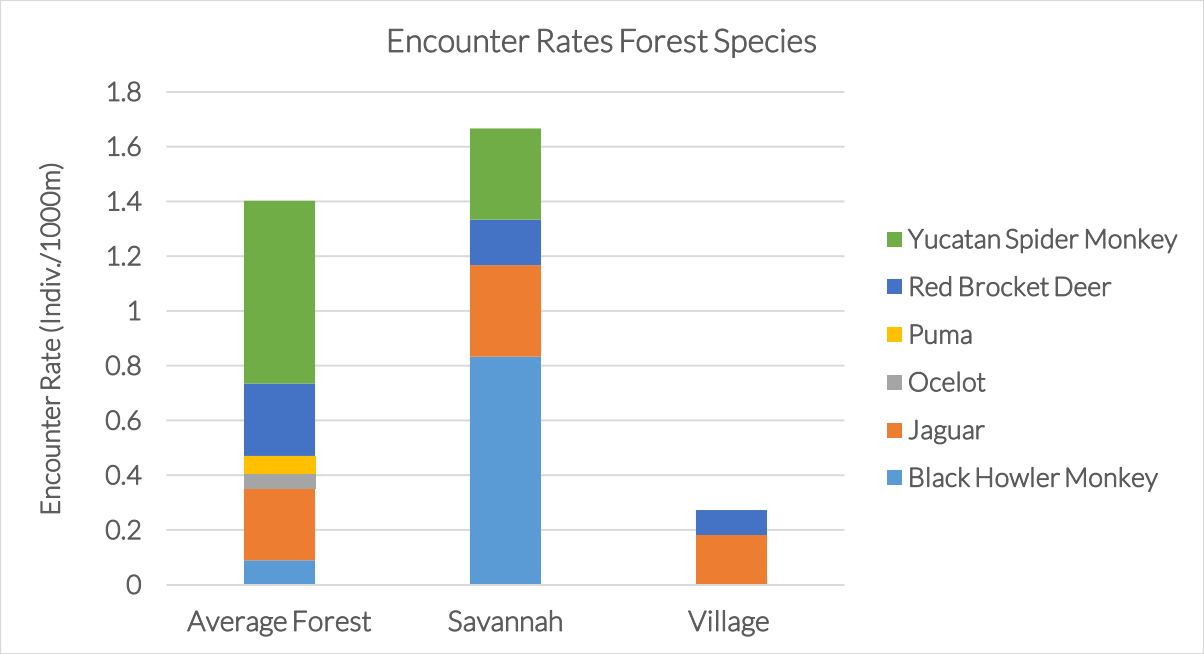


Figure 19. Encounter rate of all forest health indicator species

The encounter rate for game species was assessed in a similar manner (Figure 20). The village transect shows a higher encounter rate for collared peccary than that of the forest transects combined. Nine-banded armadillos seem to be the most evenly detected across transects. 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 only slightly lower across the other transects types. The only wetland indicator species, the Baird's Tapir was absent from the village transect in 2016.

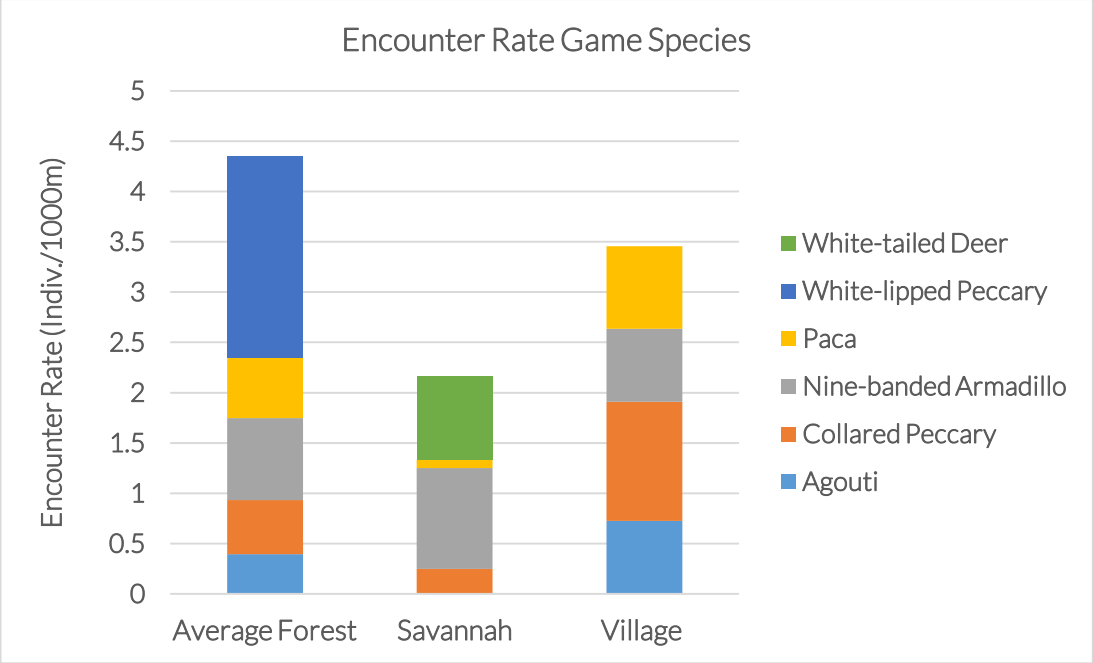


Figure 20. Encounter rate of all Game indicator species

Farm Mammal Monitoring

A total of 518 trap days/nights were recorded between July 27th, 2016 and December 13th, 2016 ranging from 75 trap days/nights in Farm 2 to 141 in Farm 3 (Table 13). A total of 2442 photographs were taken throughout the study period. Fourteen mammal species were recorded by the end of the study period of which six species are indicator species as listed in Ya'axché's BRIM Strategy (Table 14). Farm 2 had the highest species richness at nine species followed by Farm 5 at six species with both having the same three indicator species (Central American Agouti, Nine Banded Armadillo, and Paca). Farms 1, 3 and 4 all recorded four species total with Farm 1 recording three indicator species, Farm 3 recording two indicator species and Farm 4 recording one indicator species.

Diversity

We produced diversity profiles for the farms to have a better understanding of diversity and dominance in the species assemblage (Figure 21). As mentioned before Farm 2 and Farm 5 had the highest diversity but also had the highest effect of dominance by one particular species. The Central American Agouti is responsible for the unevenness of numbers. Farms 1, 3 and 4 are a more evenly distributed in numbers but still have a dominance effect by one the same species of agouti, which was the only species recorded in all five farms.

Table 13. Summary of Survey Effort with number of trap days/nights, photographs taken, species recorded and the number of months each farm was surveyed.

Summary					
	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5
Survey Effort (Trap days)	96	75	141	113	93
Number of Photographs Taken	67	914	152	160	1149
Number of Species Recorded	4	9	4	4	6
Number of Months Surveyed	5	4	6	5	6
Number of Cameras	1	1	1	1	1
Number of Camera sites	2	2	2	2	2

Table 14. Mammal Species recorded during the study period presenting common names and scientific names. NA = Not Assigned

Common Name	Species	Indicator
Central American Agouti	*Dasyprocta punctata*	Game
Collared Peccary	*Pecari tajacu*	Game
Common Opossum	*Didelphis marsupialis*	NA
Grey Four-Eyed Opossum	*Philander opossum*	NA
Grey Fox	*Urocyon cinereoargenteus*	NA
Long Tailed Weasel	*Mustela frenata*	NA
Nine-banded Armadillo	*Dasypus novemcinctus*	Game
Northern Raccoon	*Procyon lotor*	NA
Ocelot	*Leopardus pardalis*	Forest
Paca	*Cuniculus paca*	Game
Stripped Hog-Nosed Skunk	*Conepatus semistriatus*	NA
Tayra	*Eira barbara*	NA
White-Nosed Coati	*Nasua narica*	NA
Yucatan Squirrel	*Sciurus yucatanensis*	NA

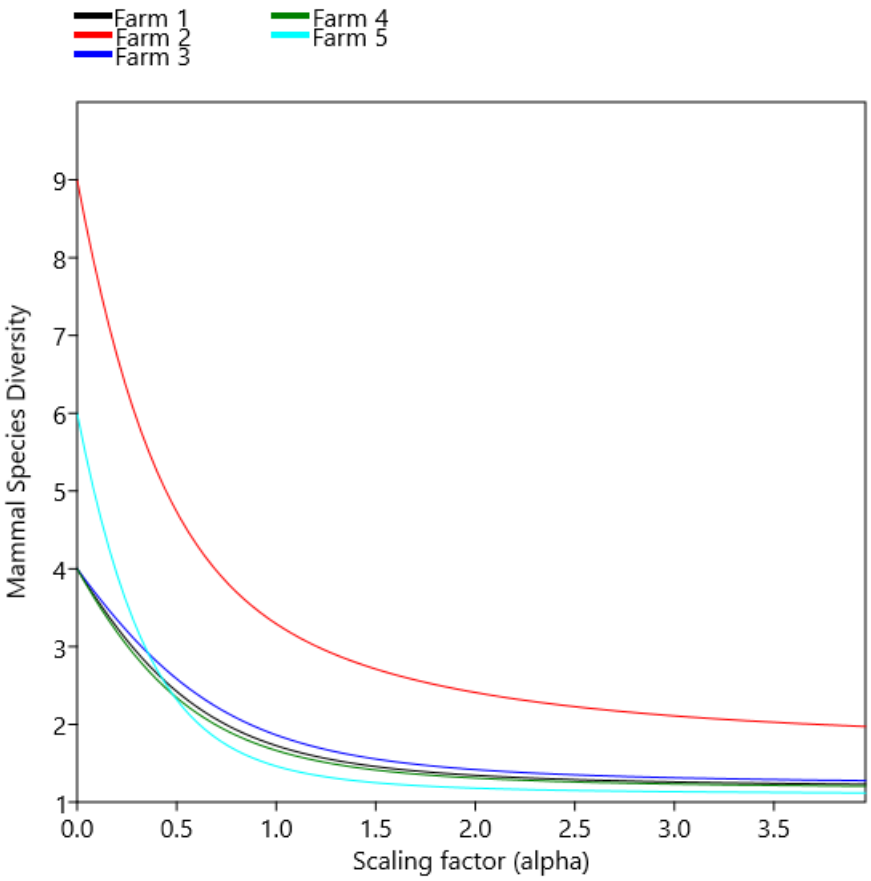


Figure 21. Mammal Species diversity and the effect of dominance of one species.

Species rarefaction curves

Even with camera trapping there are inherent challenges with the study design. Sampling effort was uneven throughout the study period for all the farms and as such, rarefaction curves were produced to compare farm species richness at the minimum number of sample periods which was four months (Figure 22). Farms were ranked from highest richness to lowest species richness (Table 15). At four months of camera trapping under the established number of cameras per farm, all farms recorded 80% of the accumulated species per farm. Farms 1, 3 and 4 had very similar numbers of species albeit differences in species composition.

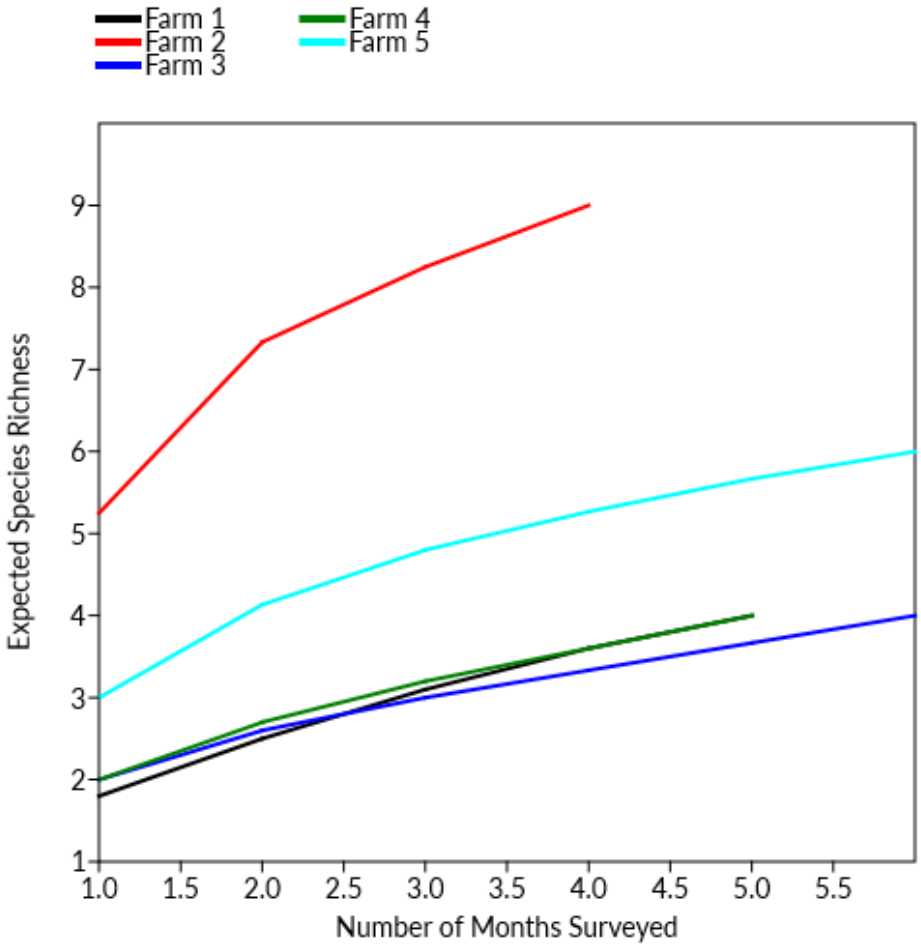


Figure 22. Rarefaction curves showing the comparison of expected number of species at four months of camera surveys.

Table 15. Ranking of Farms based on species accumulation after the minimum number of sampling periods (4 months)

Farm	Species Richness	Rank
Farm 2	9	1
Farm 5	5.2667	2
Farm 1	3.6	3
Farm 4	3.6	3
Farm 3	3.3333	4

Tree monitoring

The 100 *Dalbergia stevensonii* (rosewood) trees in Golden Stream Corridor Preserve were monitored for a total of 151 days between October 2013 and December 2016. Sixty-six of the 100 trees were observed to have flowers or fruit at least once during that time. The total number of trees represented in each size class can be found in Table 16. The proportion of trees observed in reproductive condition increased with increasing size class (see Figure 23).

Table 16. 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

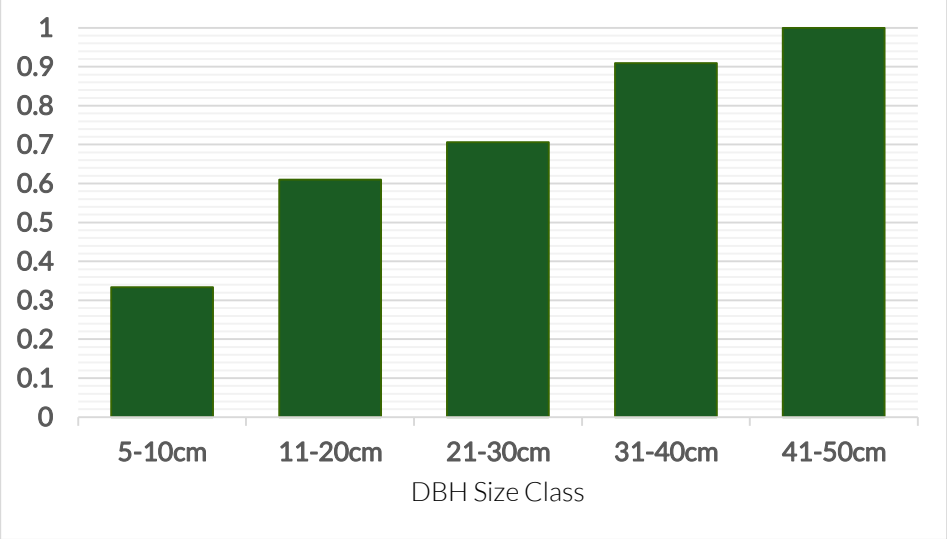


Figure 23. Proportion of *D. stevensonii* in each size class observed to have flower or fruit between October 2013 and December 2016.

Phenology

Since monitoring began in October 2013, *D. stevensonii* leaf loss has been consistent yearly, with most trees shedding their leaves between April and July (Figure 24). Flowering is observed toward the end of the leafless period, between June and August, and coincides with the period when the trees begin regaining leaves. Flowering events for the species are narrow and occur for approximately one month each year between May and July. Fruits are observed after peak flowering, though the period of fruiting is less well-defined. Fruits are first formed in July, with few trees still holding on to mature fruit into the month of December.

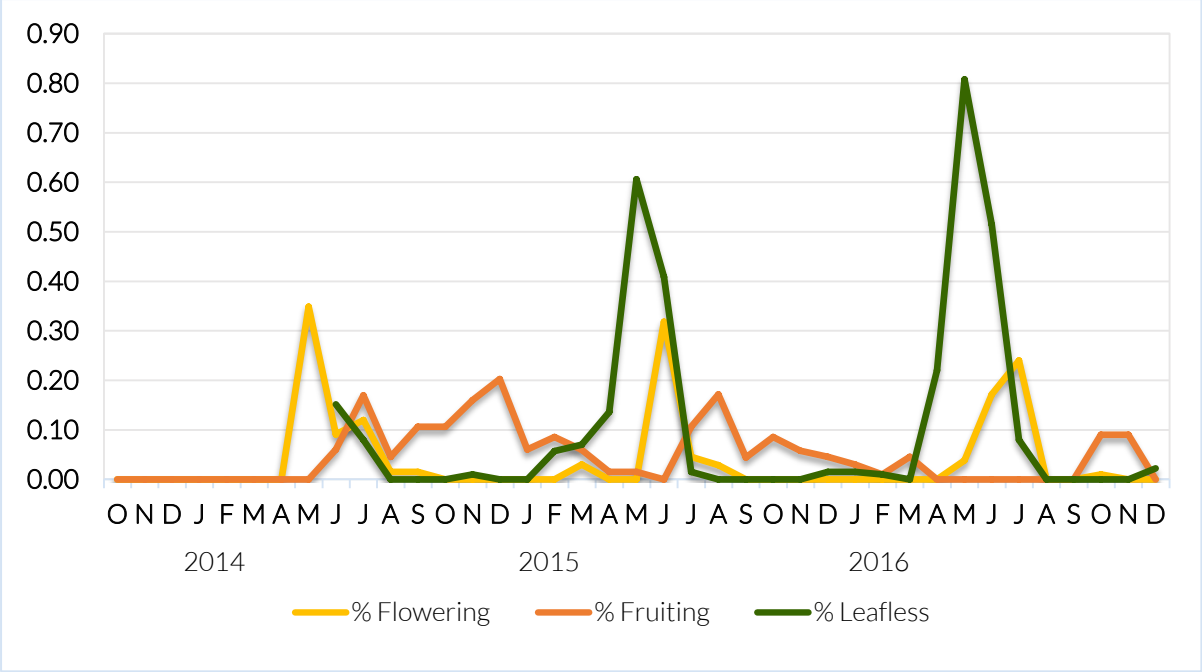
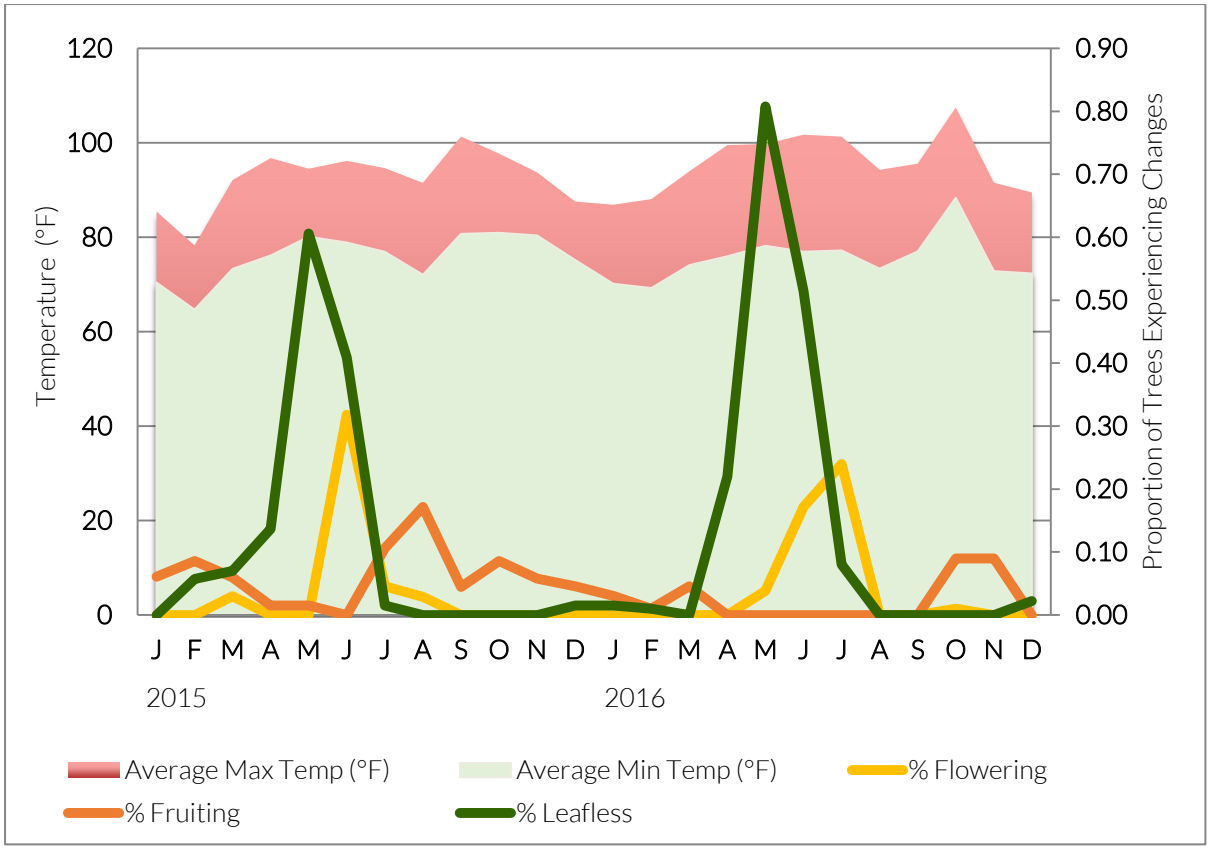


Figure 24. Phenological patterns of *D. stevensonii* in GSCP since October 2013.

Golden Stream Corridor Preserve, and Belize overall, experienced prolonged dry seasons in 2015 and 2016. In both of those years *D. stevensonii* leaf loss corresponded to increasing temperatures in April and May (at the end of the dry season), leading to peak leaf loss in May (Figure 25A). The appearance of rain in June corresponded with sudden leaf regrowth and tightly timed flower production (Figure 25B). Comparing between years, July of 2016 received twice as much rain on average daily than in 2015. In response, trees extended their flowering period through July of 2016. Though it is not unexpected that the trees' phenology is influenced by weather, these graphs stress the tight relationship of *D. stevensonii's* reproductive activity to seasonal patterns, which indicates that changes in weather could impact the species' reproductive success. This is a concern for many tree species facing the threat of climate change, though the effects of changing climate will be more pronounced for species that are characterized by long generation lengths and poor dispersal abilities, as appear to be the case with *D. stevensonii*.

A.



B.

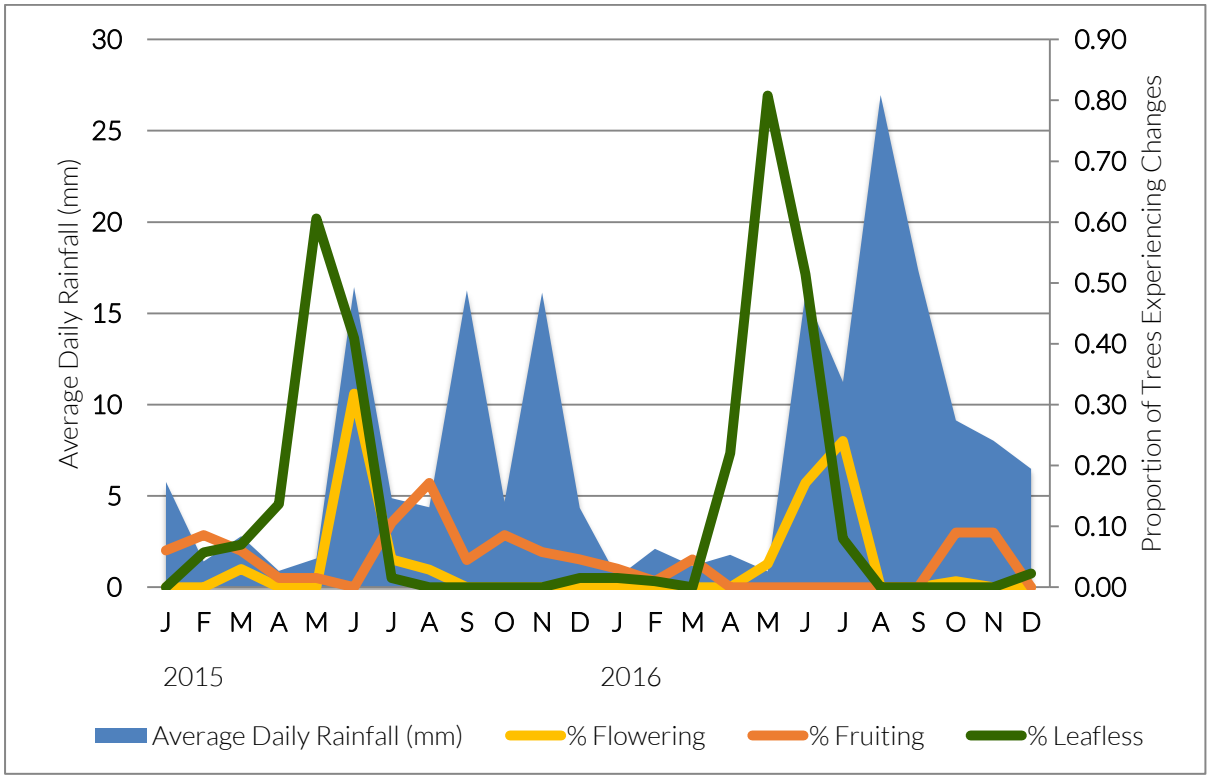


Figure 25 A&B. Phenological patterns of *D. stevensonii* since 2015 in response to temperature (A) and rainfall (B)

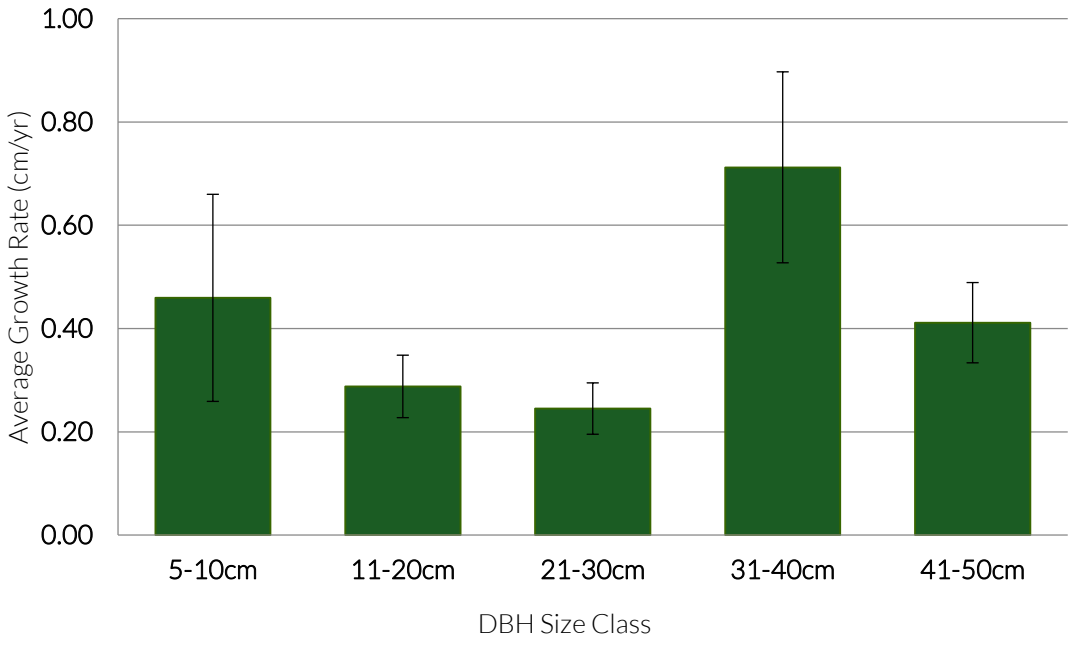
Growth rate

As a species with extremely dense timber, *Dalbergia stevensonii* has been projected to grow at very slow rates. Results from 3 years of growth of the 100 monitored trees in Golden Stream Corridor Preserve confirm this idea. Annual growth rates vary by diameter, but are on average quite slow at 0.32 cm per year. Diameter and height growth appear to be faster in the smallest trees, indicating that young trees invest energy into outcompeting other new saplings for available light (Figure 26 A and B). Diameter growth then tapers off, and the trees maintain a slower state of horizontal growth until reaching approximately 30 cm in diameter. At this point, trees experience a renewed rush of horizontal growth, which is likely the product of the trees securing upper canopy status, which allows for horizontal growth to become the focus again. General trends in tree height show that height increased more slowly with increasing diameter size class. With high standard error, height is a less reliable growth metric than DBH. This is likely influenced by crown dieback, which could also partially explain why trees in the largest size class decreased in height over three years' time.

Based on this preliminary analysis of diameter growth rates per size class, any rosewood sapling with 5cm DBH in year 1 would take roughly 115 years to reach a DBH of 45cm, the minimum cutting diameter (MCD) previously set at the Chiquibul Forest Reserve logging concession. This is consistent with the growth rates of other species of *Dalbergia* and *Pterocarpus*, which commonly take more than 100 years to reach merchantable size (Winfield et al., 2016).

An MCD of 45cm falls within the largest size class (41-50 cm) of trees monitored by Ya'axché. Phenological monitoring has also identified this to be a critical size class for *D. stevensonii* reproductive activity. Between October 2013 and December 2016, 100% of the trees in this class experienced fruiting and flowering. In comparison, only 68% of the trees with diameters between 11 cm-40 cm were found to be in a reproductive state during that time. While the sample size for the largest class is small (n=4), the high proportion of reproductive individuals indicates of the importance of maintaining large seed trees for natural regeneration, especially given that other species in the genus experience high levels of flower and seed abortion in fruit-producing trees (Bawa & Webb, 1984).

A.



B

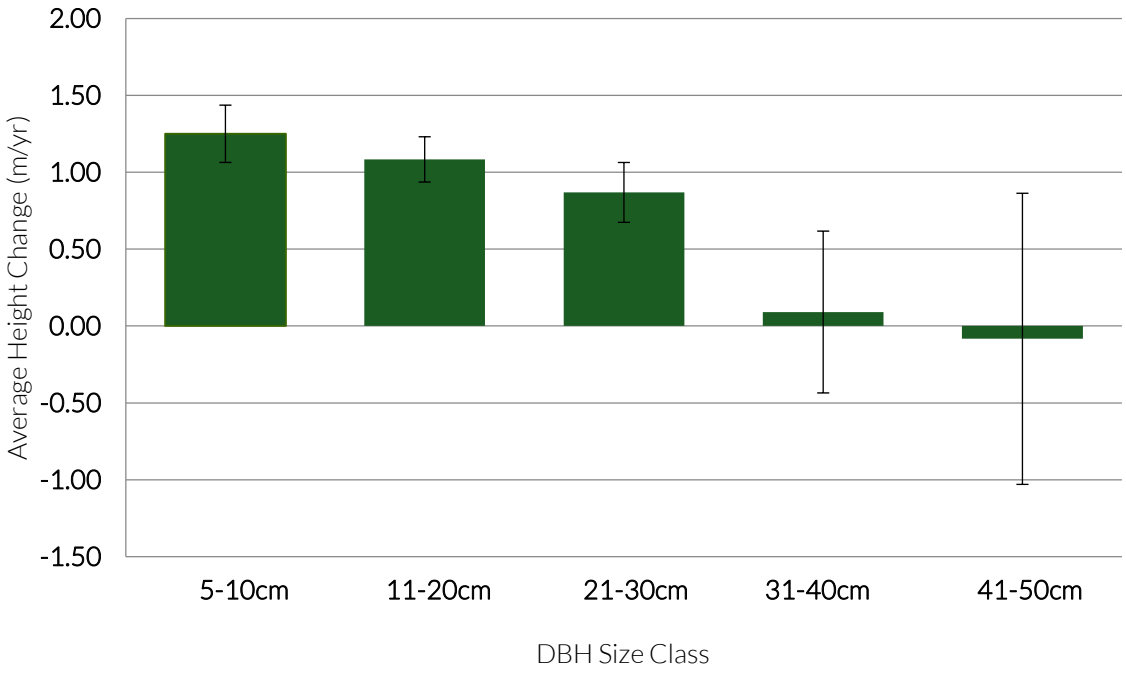


Figure 26 A&B. Average change in diameter (A) and height (B) with standard error over three years for the monitored *D. stevensonii* in GSCP according to their diameter size class.

Weather

Weather data coverage at the Golden Stream site (Figure 27) was consistently high again in 2016. At the Golden Stream field station, 25 days were not recorded, resulting in 93.2% of data coverage for the year. Temperature and humidity at the Bladen site was reported and analyzed for 94.0% of the year.

Coverage for rainfall data is lower at the Bladen ranger base due to errors in data collection and processing. To avoid bias, days in which rainfall data were unreliable were removed from the analysis. Due to very few remaining rainfall data points for the months of May, June, July, and August, no rainfall values are reported. However, coverage from January through April was very high, with consistent and accurate data collection. Only one day was not recorded; therefore, daily averages and monthly totals are reported for these months. From September through December, 9 days were not recorded and 35 days were removed for accuracy, allowing for daily averages to be reported for these months but not monthly totals. For the months analyzed, rainfall data coverage at the Bladen base was 87.7%. Raw weather data for both Golden Stream and Bladen are available upon request.

Total rainfall at the Golden Stream base was higher in 2016 than in the past two years, though the total is not unheard of for Toledo, which is the wettest district in Belize. Belize experienced one hurricane in 2016, which made landfall on August 4th. Earl was a category 1 hurricane that made landfall a few miles south of Belize City. Maximum sustained winds around that the time of landfall were around 80mph. Earl travelled in a west to southwest direction across Belize, causing 3-5 feet of surge near Ladyville and damaging infrastructure along the way. Though no deaths occurred due to the storm, the damage to homes and roads is estimated in the millions of dollars (Gordon, 2017). The arrival of Hurricane Earl in August is captured in the Golden Stream data presented below.

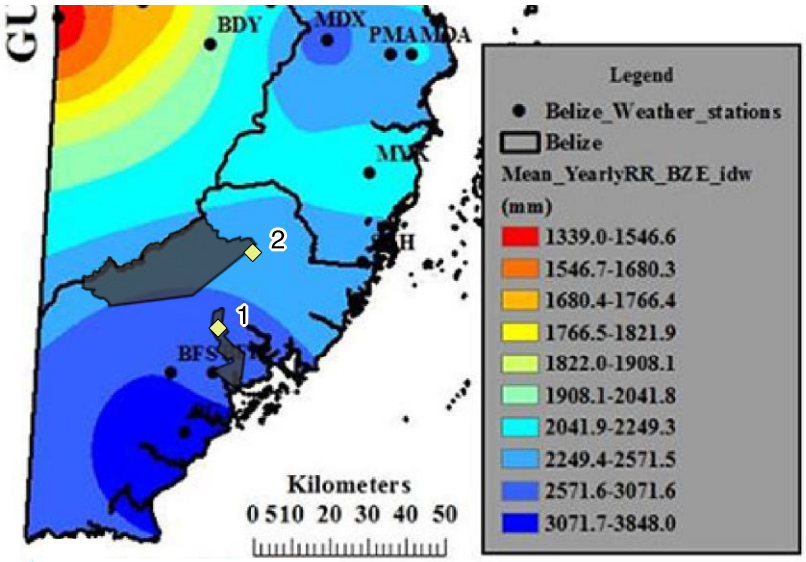


Figure 27. Detail of the mean rainfall map presented in the methodology section with the location of the GSCP and the BNR stations (Figure 5 on page 19)

Golden Stream Corridor Preserve Field Station

Ya'axché rangers recorded a total of 2937.0 mm of annual rainfall at the Golden Stream Corridor Preserve field station. This is consistent with the expected rainfall amount for the reserve according to trends over the past 60 years.

The Golden Stream Corridor Preserve experienced an extended dry season with little rain recorded between January and May (Figure 28A). January was the driest month in Golden Stream, receiving only 8 mm of rain. According to the National Meteorological Service of Belize, the rainy season is expected to begin in mid-May in southern Belize. However, the dry season was prolonged again this year, similar to the El Niño year of 2015, with May receiving comparable amounts of rain (26.0 mm total versus 41.0 mm in 2015).

The onslaught of the rainy season occurred in June, during which time an average of 16.0 mm of rain per day were recorded. This is an average amount of rainfall for the month, according to the National Meteorological Service's predictions for the Toledo District. August was exceptionally wet in 2016, which is likely a product of Hurricane Earl making landfall at the beginning of the month. The total rainfall for August reached an impressive 781.8 mm (nearly 27 mm per day), compared to only 127.0 mm for the entire month in 2015.

October was the hottest month at the Golden Stream site, with average daily temperatures of 107.5 °F and lows of 88.3 °F (Figure 28B). The coolest temperatures for the year were recorded between November and February. Maximum humidity ranged from 79.7%-90.0% and the minimum humidity averaged between 39.7%-53.0%. According to the National Oceanic and Atmospheric Administration (NOAA), the impact of these humidity values on the daily temperature resulted in a heat index at least 3 degrees warmer than the highest average temperatures recorded (NOAA, 2016).

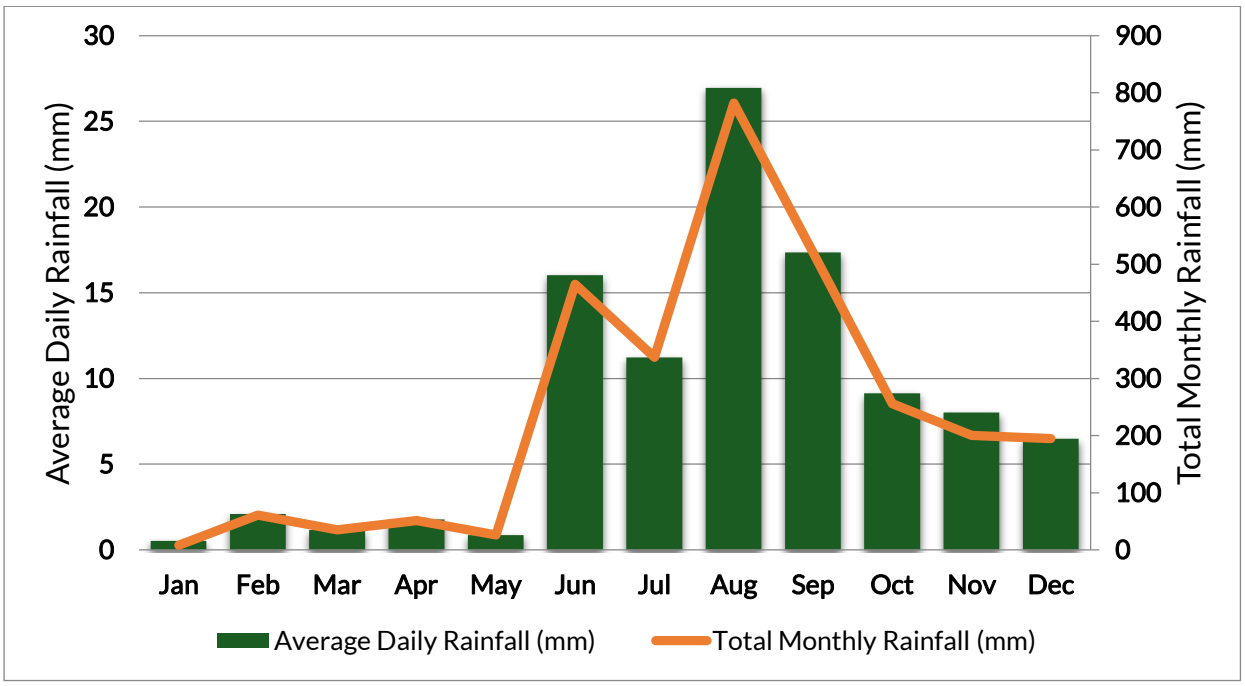
Bladen Nature Reserve Ranger Base

Belize's seasonal climate pattern is still evident in the Bladen station weather data, even though rainfall for the transitional month of June was not captured. The dry season months of January through April each received less than 7 mm of rain per day (Figure 29A), which is similar to 2015 patterns. However, the monthly rainfall total for April was much higher for 2016 than 2015 at 194.0 and 25.0 mm, respectively. Daily rainfall in September and October are consistent with the previous year, but less rain was recorded in November 2016 than 2015 (1.9 mm compared to 16.0 mm).

Daily average temperatures were generally higher in Bladen than in Golden Stream. The months of January as well as the wet season months of May through October averaged daily high temperatures greater than 100 °F (Figure 29B). Temperatures peaked in June, with highs averaging 111.3 °F and lows near 77.4 °F. The lowest minimum average temperature of 66.2 °F was recorded for the month of February. Though temperatures were higher in Bladen than Golden Stream, the averages for maximum and minimum

humidity each month were 9-15% lower at the Bladen station and remained fairly consistent throughout the year. Maximum humidity at the site ranged from 69.1 %to 75.2% and minimum humidity ranged from 30.5% to 43.8%.

A.



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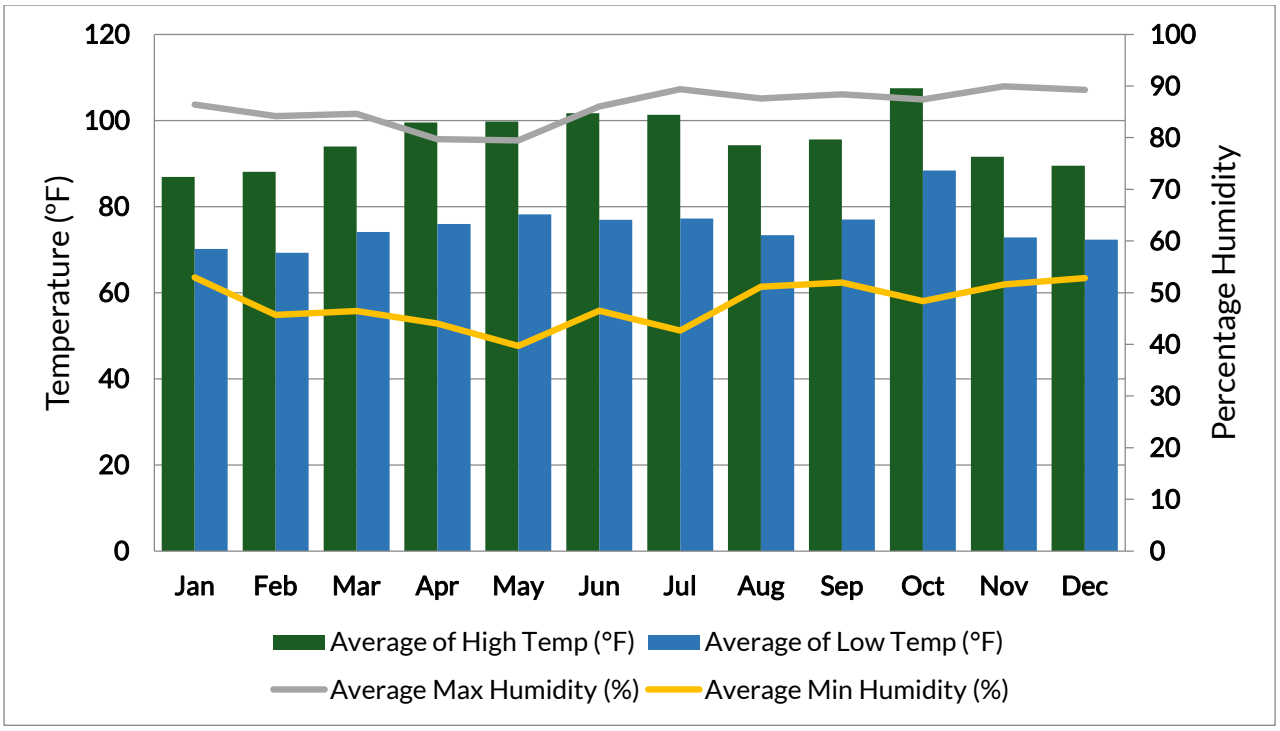
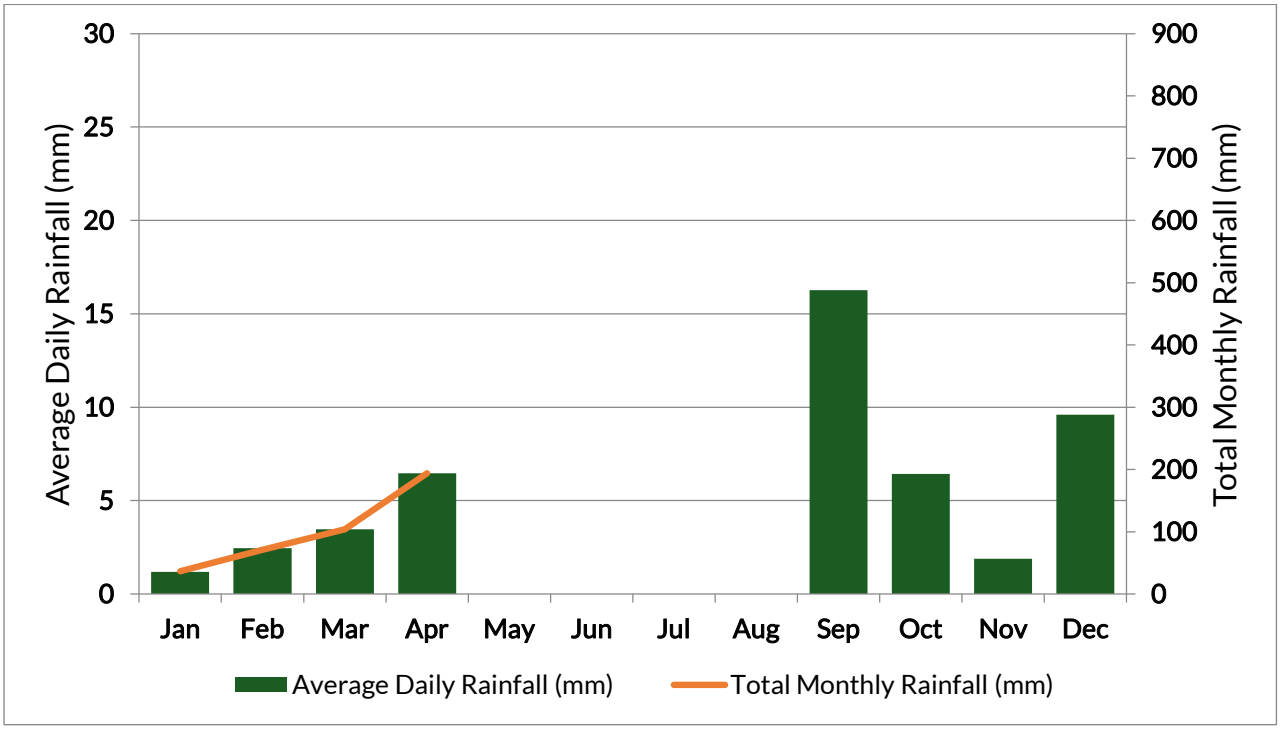


Figure 28. GSCP field station rainfall (A) average daily and (B) total monthly temperature and humidity patterns throughout 2016

A.



B.

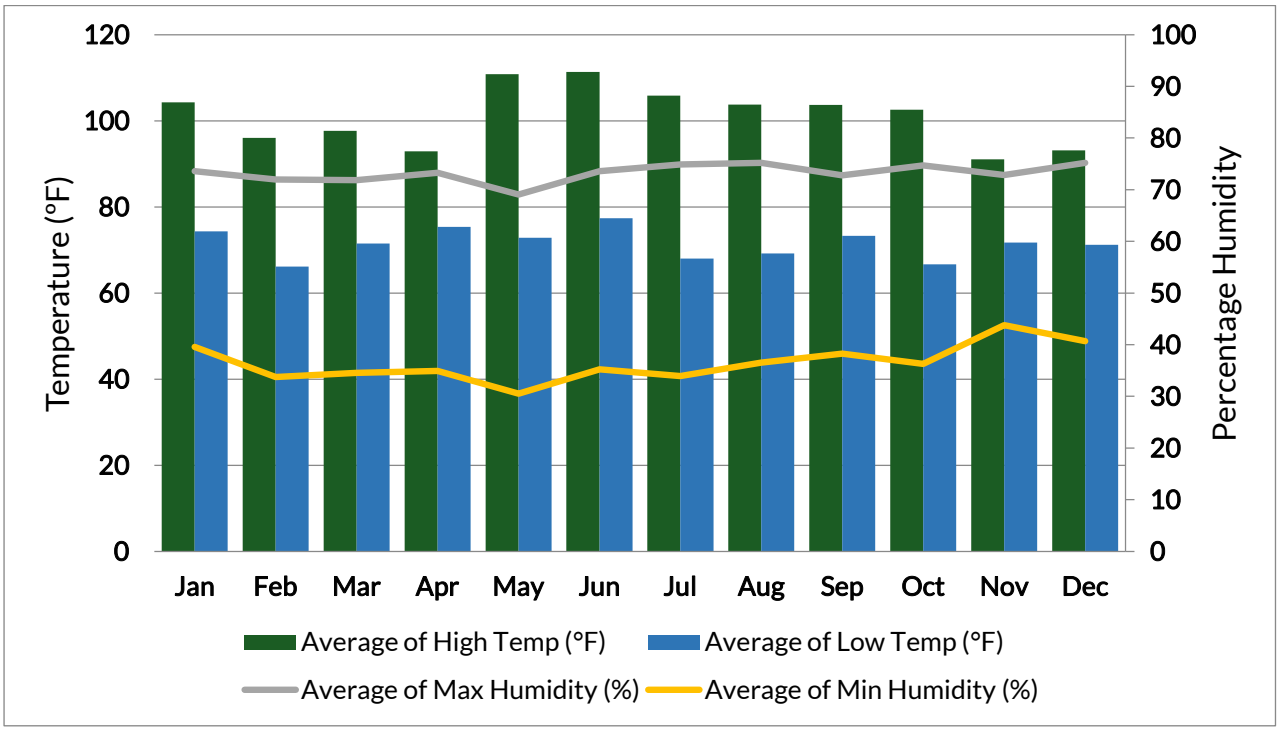


Figure 29. BNR ranger base rainfall (A) average daily and (B) total monthly temperature and humidity patterns throughout 2016

Conclusions

The challenges with data collection were similar to previous years. There was another slight decrease in effort compared to the previous two years but 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. The introduction of farm monitoring into the monitoring program exemplifies our commitment understanding the link between human development and nature. The long term tree phenology monitoring, focused this year on rosewood, has increased our knowledge of one of Belize's most precious and culturally important tree species. Overall, Bladen Nature Reserve provides the highest diversity of species but is 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 MGL, so does the programs it has established. 2016 was a continuation for the restructuring of the science program with establishment of new transects that will be featured in the 2017 report. Much of the information gathered in 2016 has been useful information for the expansion of data collection, particulary where data is deficient. The data and report for 2017 will reflect an increase in monitoring effort. The implications of this will be discussed in detail with a comparison of the 8 years of data that Ya'axché has been collecting since 2010.

Birds – BNR3 recorded the highest number of bird species followed closely by CRFR4. This transect attracts many forest species that have an affinity 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. Overall species richness was relatively high for all forest transects with the lowest being GSCP2. However, this was not the only transect with a lower species richness. IV1 had the second lowest number of species recorded. 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, CRFR1, CRFR3 and CRFR4. These had a more even distribution of relative abundances.

When looking at indicator species, the transect with the most interesting trend was the savannah transect. In previous years it recorded high species richness and in 2016 it topped the list. Of interest was that all but 7 indicator groups were represented in this transect albeit the abundances varied with savannah species dominating in numbers. A large proportion of the species recorded within the village transect were migratory species. The same pattern was observed for GSCP9 and BNR3 two other transects with fairly open habitats. This places great importance in keeping as many green areas within village lands and leaving other open habitats as intact as possible as these areas serve as important migratory habitat. Game birds were completely absent from this transect;

which was expected given the prevalence of hunting within village lands but the one disturbance indicator, the chachalaca was very dominant. CRFR4 recorded all forest health indicators, followed by BNR2, CRFR1, CRFR3. The GSCP transects recorded lower numbers for forest health indicators consistent with the habitat quality in Golden Stream Corridor Preserve.

Overall, the forest transects in BNR and CRFR appear to be in good standing with a high diversity of forest and other indicator target species. The forest transects in Golden Stream Corridor Preserve are consistent with species richness recorded in previous years and are yet to show a marked increase in richness that signals an equally marked healthier forest recovery. The habitat around the village land transect appears is consistently recording increasing numbers indicated by the prevalence of many forest and migratory species, but the composition of species reflects the fact that this transect is within close proximity to converted or distrubed habitat.

Large mammals – BNR3 and CRFR3 recorded the highest species richness for target mammal species. They both exibited minor effect of dominance by nine-banded armadillo and white-lipped peccaries respectively, the latter species is of great importance as an indicator of forest health due to its requirement of large areas of forested land for survival. A heavier pattern of dominance was observed in CRFR2 where white-lipped peccaries were also detected in large herds. The village transect and the GSCP transects did not differ in species richness but the composition did change from transect to transect. Game species like pacas and armadillos 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 with the exception of collared peccaries that were very common in the village transect in 2016. Tapirs were present in all transects except the village transect. 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)

Farm mammal monitoring – The mammal assemblage was relatively good in terms of diversity for farms. Five of the species recorded are indicator species with four identified as game species and one as a forest indicator. The remaining nine species are not currently assigned to any indicator group. The high number of unassigned species is an indication of a potentially higher diversity than expected in these farm areas. While the number of individuals of unassigned species were lower than the game species it is an expected pattern as some of these species have inherently low numbers and large home ranges and the farms form only a fraction of these home ranges. A couple of species such as the Central American Agouti and the Paca were expected in the majority of the farms as was their potential dominance in numbers due to their natural behaviour and distribution (Smythe, 1986; Maher & Burger, 2011). Some of the species captured were

not high on the list of expected captures and is a good sign of connectivity working within the area. This is particularly true for certain forest species such as the Ocelot and the Tayra, which are considered uncommon and more likely to be found within intact broadleaf forests (Reid, 2009). It is likely that there are more species that require more trapping effort in order to be captured on camera or require a modification of the methodology to increase the probability of capture. As mentioned before in the birds section, there is a likelihood that forest fragments are contributing significantly to the number of mammal species that occur in the landscape of the MGL.

Vegetation – Tree Monitoring – The individual *Dalbergia stevensonii* trees monitored provide valuable insight into the ecology of the 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. A higher proportion of the larger size classes were observed flowering and fruiting, which highlights the importance of larger trees as seed producers. Results from 3 years of growth show that annual growth rates vary by diameter class but are on average quite slow. Based on this preliminary analysis, any rosewood sapling with 5cm DBH at year 1 would take roughly 115 years to reach a merchantable DBH of 45cm, the minimum cutting diameter (MCD) previously set at the Chiquibul Forest Reserve logging concession.

Weather – The tropical wet-dry seasonal patterns that Belize experiences were felt strongly in the MGL in 2016. The dry season was prolongued through the end of May and was very intense in Golden Stream. At the Golden Stream ranger base, the rainy season started in June, tapered off, and then peaked in August in response to the landfall of hurricane Earl. Golden Stream received an average amount of precipitation for the site. Temperatures in the MGL were quite warm, especially at the Bladen ranger base, where the months of May, June, July, August, September, October, and January all experienced average daily high temperatures greater than 100 °F. Due to its placement on the edge of a pine savannah, this weather station typically records higher temperatures than the more forested Golden Stream station. However, average maximum temperatures were still lower than they were in 2015,which was an El Niño year.

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 was 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 – Capacity building has to be an ongoing strategy for the for monitoring program to function properly in the longterm. 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.

Farm mammal monitoring – A closer look at abundances is necessary to make better inferences on any direct benefits of cacao agroforestry at sustaining bird and mammal assemblages in an agricultural landscape. While this study provides a first look at the occurrence of species, there needs to be more effort placed on habitat associations and a closer look at all possible variables that contribute to over all species composition. Combining remote sensing with monitoring has proven a valuable asset when assessing wildlife presence and its potential habitat association. We recommend adding ground-truthing to future work and expanding remote sensing analysis to look at connectivity between the protected areas in the Maya Mountains and the coastal lowlands of the Toledo District. The study area provides an important opportunity to study the effects of the changing landscape on both biodiversity and the livelihoods of the people of the MGL. Furthermore, the information in the long term can assist with initiatives that aim at improving the livelihoods of the people while preserving the resources that ensure the sustainability of traditional practices and persistence of a healthy environment.

Vegetation – Monitoring of *Dalbergia stevensonii* over the past three years has increased our knowledge of this economically important species' biology and reproductive ecology. The tree monitoring dataset to date allows for a preliminary analysis of the growth rates of rosewood within GSCP using only two time points. Growth measurements of these trees should continue to be recorded every three years to strengthen the temporal analysis and confirm patterns of growth. In addition, the number of trees in the study should be increased to see if growth patterns vary across the landscape. It is important to both increase the spatial distribution of trees sampled across the MGL and the number of trees in each size class. Importance should be given to adding trees to the smallest and largest size classes, which are underrepresented in GSCP due to difficult nature of confirming species identity of saplings as well as selective prior logging that has nearly eliminated the larger size classes from the Toledo District. Finally, as the species has the ability to regrow from stumps, stumps with sprouts should be identified and a system for taking repeated measurements of sprout height and diameter established. An assessment of re-sprout success from stumps would provide valuable information on the regenerative capacity of the species and help identify the amount of time it takes for the regrowth to form valuable heartwood.

Ya'axché plans to address these recommendations beginning in early 2017 through its partnership with the Global Trees Campaign. Trees and stumps for long-term monitoring and growth research will be established in MMNFR, the southern region of which has preferred rosewood habitat. Monitoring and research will continue through the duration of the project in order to inform policies and actions toward rosewood conservation.

Additional vegetation work will continue in 2017, with the remeasurement of trees within 2 permanent sample plots in BNR. These plots were established in 2012 with the goal of increasing knowledge of vascular plant species diversity across the BNR landscape.

Finally, in 2017, one experimental plot will be established in GSCP in order to study the regenerative capacity of cohune palms in response to selective leaf harvest treatments. The results of this study will be used to inform the sustainable harvest plan for the species in the designated extraction areas of GSCP.

Weather – There are two rainfall gradients thought to exist in BNR. The first rainfall gradient is expected to arise from clouds blown in with the prevailing NE-winds. The clouds hit the Maya Mountains and condense as they move up the Main Divide, causing rain to fall along 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.

In an effort to collect valuable weather data from within the furthest reaches of the Bladen Nature Reserve, automated data loggers should be placed on an increasing

priority list of equipment to acquire. The establishment of additional weather stations across the MGL could benefit implementation of our sustainable agroforestry and other alternative agricultural practices by providing accurate localized weather information for planned development. To increase reliability of manually logged rainfall data at the ranger bases, measurements should be double-checked by a second team member where possible before they are recorded. A training will be held to reinforce methods for collection and recording data.

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