Farmscape Biodiversity Report 2021

An assessment of biodiversity, social, and ecological conditions across the MGL farming landscape

YA'AXCHÉ CONSERVATION TRUST

March 2022

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With special thanks to participating agroforestry citizen scientists of the MGL.

Cover photo. A citizen scientist's son programming a camera trap on their farm, Ya'axché Conservation Trust, 2022.

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Acronyms

BNR	Bladen Nature Reserve
BRIM	Biodiversity, Research, Inventory and Monitoring
BSR	Biodiversity Synthesis Report
COL	Community Outreach and Livelihoods
CRFR	Columbia River Forest Reserve
DBH	Diameter at Breast Height
EC	Electrical Conductivity
GSCP	Golden Stream Corridor Preserve
IUCN	International Union for Conservation of Nature
LULC	Land Use Land Cover
MGL	Maya Golden Landscape
MMM	Maya Mountain Massif
MMMC	Maya Mountain Marine Corridor
MMNFR	Maya Mountain North Forest Reserve
NPAS	National Protected Areas System
NTFPs	Non-timber Forest Products
PAM	Protected Areas Management
PA(s)	Protected Area(s)
SPAR	State of the Protected Area Report
SVAP	Stream Visual Assessment Protocol
Ya'axché	Ya'axché Conservation Trust

Executive Summary

Ya'axché manages the Golden Stream Corridor Preserve (GSCP) and co-manages the Bladen Nature Reserve (BNR) and the Maya Mountain North Forest Reserve (MMNFR) along with the Government of Belize. For the last 23 years, Ya'axché has been actively involved in Protected Areas Management (PAM) and has grown to become one of the leading organizations in Belize promoting sustainable livelihoods, as well as conservation of natural resources. With the growth of the organization came the need for adequate assessments of biodiversity, social, and ecological conditions, particularly in the buffer zones where communities are adjacent to Protected Areas (PAs). This report is the first of its kind at the organization and is intended to provide a summary of the status of multiple target areas relevant to livelihoods and the monitoring and conservation of resources within the farming landscape.

Four (4) Priority Target Areas (PTAs) for research have been selected for this report. These target areas are not absolute and may include other targets of interest in future report iterations. For this report we include: (i) Habitat Connectivity, (ii) Ecosystem Services (iii) Biologically and Socioeconomically Sustainable Land Use, and (iv) Minimizing Negative Impacts to Biodiversity and Livelihoods. All four (4) PTAs were chosen based on its ability to indicate changes in conditions over time and whether there was data available and/or baselines in the process of being established. A combination of data analysis and expert opinion guided the assessment of condition thereafter.

Based on the assessments, Habitat Connectivity is of moderate concern across the farming landscape. While freshwater ecosystems are in good condition with negligible barriers preventing connectivity and movement, broadleaf forests especially around the Southern Highway are increasingly fragmented and predicted to decline even more. While only baseline information exists so far on Ecosystem Services, the available data suggests that soil health and native bee species are in good condition across the landscape. Results of wildlife monitoring on agroforestry farms indicate that Biologically and Socioeconomically Sustainable Land Use is stable and in good condition. Minimizing Negative Impacts to Biodiversity and Livelihoods is assessed as good overall; however, the specific measure of number of active fires per year warrants concern and shows a deteriorating trend.

Moving forward, efforts of the organization should focus on outreach to communities on the responsible use of fire as well as provision of fire equipment and training for its use. Further monitoring needs to be done in freshwater ecosystems to assess water quality and document changes to connectivity. Monitoring of native pollinators, mammalian predators, and prey species should continue to detect trends or changes in species composition or abundance and assess whether interventions are needed. Finally, Ya'axche should continue to build staff capacity to expand soil testing and soil extension support on farms.

Introduction

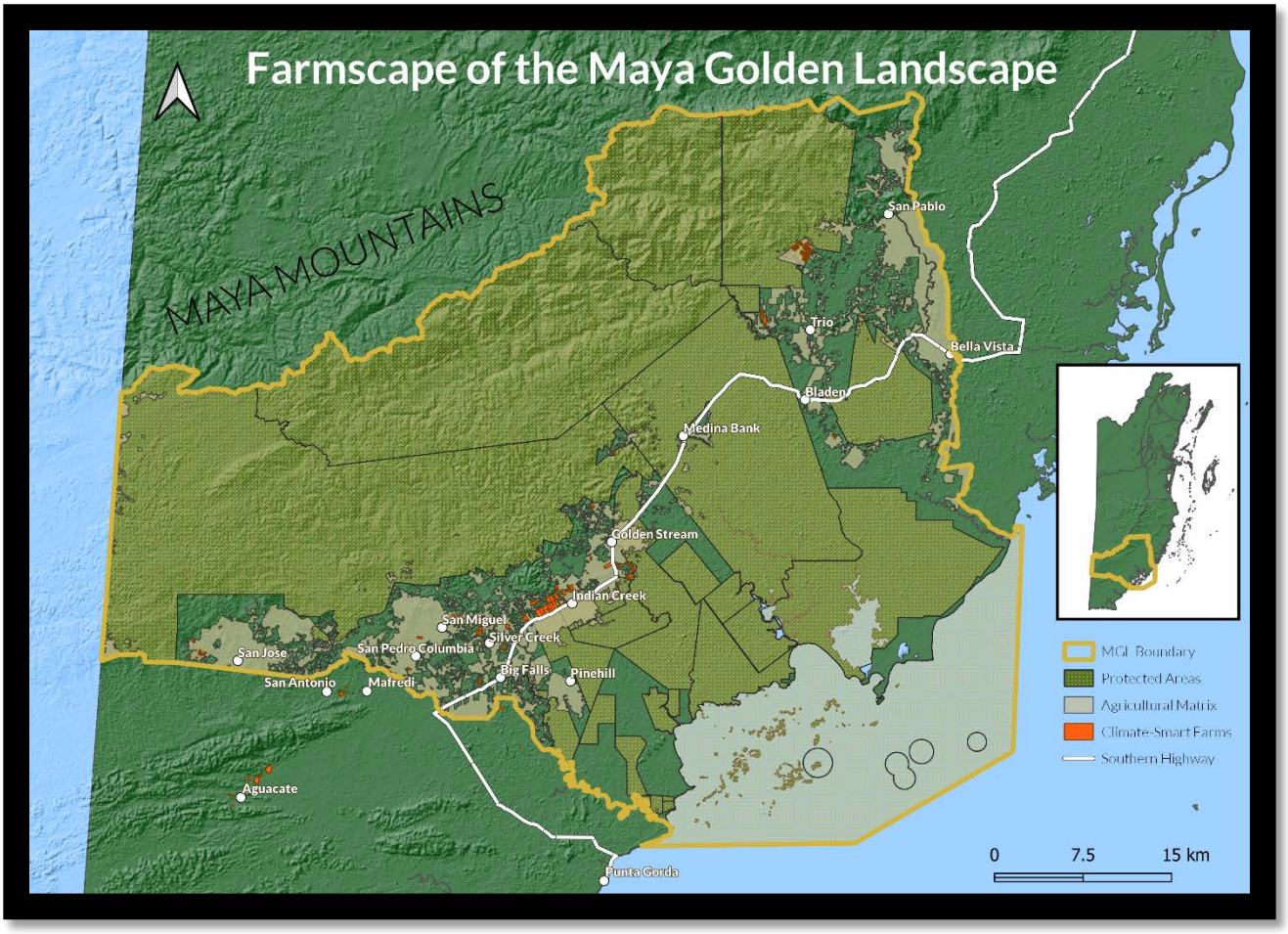


Figure 1. Agricultural areas, including climate-smart farms, within the Maya Golden Landscape of Toledo, Belize.

Ya'axché works within a conceptual area known as the Maya Golden Landscape (MGL) in the Toledo District of Belize (Figure 1). The MGL is a diverse, mosaic landscape comprised of protected areas, private lands, indigenous communal lands, and agriculture lands.

Ya'axché currently manages and co-manages three Protected Areas (PAs) with three distinct reserve designations under Belize's National Protected Areas System (NPAS). These three protected areas are the Golden Stream Corridor Preserve (GSCP), the Bladen Nature Reserve (BNR) and the Maya Mountain North Forest Reserve (MMNFR). The organization implements patrols and monitoring within these reserves to safeguard their resources and biodiversity.

The MGL also has a diverse cultural landscape, with most communities composed of indigenous Q'eqchi' and Mopan Maya families, and others with families of mixed Maya, Creole, Hispanic, or Mennonite descent. All these communities are supported through rural

livelihoods that depend to some degree upon PAs, forests, and forest products. The indigenous Maya communities in particular are traditionally organized around agriculture and other extractive activities (e.g., fishing, hunting, and harvesting of non-timber forest products). Farmers are engaged in subsistence farming and/or small-scale commercial farming and hunting. Ya'axché provides technical support for biologically and socio-economically sustainable forms of agriculture in 10 of these MGL communities: Trio, Bladen, Medina Bank, Golden Stream, Indian Creek, Big Falls, San Miguel, Silver Creek, San Jose, and Aguacate.

When looking at landscapes like the MGL within a global context, trends show that about half of all reserves in the tropics worldwide have experienced an erosion of biodiversity over the last three decades that is often alarmingly widespread across taxa and functional groups (Laurence et al. 2012). Habitat disruption, hunting, and exploitation of forest products are strong predictors of declining reserve health. Critically, environmental changes occurring inside reserves strongly mirror those occurring just outside the reserve boundaries, with changes from outside being nearly as influential on reserve ecological condition as those within. This suggests that tropical PAs have close ecological links to their surrounding habitats, and that a failure to address broad-scale loss and degradation of such habitats could sharply increase the likelihood of serious biodiversity declines (Laurence et al. 2012; Woodroffe & Ginsburg 1998; Hansen & DeFries 2007).

Therefore, it becomes increasingly important to explore the benefits and possibilities of conservation in the working landscape, or *farmscape*, outside of reserves for people and for biodiversity (Kremen & Merenlender 2018).

As such, Ya'axché has taken a holistic, landscape-focused approach to conservation and has established targets for research, inventory, and monitoring of biodiversity, as well as ecological and social factors, within PAs and in the buffering farming landscape.

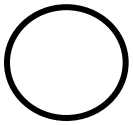
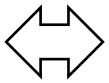
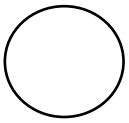
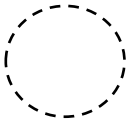
This report highlights Ya'axché's priority conservation and livelihoods research targets within the farmscape of the MGL along with an assessment of their conditions and trends from 2016 to 2021.

This report is complemented by a second, biennial report produced by Ya'axché titled the *State of the Protected Areas Report*. Together, these reports assess the overall conditions of the PAs and the farming landscape to communicate conditions to management partners, donors, other stakeholders, and the public. The reports also provide recommendations for future work particularly in the areas of concern.

This report is organized in a table format for four target areas of research and monitoring activities. An *Information Brief* providing details for specific target areas can be found at the end of select sections.

Evaluating Farmscape Conditions and Trends

In order to standardize the evaluation of conditions and trends across the MGL's farmscape, we use the evaluation key in the table below. The colors represent the condition of the resource, whether that be **significant concern**, **moderate concern,** or **good condition**. Arrows represent the trend in condition such as **improving**, **stable** or **deteriorating**. The confidence of the assessment is represented by bold solid circle for **high confidence**, solid line if **medium confidence** or dotted circle if **low confidence**. If the organization is still gathering baseline data on a particular target or if data is in the form of a one-time inventory, the trend arrows are omitted. This evaluation system is adapted from the United States National Park Service State of the Park reporting format (Fancy & Bennetts, 2012).

Resource Condition		Trend in Condition		Confidence in Assessment	
	Resource is in Good Condition		Condition is Improving		High
	Warrants Moderate Concern		Condition is Stable		Medium
	Warrants Significant Concern		Condition is Deteriorating		Low

Summary of Farmscape Research Targets and their Conditions and Trends

Priority Targets	Condition Status/Trend	Rationale
I. Habitat Connectivity		Ya'axché monitors connectivity in freshwater ecosystems and in broadleaf forest using a combination of field assessments and remote sensing. In 2008, the baseline year of freshwater monitoring, no barriers existed to prevent connectivity between drainages. In 2016, the most recent year that streams were evaluated, all sites continued to be ranked as either "good" or "excellent", reflecting low human impact and little to no barriers to connectivity. This last assessment is now several years old and should be repeated to increase accuracy of the condition and assess if the trend direction has changed. Forest connectivity between protected areas has decreased since 2014 and is of moderate concern. The greatest losses are centered around the Southern Highway. Predictive modeling indicates that mature forest cover in this area could decrease from 49.5% in 2016 to 40.0% by 2026 if trends continue. In comparison, mature forest in the MGL protected areas is predicted to remain near 84%.
II. Ecosystem Services		Pollination and nutrient cycling are two of many important ecosystem services that affect farmer livelihoods. Ya'axche is building its capacity to test soil quality parameters to ensure soil health is maintained in farms across the MGL. Baseline information has also been collected on which species of native bees are found in the MGL farms and surrounding area. At 111 fields across 60 farms and 12 communities, soil nutrient levels (nitrate, calcium, ammonium, and phosphate), bulk density, moisture, electrical conductivity, and pH values fell within acceptable ranges. This indicates that the soil is in good condition at the testing locations and is suitable for the crops being grown. No trends could be determined as the

Priority Targets	Condition Status/Trend	Rationale
		data were collected at a single time point; further studies could be done to evaluate changes in soil condition. Thirty-three (33) native bee species have been documented in cacao agroforestry farms of the MGL in comparison to 52 species found across the entire landscape. These include bees that are rare, endemic, and have value as honey producers. The presence of many ground-nesting species and bees that are susceptible to pesticide use indicate that agroforestry management practices are bee-friendly and that farms can be refuges for native bee fauna.
III. Biologically & Socioeconomically Sustainable Land Use		Point counts and camera traps have been used to document the presence and abundance of birds and mammals, respectively, on agroforestry farms across the MGL since 2016. Across 19 farms, 97 species of birds, mammals, and reptiles have been documented using camera traps. Species of conservation concern include the Baird's tapir, jaguar, jaguarundi, ocelot, margay, and great curassow. 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. The distribution and frequency of detection of wildcats and prey species across the farmlands also reflect healthy forest patches existing with these farms that support the movement of wildlife.
IV. Minimizing Negative Impacts to Biodiversity & Livelihoods		Conservation efforts in agricultural land outside of PAs are crucial to reduce the threats that cross reserve boundaries and support livelihoods. Ya'axche monitors and works to mitigate the effect of fires, the number of jaguar attacks on livestock, and the number of jaguars killed in retaliation.

Priority Targets	Condition Status/Trend	Rationale
		The number of active fires per year is of moderate concern, and trends show this condition is getting worse. The average number of active fires in the MGL per year increased from 109.9 between 2001 and 2010 to 470.6 between 2011 and 2019. Less than half of the fires in 2018 were in the fire-adapted savanna ecosystem. The severity of fires was not assessed. However, threats to jaguars remain low and stable over the last few years. Reports of jaguar attacks on cattle decreased between 2020 and 2021. Similarly, no jaguars were reported as killed due to persecution, though one (1) individual was killed by a road traffic collision in 2020. Wildlife monitoring using camera traps has identified that jaguars are present and are actively using the farming landscape, as least five (5) individual jaguars were detected during the same time period.

I. Habitat Connectivity

Habitat connectivity is critical for maintaining key ecological functions, which include allowing: 1) wide-ranging (terrestrial and aquatic) animals to migrate and meet mates; 2) plants to propagate; 3) genetic interchange; 4) populations to move in response to environmental change; and 5) individuals to recolonize habitats from which populations have been locally extirpated. The aim is thus to create a space for the free passage of animals and seeds to connect valuable biodiversity areas which, if they remain isolated, would otherwise sooner or later disappear.

For aquatic ecosystems, maintaining stream flows and hydrologic connectivity is essential for conserving freshwater biodiversity and water availability. Lack of fresh water limits the production of many natural resources, and water quantity and quality are in turn affected by landscape management. Appropriate management techniques can promote groundwater recharge and stream flow in farming landscapes (Schulte et al. 2017).

The availability and quality of the matrix habitat (including farmlands) between protected areas becomes especially critical in the face of climate change; less than 10% of PAs are expected to represent current climatic conditions within 100 years, increasing the criticality of matrix connectivity to permit species to follow their suitable climates (Loarie et al. 2009).

Within the MGL, a key region between the Golden Stream and Deep River has been unofficially designated as the Southern Biological Corridor of Belize. This area is composed of a mix of public and private protected areas, crown lands, and community lands and generally provides an important forested link for wildlife populations of the Maya Mountains and the coastal plains. The same area has also been designated the Maya Mountain Marine Corridor (MMMC) for its "ridge-to-reef" role in connecting aquatic ecosystems between the Maya Mountains and the Mesoamerican Reef.

Broad research questions:

1) How well connected are broadleaf forests within the MGL and between the MGL and surrounding areas?
2) How well connected are the MGL's protected areas to other protected areas?
3) Is barrier-free longitudinal connectivity of drainages being maintained?

Habitat Connectivity			Overall Condition 
Indicator	**Specific Measures**	**Condition Status/ Trend**	**Rationale**
Connectivity between freshwater ecosystem nodes	Barrier-free longitudinal connectivity among MMMC drainages		Ya'axche began monitoring freshwater quality and stream health in 2008. This effort took place across four (4) watersheds in the MMMC: Monkey River, Deep River, Golden Stream, and the Rio Grande. Stream conditions, including channel condition, barriers to fish movement, and hydrologic alteration, were assessed across the watersheds using a version of the Stream Visual Assessment Protocol (SVAP) (Natural Resources Conservation Service 1998) adapted for Belizean streams (Esselman 2001). This method qualitatively ranks the condition of physical attributes from 1 to 10. The average of these features provides an overall site score ranging from degraded (1) to reference condition (10). Reference condition exists where no human impact occurs. In the baseline year of monitoring, no barriers existed to prevent connectivity between drainages. In 2016, the most recent year that SVAP was conducted, all sites continued to be ranked as either "good" or "excellent" (scoring 7.5-8.9 and >9.0, respectively).
Forest connectivity between PAs	Forest percent cover between PAs of the MGL		As of 2018, over 90% of the MGL was covered by natural vegetation, including savanna, wetland, and early to mid-regeneration forests in fallow (Cayetano 2018; Meerman & Clabaugh 2015). The major land cover class was mature forest—forest not cleared since 1980—making up 76.17% of the MGL. Between 2014 and 2018, Ya'axche has documented a total loss of 5.67% of MGL mature forest. Forest cover and loss are not distributed evenly across the MGL. In 2018, the deforestation rate within the PAs in the MGL was only 0.05%, while

Habitat Connectivity			Overall Condition 
Indicator	**Specific Measures**	**Condition Status/ Trend**	**Rationale**
			the deforestation rate outside of the PAs in the MGL was 1.65% (Cayetano 2018). This loss is focused mainly along the Southern Highway. Predictive modelling by Voight et al. (2019) indicates that while the mature forest cover in PAs will likely remain around 84.0% through 2026, mature forests in zones along the highway will likely decrease from 49.5% in 2016 to 40.0%. This is also predicted to result in changes of spatial distribution of mature forests in that zone, such as increased fragmentation. This prediction is a worst-case scenario that measures loss in mature forests only and does not account for the mitigating effect that agroforestry farming could have in the zone along the highway. The impact of mature forest loss on wildlife in this area needs to be explored further.

II. Ecosystem Services

Cultivated lands make up 7% of Belize's terrestrial area and include row and forage crops, pastures, orchards, rice wetlands, mixed crop and livestock systems, and tree crops and plantations (CIAT 2018). Cultivated lands are often highly simplified ecologically. As a result, they rely extensively on chemical fertilizers and pesticides to replace ecosystem services formerly generated within or around agroecosystems, often creating negative consequences for the environment and human health (Ramankutty et al. 2018). The pursuit of productive lands under these simplified agricultural systems leads to continued large-scale forest conversion in some areas of the biodiverse tropics.

On the other hand, diversified farming systems using agroecological management practices function by promoting biological conditions and ecological interactions that are favorable to crop production (Kremen & Miles 2012; Altieri 1999), reducing the amount of external inputs needed to maintain productivity. Ecosystem services, such as pollination, pest control, and nutrient cycling that underlie production are provided by a suite of diverse organisms, from microbes to mammals. Maintenance of these organisms is necessary for the long-term productivity of working lands.

Ya'axché's Community Outreach and Livelihoods (COL) program promotes multiple methods of farming that incorporate elements of natural ecosystems, such as alley cropping with *Inga* trees, growing cacao under a shade canopy, and cultivating bee gardens for apiaries. Ya'axché is interested in studying how well these methods sustain ecosystem services within farms and the wider landscape.

Broad research questions:

1) Are we maintaining soil and water quality?
2) Which native bee species exist in the MGL?
3) Which native bees are rare, have socioeconomic value, or are indicators of habitat quality?

Ecosystem Services			Overall Condition 
Indicator	**Specific Measures**	**Condition Status/ Trend**	**Rationale**
Baseline data on soil health	pH, EC (g/cm^3), nutrient content (ppm), bulk density (g/cm^3), and moisture (%)		In 2021, Ya'axché conducted soil tests on 111 fields across 60 climate-smart farms of the MGL. This was done to assist farmers with farm planning and management but also to establish baseline data for future studies exploring soil health under different management practices and over time. Various physical and chemical parameters were recorded, including texture, bulk density, moisture, pH, electrical conductivity, and nitrate and other nutrients. Soil test reports were generated for each farmer; these compared test results to the optimal values for the crop and soil type. Most test values fell within satisfactory ranges; only nutrient levels (nitrate, calcium, ammonium, and phosphate) were consistently low. This is not unexpected due to the transient nature of these nutrients, but repeated testing can help determine if low nutrient conditions persist and if interventions are required. Across the MGL, bulk density is suitable for the soil textures present, indicating that compaction is not a major issue. Electrical conductivity is low across the MGL, and the levels are acceptable even for the most salt-sensitive crops. Generally, farmers are growing crops that are appropriate for the pH of their soil; only a few farmers were recommended to apply lime amendments to raise the pH slightly. See the *Soils Information Brief* for more details.
Baseline data on key native bee species	Species richness		Starting in June 2019, Ya'axché has actively captured and documented native bee species across the MGL PAs and farms to create a species list for the area (reported in Dorgay 2021). To date, 52 bee species from 13 tribes have been recorded for the entire landscape. This is roughly 1/3 of the species documented for the country of Belize, as 148 species are currently known nationwide. Across all areas sampled, stingless bees from

Ecosystem Services			Overall Condition 
Indicator	**Specific Measures**	**Condition Status/ Trend**	**Rationale**
			the tribe Meliponini make up the majority of individuals captured. In total, 15 species of meliponines are known across the MGL. Ten of those have socio-economic value as honey producers. Within the farming landscape, bees were collected on five (5) agroforestry farms in the communities of Golden Stream, Indian Creek, Hicattee, Silver Creek, and San Miguel. On these farms, 33 native bee species from 12 tribes were recorded. Twelve of these species belong to the stingless bee tribe Meliponini; one (1) of these is an endemic species (*Tetragona mayarum*) found in Mayan forests. Three more meliponines, *Scaptotrigona pectoralis*, *Melipona beechei*, and *Nannotrigona perilampoides* are especially susceptible to pesticides and can be considered indicators of chemicals in their environment (de Souza Rosa et al. 2015; Roubik 1995; Valdovinos-Nuñez et al. 2003). One (1) bee, *Epicharis lunulata*, is considered rare or uncommon (Michener, 1994). Meliponine bees nest in hollow trees, putting them at risk in areas where deforestation pressure is high. Similarly, five (5) species of Augochlorine and one (1) species of Halictine bee captured nest primarily in the ground and are sensitive to disturbance like tilling and fire, which is often used for farm management. The agroforestry farms sampled in this inventory have high bee richness compared to the overall landscape, showing that these sorts of agricultural practices can be bee friendly. Numbers (N=52) of species (richness) are reported this year; subsequent years of native bee monitoring will establish trends that will be shared in future reports.

Information Brief: Soils of the MGL

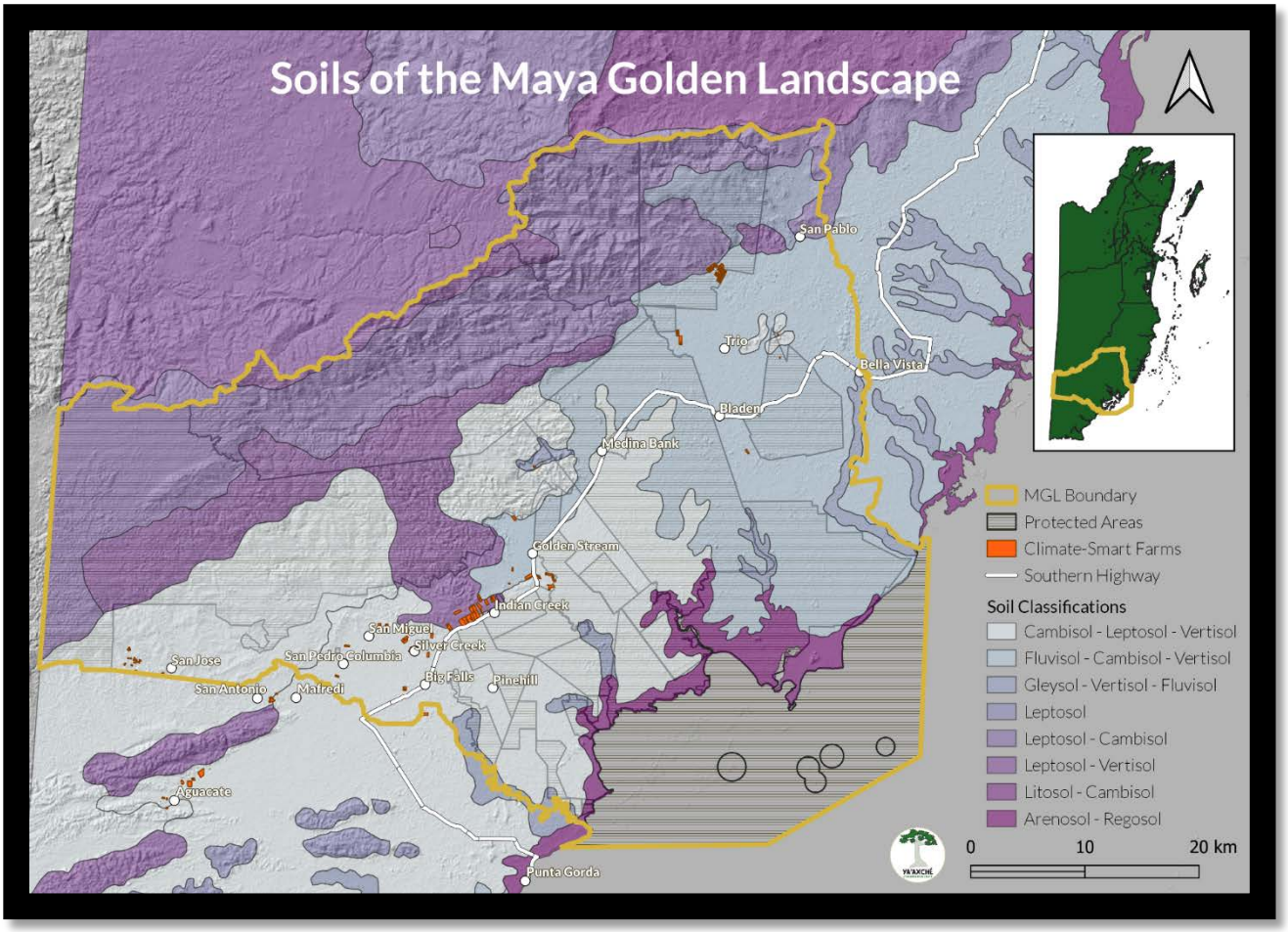


Figure 2. Soil types are variable across 12 communities in the MGL where climate-smart farms are located. Soil dataset from the Selva Maya Consortium (2004).

In 2021, Ya'axché began a year-long effort to create farm maps and profiles for 60 climate-smart farmers in 12 communities, with support from the Inter-American Development Bank project entitled "Enhancing Conservation in Belize Protected Areas Through Disruptive Technologies". During this profiling process, soil tests were also carried out across the 60 farms, with the following goals: 1) to give farmers immediate soil quality results for farm planning purposes, 2) to diagnose possible soil health problems due to land use and management (and therefore identify areas for Ya'axché extension support), and 3) to provide baseline data for future studies that monitor changes in soil quality over time. See Figure 2 for the distribution of climate-smart farms and their underlying soil classes.

MGL Soil Classes

Vertisols are clay-rich soils that shrink and swell with changes in moisture content. They are common in tropical savannas and

rolling hill landscapes. Generally, they are suitable for pasture or crops that can tolerate standing water such as rice.

Cambisols in the humid tropics occur at medium altitudes in hilly regions and in deposition areas. Most have a good structural stability, a high porosity, good water holding capacity and good internal drainage, making them suitable for agriculture.

Leptosols are generally very shallow soils over hard rock or highly calcareous material. They have limited potential for tree crop production or extensive grazing and are best kept under forest.

Fluvisols are recent soils formed through river or marine deposits in periodically flooded areas of alluvial plains, valleys and marshes. Fluvisols can support annual crops, orchards, or pasture but drainage and/or irrigation are normally required.

MGL Soil Texture

Soil texture refers to the distribution of sand, silt, and clay-sized mineral particles in the soil. This is one of the most stable properties of the soil, modified only slightly by cultivation and other practices that cause mixing of the different soil layers. Soil texture is linked to the physical, chemical, and biological components of the soil and influences the types of crops that can be grown.

Most MGL communities have vertisol-based soil, which tend to be rich in clay. Communities between Aguacate and Big Falls are located in a band of soil classified as Cambisol–Leptisol-Vertisol. Bladen, Medina Bank, Golden Stream, and Trio have Fluvisol-Cambisol–Vertisol influence. These soil types converge at Indian Creek community, which has a mixture of all the above, leading it to have the most diverse soil textures of all 12 communities sampled (Figure 3).

Soil Test Results

Electrical conductivity (EC) indicates the amount of salts present in the soil. Salts are essential for plant growth, but high levels can affect soil microbes and restrict plant growth. Salinity increases during droughts and with the application of some fertilizers. Ideal conductivity levels vary by crop, but levels below 0.98 dS/m are acceptable for all crops. Across the MGL farms tested, EC is quite low and is within acceptable range for even the most sensitive crops.

		Electrical Conductivity (dS/m) Across the MGL
AVE	0.20	
STDEV.S	0.16	
MAX	0.91	
MIN	0.01	

Soil pH is a measure of soil acidity, which influences biological activity and the availability of nutrients. Soil pH across the MGL falls within the acidic to neutral range. This is common in the neotropics. In general, MGL farmers are growing the crops that are best suited for the pH of their fields. Coffee and pineapple can tolerate the most acidic soils found in the MGL (pH 4.5-6). Cacao and annatto grow well in pH up to 7.5. Other common MGL crops generally prefer pH between 5-7.

AVE	5.95
STDEV.S	0.65
MAX	7.80
MIN	4.09

pH Across the MGL

Calcium, ammonium, phosphate, and nitrate were consistently low in most fields tested. This is not unusual due to the transient nature of these nutrients, but repeated testing can help determine if low nutrient conditions persist. Notably, calcium was low in all fields except for one garden plot in Medina Bank. Phosphate was high in pastures.

The amount of **nitrate** available to plants depends on farm management activities (e.g., fertilizer input) and on microbial decomposition of organic matter. Available nitrate can fluctuate widely while crops are growing and is influenced by temperature, moisture, the type of organic residue, and pH. Ideal levels of nitrate vary per crop, but generally, between 10-50 ppm is desired.

AVE	1.96
STDEV.S	4.34
MAX	20.00
MIN	0.00

Nitrate (ppm) Across the MGL

Nitrogen in organic matter first must be converted to ammonia or nitrate before it is in a state available for plants. **Ammonium** nitrogen is just as available to plants as nitrate nitrogen, but typically little accumulates in the soil because it is readily

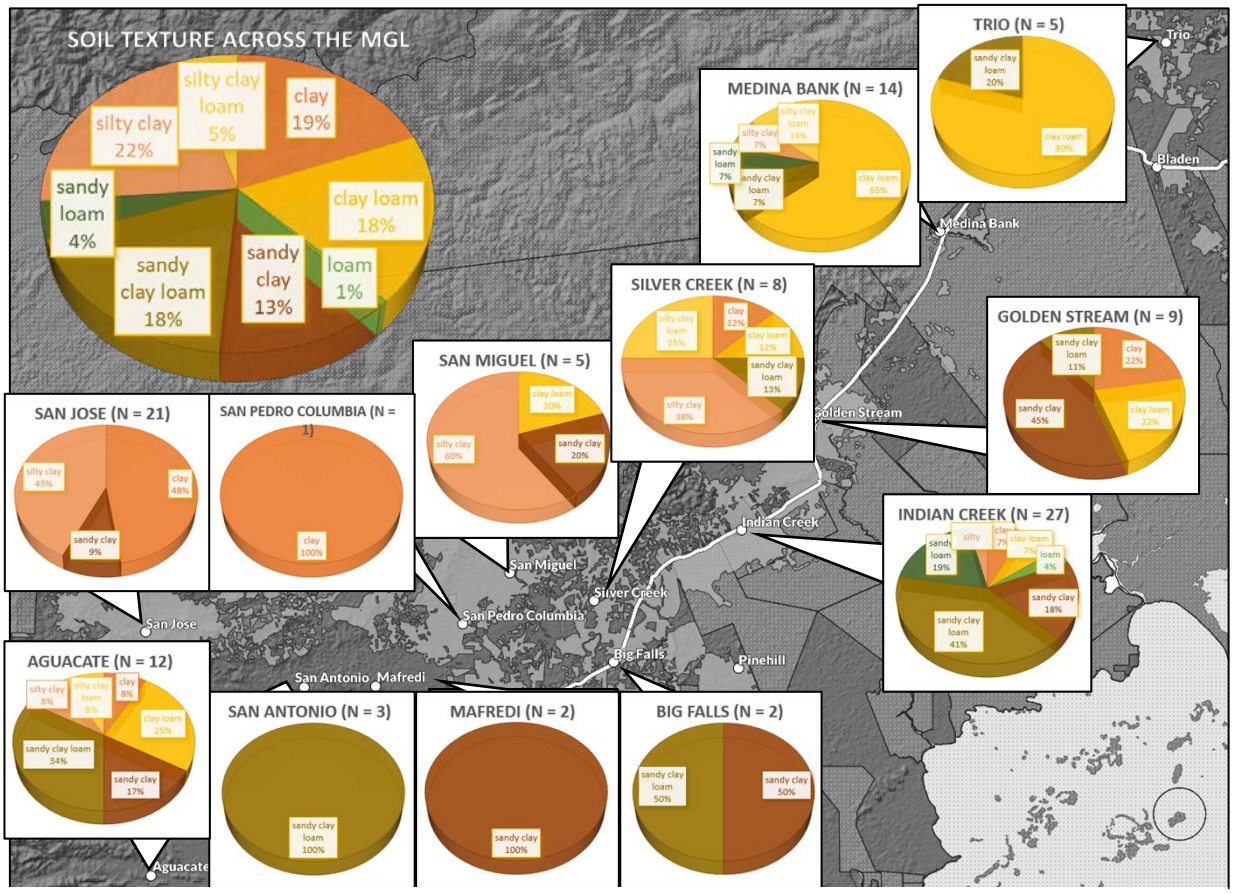


Figure 3. Eight (8) soil textures were classified across 60 MGL farms. The results are shown as a whole and for individual communities. The number of fields sampled per community are indicated in parentheses.

converted to nitrate under most conditions. Values from 0-5 ppm are optimal.

AVE	0.44	Ammonium (ppm) Across the MGL
STDEV.S	0.58	
MAX	3.00	
MIN	0.00	

Calcium is essential for proper functioning of plant cells. Sufficient calcium must be present in actively growing plant parts, especially in fruits and roots. Calcium levels are usually higher in soils with higher pH and higher clay content. Calcium less than 400 ppm is generally considered low, but if the soil pH is maintained in the recommended range for the crop grown, calcium deficiency is very unlikely.

AVE	219.74	Calcium (ppm) Across the MGL
STDEV.S	77.09	
MAX	425.00	
MIN	125.00	

Though phosphorus (phosphate) is not needed in large quantities like nitrogen and potassium, it is vital to growth and is easily depleted. Plants lacking phosphorus are typically stunted, with poor roots and thin stems. Ideal values range between 25-35ppm for most plants.

AVE	7.00	Phosphate (ppm) Across the MGL
STDEV.S	5.96	
MAX	30.00	
MIN	0.00	

Bulk density is a measure of compaction of the soil. It is influenced by soil texture, organic matter, tilling, livestock grazing, cultivation, and weather. The ideal value varies by soil texture, but bulk density values less than 1.4 g/cm^3 are considered acceptable for soils with clay composition. The highest bulk density in the MGL was recorded from a sandy clay field in Mafredi, which had a density of 1.57 g/cm^3. Values above 1.58 g/cm^3 can restrict root growth.

Soil moisture, or volumetric water content, is the amount of water available to plants. It affects biological activity, nutrient cycling, and root growth. It is affected by soil texture and is decreased by compaction. Different crops have different moisture needs depending on their root structure and growth patterns. For example, the ideal range for corn in clay soil is 33-40%.

III. Biologically & Socioeconomically Sustainable Land Use

Farm management actions within the agricultural matrix are important for conserving what biodiversity remains within fragmented landscapes and for buffering the effects of agriculture on nearby forests (Janzen 1983; Perfecto and Vandermeer 1997). Beyond providing resources and habitats for agro-biodiversity, specific techniques such as agroforestry and the use of silvopasture, hedgerows, flower strips, living fences, and riparian buffers may also enhance the connectivity of landscapes and promote the dispersal of various wildlife species (Kremen 2015). These structural features are known to increase the occurrence of a wide variety of organisms within agricultural landscapes, though how they affect the dispersal potential of organisms within diversified agricultural lands is still poorly understood.

Studies in pastoral systems in Nicaragua have shown that species assemblages of birds, bats, dung beetles, and butterflies are different among tree cover types, so that maintaining a diversity of forms of tree cover can lead to conservation of more animal species in the landscape as a whole (Harvey et al. 2006; Harvey et al. 2005). Conservation efforts need to target forms of tree cover that conserve the taxa that are of interest locally. Similar conclusions about the potential importance of tree cover within agricultural landscapes for conservation efforts have been established from other studies in the neotropics (Daily et al. 2001; Ricketts et al. 2001; Estrada et al. 1993; Estrada and Coates-Estrada 2001.)

In 2016, Ya'axche began monitoring biodiversity within the farming matrix surrounding the forested protected areas. This study was focused on 5 cacao agroforestry farms. Cacao, grown under a diverse shade canopy, is a climate-smart form of agriculture promoted by Ya'axche to increase and maintain tree cover in the landscape. The pilot study showed that shaded farms can support many species, even those considered indicators of forest health. The study was expanded in 2020 to include a total of 19 farms. We aim to provide baseline information on species diversity, abundance, and distribution in the working landscape which will allow for future studies into cultural, ecosystem, economic services and resource use.

Broad research questions:

1) How well do shaded cacao farms protect biodiversity, especially rare, endemic, and forest-dependent species?
2) What are the economic benefits to farmers who are practicing climate-smart farming methods?

Biologically & Socioeconomically Sustainable Land Use			Overall Condition 
Indicator	**Specific Measures**	**Condition Status/ Trend**	**Rationale**
Impact of cacao agroforestry on biodiversity	Bird richness		A pilot study by Ya'axche in 2016 (Gutierrez) explored bird and mammal diversity on five (5) agroforestry farms across Golden Stream, Indian Creek, Big Falls, and San Miguel. Each of the farms was visited at dawn and dusk six (6) to 12 times through the rainy season. Rangers recorded bird indicator species by sight and sound based on Ya'axché's Biodiversity Research, Inventory and Monitoring (BRIM) Strategy. 202 bird observations were made during the study, and 15 out of 31 possible indicator species were recorded. Two (2) of the farms shared the highest richness at 12 species. The farm with the lowest richness recorded only eight (8) species. Across all PA biodiversity transects in the same year, 26 indicator species were recorded; 18 in GSCP, 22 in MMNFR and BNR, 20 in CRFR, and only 14 in the village transect. Though the species list is the same, the method used in the transects varies from the method used to record birds in the farms and these comparisons should be made with caution. Species recorded in the farms include the endangered yellow headed parrot (*Amazona oratrix*, IUCN Red List), eight (8) migratory species, and five (5) forest-dependent species. One (1) disturbance indicator, the plain chachalaca (*Ortalis ventula*) was common across farms. This is to be expected, as this species is regularly recorded across all PA transects. No game birds were recorded. This trend is shared with the biodiversity transect located at a traditional farm in Indian Creek; zero (0) game birds have been recorded in that transect between 2010 and 2021. In comparison, the nearby GSCP transects record consistently low numbers of game birds, while MMNFR, BNR, and CRFR commonly observe these

Biologically & Socioeconomically Sustainable Land Use			Overall Condition 
Indicator	**Specific Measures**	**Condition Status/ Trend**	**Rationale**
			species. The absence of game birds is likely due to hunting pressure in community lands. Despite having no game birds recorded on agroforestry farms in 2016, the presence of migratory and forest-dependent species suggests these farms play an important role for transient and resident forest species.
	Mammal richness & abundance		A pilot camera trap study of mammals on five (5) agroforestry farms in the rainy season of 2016 recorded 14 species. The diversity of this mammal assemblage was relatively better than expected. A couple of species such as the Central American agouti and the paca were expected as dominant prey species in the majority of the farms due to their natural behaviour and distribution (Smythe 1986; Maher & Burger 2011). The presence of certain forest species such as the ocelot and the tayra indicates connectivity, as they are considered uncommon and more likely to be found within intact broadleaf forests (Reid 2009). Ya'axche expanded its agroforestry camera grid in 2020 to include 19 farms in nine (9) communities. Camera surveys were executed for three months during the wet and dry seasons respectively in 2020 through 2021. Over the two years, 97 species, which include 26 mammals, 63 birds, 7 reptiles and 1 amphibian were recorded (Chiac 2022). Species of conservation concern include the Baird's tapir, jaguar, jaguarundi, ocelot, margay, and great curassow. Individual farms recorded between 8 and 21 mammal species with an average of 15.5. The distribution and frequency of detection of wildcats and prey species across the farmlands reflect healthy forest patches existing with these farms that support the movement of wildlife. See the following information brief for more details.

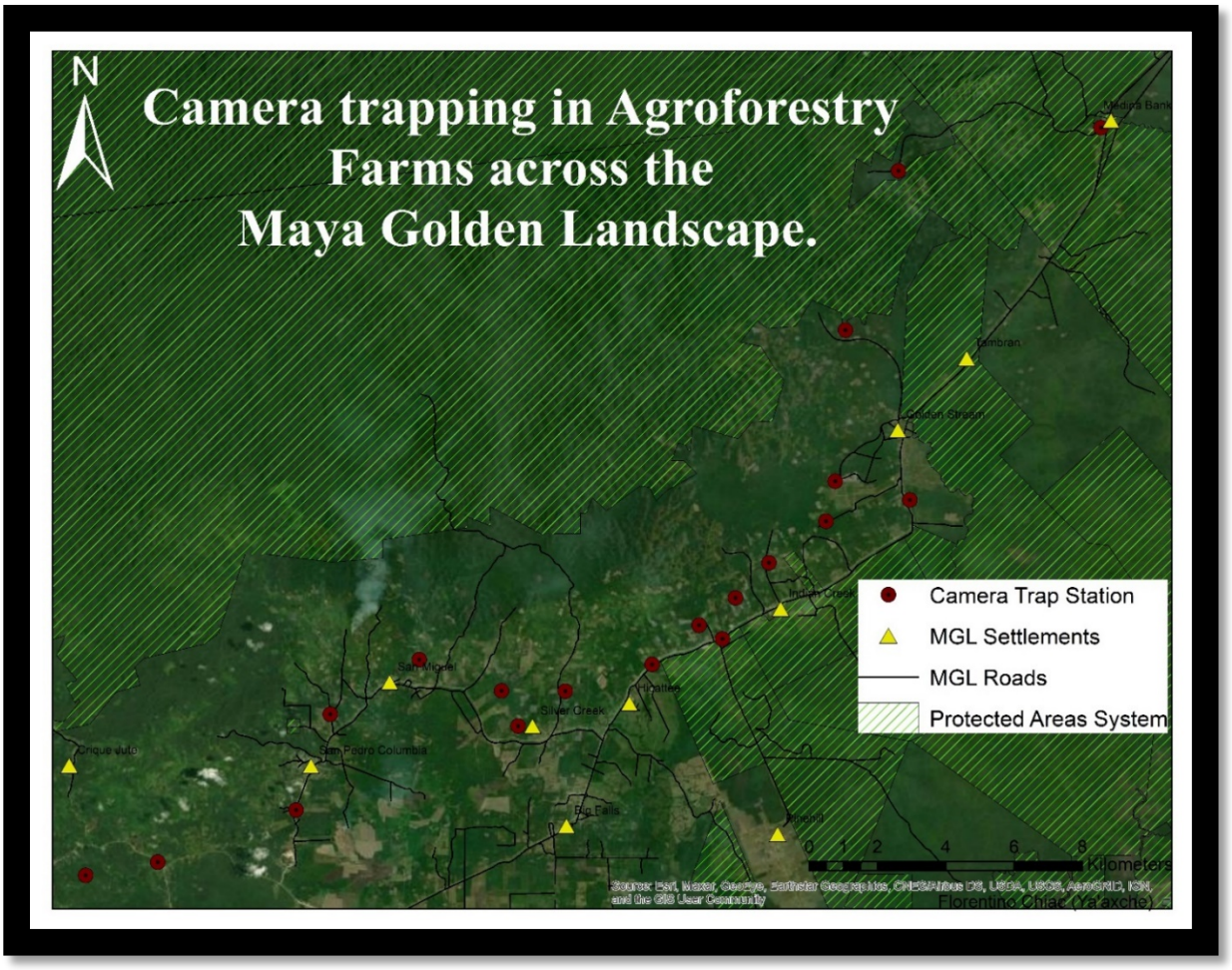


Figure 4. Spatial distribution of camera trap stations in 19 agroforestry farms across the MGL.

Monitoring biodiversity across farmscapes serves a crucial role in understanding the distribution and relative abundance of species, and how human activities have influenced the activity pattern of wildlife. Ya'axché began monitoring biodiversity in the protected areas it comanages, and the monitoring effort subsequently expanded into farmlands. The camera trap survey started in 2016 across five (5) agroforestry farms in four (4) communities of Golden Stream, Indian Creek, Big Falls and San Miguel. In 2020, camera trap monitoring in farmlands expanded to fourteen new agroforestry farms from five new communities of Medina Bank, Silver Creek, Columbia, Mafredi, and San Antonio, which sum up to nineteen agroforestry farms under wildlife monitoring (Figure 4). Farmers were trained in camera trap handling and deployment in an effort to become citizen scientists on their farms in wildlife monitoring. Farmers were intrigued by the capability of the camera trap in capturing wildlife photos without having to be present on their farm and they could see the different wildlife dwelling on their farms. Wildlife monitoring via camera

traps in farmlands help us to better understand the assemblage of species in a fragmented landscape. Data gathered on species richness also show us how these various farming practices support biodiversity and habitat connectivity in the Maya Golden Landscape.

Methods

The 19 chosen agroforestry farms are characteristic of MGL farms; they are adjacent to a mosaic landscape of forest patches, farmlands, and communities. Each farm is approximately 2 km apart from the next and has a plot devoted to climate-smart agriculture practices such as cacao-based agroforestry, inga alley cropping, and beekeeping. A single camera station with a pair of Moultrie camera traps was deployed on each farm. The camera trap surveys were executed for three months during the wet and dry seasons respectively in 2020 through 2021. Ya'axché's science rangers along with the citizen science farmers deployed the cameras, and the rangers conducted monthly camera checks to retrieve the data. The photographic data was then processed and collated, subsequently uploaded into Camelot camera trap database management software for identifying and quantifying individual wildlife. (Hendry & Mann, 2018). Summary effort and summary statistics reports generated by Camelot were utilized for the analysis.

We were also interested in identifying how many individuals based on the captured-recapture method. Photos were individually named based on the camera station and time stamp of the captured photos, subsequently group by right and left flank of the jaguars. Photos were then uploaded to HotSpotter by years to identify individual jaguars based on their unique spots called rosettes on left and right flank. HotSpotter is a pattern recognition software utilize to expedite wildlife identification (Crall et al. 2013); however, manual verification was conducted to ensure it is the same individual based on sex and time stamp of the photos.

Results

In total, the 2020-2021 dry and wet season camera trap survey recorded 97 species of animals, which include 26 mammals, 63 birds, 7 reptiles and 1 amphibian. Domestic animals such as cats, dogs and pigs were not included.

The number of species recorded, number of indicator species, and number of species of conservation concern were relatively stable across seasons. The breakdown of these along with trap effort can be found in Table 1.

The species richness among the agroforestry farms fluctuates across the 9 communities of the MGL. Data indicates that the highest species richness for mammals was found in farm 6 which is in San Pedro Columbia followed by farm 5 in San Miguel and farm 16 in Golden Stream respectively. Other agroforestry farms remain with a steady influx of species which

include species of conservation concerns and are indicators of environmental conditions.

Table 1. 2020-2021 summary effort for camera trap survey, excluding domestic animals.

Summary Effort	2020 Wet Season	2021 Dry Season	2021 Wet Season
Survey Effort/ Trap Days	1,379	1,633	1,462
# of Photos	18,801	13,201	31,366
# of Spp.	73	78	74
Independent Observation	4,196	3,757	7,221
# of Indicator Spp.	21	19	18
Spp. of Conserv. Concern	6	5	5

For carnivores, four (4) wildcats, the jaguar, ocelot, jaguarundi, and margay were detected throughout the camera trap survey seasons. Ocelots had the highest detection rate among the four wildcats; their presence was detected across 17 farms. Jaguarundis had the second highest detection rate at 16 farms followed by jaguars detected across 7 farms and margays detected across 5 farms. The data also indicated that these four wildcats overlapped across both seasons, wet and dry, which continues to denote those predators remain active across farmlands.

Game species detected across the survey seasons were comparable, which includes the Central American agouti, collared peccary, paca, nine-banded armadillo, red brocket deer and white-tailed deer. The Central American agouti had a highest detection rate among the game species and their presence were detected across nineteen (19) camera stations followed by paca and nine-banded armadillo detected across 16 farms respectively. Collared peccary was also detected across 14 farms, followed by white-tailed deer detected across 11 farms and red brocket deer detected across three (3) farms. These key species reflect food availability for top predators and are important protein source for the Mayan communities. The Baird's tapir was also present in seven (7) farms, which is associated with riparian forest health. Additional species recorded in farmlands and not necessarily recorded in protected areas include the greater grison, hispid pocket gopher and long-tailed weasel.

The presence of jaguars was detected across seven (7) farms throughout our monitoring from 2020 to 2021. Individual jaguars were categorized by seasons. The results shows that there were five (5) unique individual jaguars (4 males and 1 female), and their event frequency varies across the farmlands. For the 2020 wet season, two (2) jaguars were detected in two (2) farms: a female called Jane in San Pedro Columbia and a male called Jim in Medina Bank. In the 2021 dry season, three (3) new individuals were detected: a male called Jack on two (2) farms in Indian Creek, another male called Josh on two (2) farms in San Miguel, and a cub called Jr. in San Pedro Columbia. Jr. was photographed along with a recapture of Jane from 2020. As for the 2021 wet seasons, there were two recaptures of Jim from Medina Bank and Jack from Indian Creek. The

distribution of jaguars as top predator along with the abundance of prey base in farmlands relatively denotes intact trophic level in a disturbed landscape.

Discussion

Wildlife monitoring in farm landscapes is not commonly conducted in Belize since many protected areas managers and researchers focuses their monitoring effort in protected areas. Ya'axché pioneered citizen science camera trapping in several agroforestry farms in southern Belize, capturing a wider landscape influenced by human activities. The camera trap survey yielded remarkable findings on high species richness and abundance index of species for both the dry and wet seasons of 2020 and 2021. The majority of the wild cats and prey species overlapped in both seasons, ultimately denoting active wildlife in their spatial-temporal niche. The presence of these various species also has cultural and socio-economic value for Belizeans alongside having ecological role in the ecosystem.

The expansion of the camera trap survey to new farms since 2016 has shown records of new game species such as the red-brocket deer and the great curassow as well as other species like the margay and hispid pocket gopher which hadn't been previously recorded throughout our monitoring effort in the agroforestry landscape of the MGL.

Habitat connectivity is crucial for the survival large predators and supporting viable population of prey base. Consequently, continuous monitoring of these farmlands will assist in further understanding the trends and fluctuation of prey and carnivorous species in the human-influenced landscape. It is therefore imperative for the continuation of work efforts with agroforestry farmers, as their farms support biodiversity conservation while sustaining their livelihoods through food security and income generation.

IV. Minimizing Negative Impacts to Biodiversity & Livelihoods

As with the other priority targets reported above, effectiveness in controlling biodiversity threats, such as invasive species, encroachment, poaching, and other impacts on protected lands also critically depends on the surrounding matrix (Laurence et al. 2012). To slow the loss of biodiversity, we must expand beyond protected areas, using conservation in agricultural land both to reduce the threats that cross reserve boundaries and to create additional habitats for species movement and survival.

Maintaining populations of large carnivores ranks among the greatest of conservation challenges. These area-demanding species require larger territories than most protected areas possess, potentially causing species to undertake costly translocations to ensure gene flow and maintain populations. Further, these species conflict with people in buffering communities through predation on livestock.

In the MGL, jaguars are wide-ranging carnivores that face threats from agricultural expansion. Jaguars are more transient where the landscape is fragmented with settlements and agriculture than in contiguous forests (Foster et al. 2020). In addition, human-induced mortality of jaguars outside the protected forest is mainly associated with livestock predation (Foster 2008). Ya'axché's human-jaguar conflict sub-program was designed to prevent jaguars from attacking cattle, support farmers to maintain their herds and thus their livelihoods, while allowing jaguars to thrive.

A second major threat to MGL biodiversity comes in the form of fire. Anthropogenic fires causing damage to forest cover can be attributed to escaped fires as a result of land clearing and slash-and-burn practices. Anthropogenic fires have variable impacts measured through the intensity, frequency, scale and timing of the disturbance. In forest ecosystems, biodiversity, forest structure, and composition across the landscape are influenced by fire. Landscape alteration such as conversion to agricultural lands, pasture and power line development have all contributed to a loss of local biodiversity due to changes in the fire-adapted ecosystems. Ya'axche advocates for responsible fire use and supports farmers who practice burning with the tools and training to use fire safely.

Broad research questions:

1) Has fire extent and severity remained stable or decreased in the MGL over time?
2) Are jaguars coexisting with farmers in the MGL?

Minimizing Negative Impacts to Biodiversity & Livelihoods			Overall Condition 
Indicator	**Specific Measures**	**Condition Status/ Trend**	**Rationale**
Reduced extent and severity of fire	Number of fires per year		Ya'axche monitors annual fire occurrence using NASA's active fire map (FIRMS: Fire Information for Resource Management System). Between 2001 and 2010, the MGL experienced an average of 109.9 fires per year. Between 2011 and 2019, that average increased to 470.6 per year (Ya'axche Conservation Trust 2019). It is assumed that the majority of the fires that occur in fire-adapted savanna ecosystems are naturally occurring, though there is also a local hunting practice where savannas are intentionally burned to attract deer to the new, post-burn growth. In 2018 and 2019, MGL savanna ecosystems saw 262 and 268 active fires, respectively (Cayetano 2019). These account for only 68% and 40% of the fires that occurred in those years. The remaining fires were either in community farms or other ecosystem types, including broadleaf forest. It is necessary to monitor the presence of fire for subsequent years, including 2020 and 2021, to see if the trend continues.
Reduced occurrences of human-wildlife conflict	Number of jaguar attacks reported in the MGL		Ya'axche received two (2) calls to report jaguar attacks in 2020, and an additional nine (9) calls were made in 2021 from five (5) communities of the MGL. In all cases, an investigation of the site was conducted to document available evidence of the attacks and farm management practices. Site investigation indicates that predation was mainly on calves and dogs and the suspected predator was a jaguar due to paw prints visible at the attack sites. Besides the gathering of information on the attacks, camera traps were deployed to confirm the identity of the predators that attacked. Close communication with the affected residents or farmers was maintained for follow-up.

Minimizing Negative Impacts to Biodiversity & Livelihoods			Overall Condition 
Indicator	**Specific Measures**	**Condition Status/ Trend**	**Rationale**
	Number of jaguars killed in the MGL		There was no report made on persecution of jaguars in 2021; however, in November of 2020, there was a roadkill of a young male jaguar in the vicinity of Deep River Forest Reserve in the Toledo District. In December of 2020, Ya'axche responded to an incident of a young jaguar trapped on a farm from a Mennonite community of Pine Hill. The farmers trapped the young jaguar to avoid another jaguar attack on their livestock. A collaborative effort with the Belize Forest Department and the Belize Zoo has led to the jaguar being sedated and was successfully relocated to the Belize Zoo. Ya'axche will continue to collaborate with the Forest Department to respond to conflict issues across the MGL.

Recommendations

Assessment findings show three of the four farmscape PTAs are in good condition, with Habitat Connectivity being of moderate concern. Based on the available data, freshwater ecosystems are in good condition with negligible barriers preventing connectivity and movement. However, it is recommended to conduct further freshwater monitoring to get up-to-date information on water quality and to document changes in connectivity. Mature broadleaf forests around the Southern Highway are increasingly fragmented and predicted to decline even more. Though loss of mature forest in that area is concerning, the connectivity assessment does not account for the mitigating effect that tree-based forms of agriculture could have for biodiversity.

The assessment of Biologically and Socioeconomically Sustainable Land Use suggests that agroforestry farms are providing resources for wildlife and supporting movement outside of mature forests. Further connectivity assessments should look more closely at the proportion of land cover that is allocated to agroforestry and explore the functional connectivity of the farmscape rather than structural connectivity alone.

While only baseline information exists so far on Ecosystem Services, the available data suggests that soil health and native bee species are in good condition across the landscape. Ya'axche should continue to build staff capacity to expand soil testing and soil extension support on farms. Monitoring of native pollinators should continue to detect trends or changes in species composition or abundance and assess whether interventions are needed.

Minimizing Negative Impacts to Biodiversity and Livelihoods is assessed as good overall, but the increasing number of active fires per year over the last two decades is reason for concern. Moving forward, efforts of the organization should focus on outreach to communities on the responsible use of fire as well as provision of fire equipment and training for its use.

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Farmscape Biodiversity Report 2021

An assessment of biodiversity, social, and ecological conditions across the MGL farming landscape

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