

Land Use/Land Cover change in Toledo and the Maya Golden Landscape

January 2024 to January 2025



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Harmony between nature and human development for the benefit of both



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Maya Golden Landscape
2024

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Acknowledgement

This report serves to document the land use changes over time in the Maya Golden Landscape, to ensure that management interventions are having positive impact on forest regeneration and deterring the degradation of natural standing forests in a protected landscape. We recognize the efforts of Ya'axché's rangers who patrol the protected areas monitoring for illegal activities, assist with mapping and ground truthing of illegal hotspots. We also recognize the efforts of the Community Outreach and Livelihoods team who assist in mapping exercises and on the ground verification of illegal activities.

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List of acronyms

BCEP	Boden Creek Ecological Preserve
BFREE	Belize Foundation for Research and Environmental Education
BNR	Bladen Nature Reserve
CRFR	Columbia River Forest Reserve
FAO	Food and Agriculture Organization of the United Nations
FD	Forest Department
GEE	Google Earth Engine
GIS	Geographic Information System
GSCP	Golden Stream Corridor Preserve
LULC	Land Use/Land Cover
MGL	Maya Golden Landscape
MMNFR	Maya Mountain North Forest Reserve
MSI	Multi-spectral Instrument
NPAS	National Protected Areas System
PPA	Privately Protected Area
PA	Protected Area
UTM	Universal Transverse Mercator
Ya'axché	Ya'axché Conservation Trust

Executive Summary

This report presents the 2024 Land Use and Land Cover (LULC) assessment conducted by Ya'axché Conservation Trust (Ya'axché) within the Toledo District and the Maya Golden Landscape (MGL) of southern Belize. The assessment uses Geographic Information Systems (GIS) and Sentinel-2 satellite imagery to quantify spatial and temporal changes in land cover and land use up to January 2025, supporting evidence-based conservation planning, monitoring, and management.

At the district level, forest remained the dominant land-cover class in Toledo, covering approximately 731,820 acres (69.7%) as of January 2025. Compared to January 2024, this represents a net forest loss of approximately 6,038 acres, corresponding to an estimated annual deforestation rate of 0.82% using the FAO methodology (FAO 1996, Puyravaud 2003). Anthropogenic land uses primarily agriculture; savanna conversion, roads, settlements, and fire scars expanded during the reporting period and collectively accounted for approximately 30% of the district's land area. Agriculture showed the largest increase, expanding approximately 36,667 acres, reflecting continued pressure on forested lands from small-scale farming, cattle ranching, and land conversion at the forest-agriculture frontier.

Within the MGL, forest cover remained proportionally higher than the district average, reflecting the concentration of protected and managed lands. As of January 2025, forest covered approximately 491,528 acres (75.6%) of the MGL. Despite this relative stability, the landscape experienced localized forest loss, primarily along its boundaries and in areas adjacent to agricultural expansion and fire-affected zones. Agriculture and savanna together accounted for approximately 20.6% of the MGL, while anthropogenic land uses remained spatially clustered rather than widespread. Compared to the previous reporting period, the MGL experienced a net forest loss, though at a lower rate than the Toledo District overall, underscoring the buffering role of conservation interventions and land-use planning within the landscape.

Forest cover within Ya'axché-managed Protected Areas (PAs) remained highly stable during the 2024 reporting period. Combined forest cover across the Bladen Nature Reserve (BNR), Boden Creek Ecological Preserve (BCEP), Golden Stream Corridor Preserve (GSCP), and Maya Mountain North Forest Reserve (MMNFR) exceeded 96% of total PA area as of January 2025. The estimated annual deforestation rate within these PAs was approximately 0.35%, significantly lower than rates observed in unprotected areas of Toledo. Forest loss within PAs was minimal and largely associated

with localized disturbances such as fire scars or historical land-use legacies, rather than new permanent agricultural expansion. In contrast, unprotected areas of the district experienced forest loss at a rate nearly four times higher, highlighting the effectiveness of active management, enforcement, and community engagement.

This assessment also documents selected case studies illustrating key land-use dynamics in southern Belize, including agricultural expansion near protected area boundaries, agroforestry practices within community-managed lands, and fire disturbance within the Columbia River Forest Reserve (CRFR). Together, these examples provide insight into emerging risks, areas requiring targeted intervention, and locations where continued monitoring is critical.

Overall, the 2024 LULC assessment confirms that while forest loss continues across the Toledo District, protected and actively managed landscapes within the MGL remain comparatively resilient. The findings reinforce the importance of sustained monitoring, adaptive management, and collaboration with local communities to reduce deforestation, manage fire risk, and maintain ecological connectivity across southern Belize.

Introduction

Ya'axché is a Belizean conservation organization dedicated to the conservation and sustainable use of natural resources in southern Belize. Ya'axché's primary objective is to promote the sustainable management of forest resources and the conservation of biodiversity through collaborative efforts with local communities, government agencies, and other stakeholders.

Ya'axché works primarily within the MGL (Hofman, 2013), an area encompassing approximately 780,200 acres within the Toledo District. The MGL contains twenty-eight known Protected Areas (PAs), of which Ya'axché manages or co-manages four. Together, these PAs cover approximately 165,300 acres, representing about 15% of the Toledo District and 21% of the MGL.

The BNR is the largest nature reserve in Belize and receives the highest level of protection under the National Protected Areas System (NPAS) Act. Encompassing approximately 99,600 acres within the core zone of the Maya Mountain Massif (Grant et al., 2017), BNR benefits from its remote location, which provides a natural barrier against many anthropogenic pressures affecting other protected areas. Ya'axché co-manages the reserve with the Government of Belize, assuming primary responsibility for day-to-day operations. This collaborative management approach supports the long-term conservation of this ecologically significant area.

The BCEP is a Privately Protected Area (PPA) located in the Toledo District. The property has been under private ownership since the 1960s and was historically used for agricultural activities, including citrus cultivation, banana production, and cattle ranching. In the late 1990s, the land was acquired for conservation purposes alongside the adjacent Golden Stream Corridor Preserve and was formally established as the Boden Creek Ecological Preserve around 2007. In 2021, the preserve was acquired by Fauna & Flora in partnership with Ya'axché. Ownership and management were transferred to Ya'axché in 2024. BCEP covers approximately 12,880 acres of predominantly secondary lowland broadleaf forest and, together with GSCP, forms a critical component of the Southern Biological Corridor¹.

The GSCP is also a PPA in the Toledo District and was established in 1998 through collaborative efforts involving Ya'axché, local community members, and national and international conservation partners. The preserve spans approximately 15,070 acres (Lenox et al., 2020) and consists mainly of lowland broadleaf forest. GSCP serves as an important ecological corridor linking the foothills of the Maya Mountains to the coastal lowlands of southern Belize.

The MMNFR is an extractive reserve located in the Toledo District. Historically, the reserve lacked an active management presence until 2015, when Ya'axché assumed co-management responsibilities. MMNFR covers approximately 37,700 acres, much of which is characterized by

¹ The Southern Biological Corridor originally conceptualized in The Belize National Protected Areas System Plan 2005 and subsequently identified in the National Protected Areas System Plan 2015 is an essential forested area in the Toledo district that connects the Maya Mountain Massif to the sea via a mosaic of private lands, private protected areas and forest reserves.

rugged terrain and remains largely forested. The reserve includes a community-based cacao agroforestry concession (Garcia et al., 2014), where Trio Farmers Cacao Growers Ltd. (TFCG) has direct access and is closely monitored by the Belize Forest Department, with technical support and extension services provided by Ya'axché.

GIS and remote sensing methods are widely used to quantify, map, and monitor LULC change over time (Valjarević et al., 2018). Land cover refers to the physical and biological characteristics of the Earth's surface, including natural and artificial features, while land use reflects the human activities and management practices applied to a given land cover type (Alfieri et al., 2011). Changes in LULC are a major driver of biodiversity loss and are primarily associated with anthropogenic disturbances (Falcucci et al., 2007). Although land cover can change gradually through natural processes, human-driven changes are often rapid and abrupt. Globally, the expansion of croplands, pastures, plantations, and urban areas to meet the needs of a growing human population has resulted in increased resource consumption and significant biodiversity loss (Foley et al., 2005).

Goals and Objectives

The goal of this study is to assess land use, land cover, and land use change within the Toledo District and the Maya Golden Landscape for the 2024 reporting period through supervised classification of Sentinel-2 satellite imagery.

The specific objectives of the study are to:

- Detect changes in anthropogenic activities occurring in the Toledo District during 2024
- Map and quantify Land Use/Land Cover classes and changes across the study area
- Identify areas of concern where Ya'axché can provide technical support to communities and farmers to prevent deforestation and forest degradation

Methodology

Study Area

Toledo is the southernmost and least populated district in Belize. The district experiences an average annual maximum temperature of approximately 85° Fahrenheit (30° Celsius) and an average annual minimum temperature of 73° Fahrenheit (23° Celsius). Toledo comprises approximately 1,064,547 acres of terrestrial and inland aquatic ecosystems (Figure 1).

The study area is bounded by latitudes 16°07'48" N to 16°42'00" N and longitudes 88°28'48" W to 89°12'00" W. Within Toledo, the MGL represents the portion of the district where Ya'axché focuses its conservation and community development efforts.

The MGL consists primarily of forest, savanna, mangrove, wetland, agricultural lands, and marine and coastal ecosystems, and includes twenty-four rural communities. The geographic extent of the study area remains consistent with previous Land Use and Land Cover assessments to support comparative analysis over time.

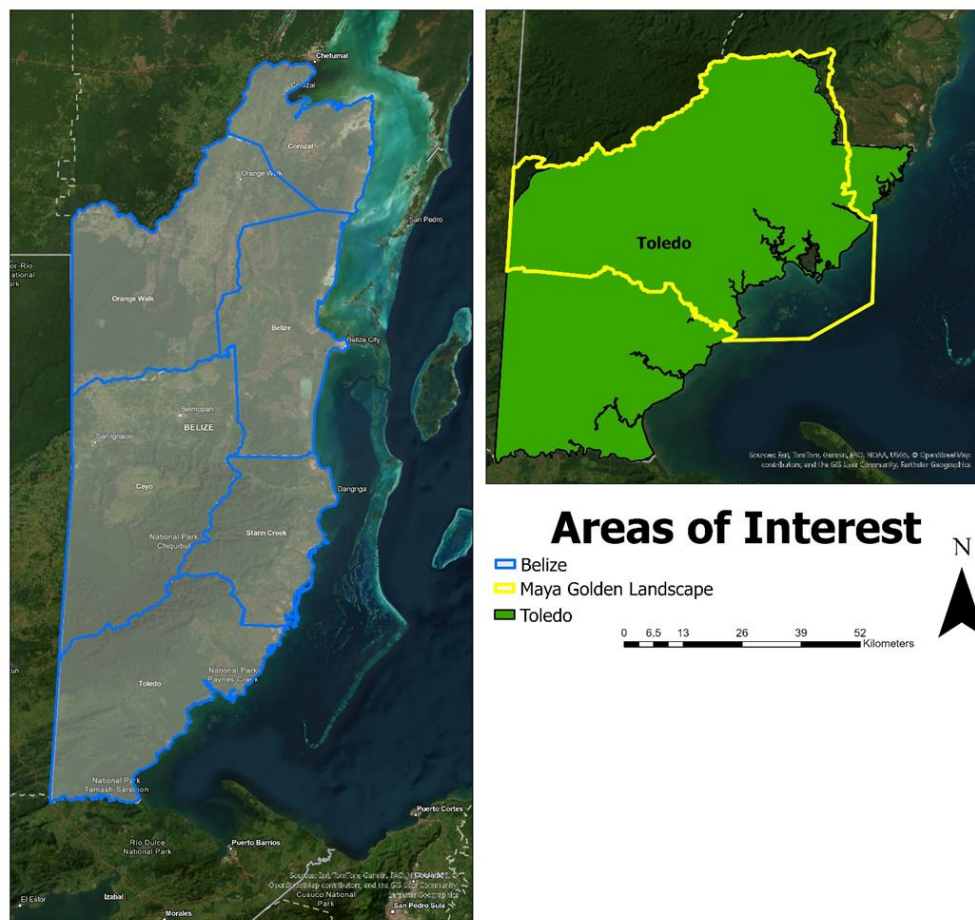


Figure 1. Map of the study area found within Belize.

Data Sources

The primary data source for this analysis was Sentinel-2 MultiSpectral Instrument Level-2A (MSI L2A) imagery, which provides atmospherically corrected surface reflectance data. Imagery acquired between January and April 2024 was accessed through Google Earth Engine and processed using the COPERNICUS/S2_SR_HARMONIZED dataset. Cloud contamination was minimized using the Sentinel-2 Cloud Probability dataset (COPERNICUS/S2_CLOUD_PROBABILITY), applying a cloud probability threshold of less than 30 percent prior to mosaicking. A median composite was generated and clipped to the Toledo District boundary obtained from internal Ya'axché spatial datasets. Sentinel-2 imagery includes 13 spectral bands covering the visible, near-infrared, and short-wave infrared regions of the electromagnetic spectrum, with spatial resolutions of 10 m, 20 m, and 60 m depending on the band.

Remote Sensing Data Collection

Sentinel-2 imagery was accessed and processed using Google Earth Engine (GEE), a cloud-based geospatial analysis platform. Imagery covering the Toledo District was obtained from the European Union's Copernicus Programme for the beginning of the year 2024. This period was selected to reduce seasonal variability and cloud cover while maintaining consistency with previous LULC assessments.

The Sentinel-2 Surface Reflectance Harmonized dataset (COPERNICUS/S2_SR_HARMONIZED) was used in conjunction with the Sentinel-2 Cloud Probability dataset (COPERNICUS/S2_CLOUD_PROBABILITY). Images were filtered spatially to the Toledo District boundary and temporally to the defined study period prior to processing.

Image Processing, Cloud Masking, and Mosaicking

Cloud masking was performed in GEE by linking each Sentinel-2 surface reflectance image with its corresponding cloud probability image using a metadata-based join. Pixels with a cloud probability greater than 30 percent were masked and excluded from analysis. Surface reflectance values were scaled to a range of 0 to 1 prior to compositing. A median composite mosaic was generated from the cloud-masked image collection to produce a single, cloud-reduced Sentinel-2 image representative of the year 2024. The final mosaic was clipped to the Toledo District boundary and exported at 10 m spatial resolution for use in subsequent GIS analysis and LULC classification. This approach ensured consistent spatial coverage across the study area while minimizing cloud interference and radiometric noise. All imagery used for LULC classification was derived from this mosaicked dataset rather than individual image tiles.

Exporting and Masking Images

Prior to image export, the dataset was re-projected from the World Geodetic System 1984 (WGS 1984) UTM Zone 16N to North American Datum 1927 (NAD 1927) UTM Zone 16N (EPSG:26716) to ensure spatial consistency with existing GIS datasets. The twelve spectral bands used in the analysis (Table 1) were loaded as individual raster layers. These bands were subsequently combined to create a composite image using the Image Analysis tools, forming the basis for further GIS processing and LULC classification.

Table 1. Characteristics of Sentinel 2 multi-spectral instrument (MSI).

Name	Resolution(m)	Wavelength (nm)	Description
B1	20	443	Aerosols
B2	10	490	Blue
B3	10	560	Green
B4	10	665	Red
B5	20	740	Red Edge 1
B6	20	783	Red Edge 2
B7	20	842	Red Edga 3
B8	10	842	Near Infrared (NIR)
B8a	20	865	Red Edga 4
B9	60	940	Water Vapor
B11	20	1610	Short-Wave Infrared (SWIR) 1
B12	20	2190	Short-Wave Infrared (SWIR) 2

Collecting Training Samples

Training samples were developed and managed in ArcGIS Pro using the Training Sample Manager toolbar. This tool was used to create, edit, merge, and evaluate training samples for each LULC class prior to supervised classification. Training samples were generated by manually digitizing polygon features directly over the cloud-free Sentinel-2 composite imagery to ensure accurate representation of spectral variability within each class.

The development of training samples involved an iterative process of testing, evaluation, and refinement. Initial classification outputs revealed high levels of noise and class confusion in several areas, particularly along class boundaries and within heterogeneous landscapes. These early results informed subsequent adjustments to both the number and spatial distribution of training samples.

Editing class

To improve class separability during supervised classification, several LULC classes were initially subdivided into more detailed subclasses during the training phase. This approach allowed the Random Forest classifier to better capture spectral variability associated with different land use practices and surface conditions. Following classification, selected subclasses were merged to produce a simplified final LULC map suitable for landscape-level analysis and reporting.

Agricultural land was initially classified into cropland, milpa farming, and cattle farming to account for differences in vegetation structure and land management. These subclasses were subsequently merged into a single Agriculture class in the final LULC output. Similarly, settlement areas were classified only as Residential and Roads, and mangrove land cover was not included as a separate class due to its limited extent within the study area and overlap with other coastal land cover types. The final LULC map, therefore, consists of eight primary classes: Agriculture, Forest, Savanna, Wetland, Water Bodies, Residential, Roads, and Fire Scars

Table 2. Classes and subclasses used in our Random Trees LULC classification and their descriptions.

Final Class	Subclass (Training Phase)	Description
Agriculture	Cropland	Actively cultivated land used for crop production with identifiable planting patterns.
Agriculture	Milpa Farm	Shifting cultivation areas characterized by mixed crops, fallow stages, and variable canopy cover.
Agriculture	Cattle Farm	Pastureland dominated by grasses and low vegetation used for livestock grazing.
Forest	—	Land dominated by trees with continuous or near-continuous canopy cover.
Savanna	—	Naturally occurring grassland with scattered trees and shrubs.
Residential	—	Areas dominated by individual housing structures and associated cleared spaces.
Roads	—	Paved or cleared transportation corridors, including highways and secondary roads.
Wetland	—	Areas characterized by saturated soils and hydrophytic vegetation, including seasonally flooded zones.
Water Bodies	—	Inland and coastal water features such as rivers, streams, lakes, and marine waters.
Fire Scars	—	Areas of recently burned vegetation identifiable by darkened surfaces and reduced vegetation cover.

Classification

We used the Random Trees classifier, based on the Random Forest Algorithm (**Figure 2**) as our supervised classification method. Our classification was pixel based. The Random Trees Classification was executed on the **Image Classification** toolbar by clicking **Classification > Random**

Trees Classification. We used a maximum number of trees of 100 and a maximum tree depth of 30.

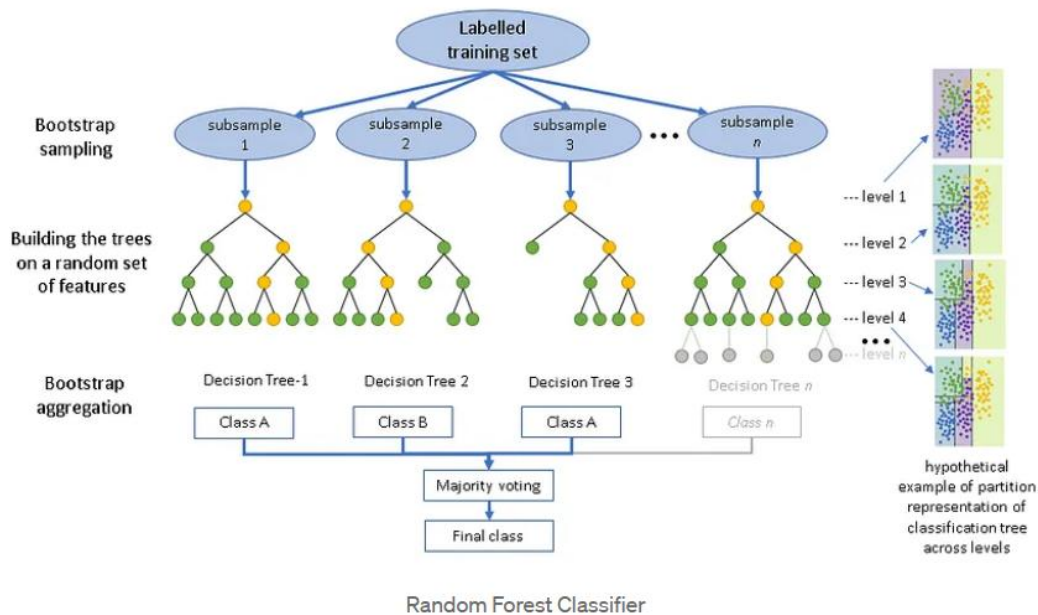


Figure 2. Random Forest Algorithm.

Generating Statistics from Classification

Once the LULC classification was created, the color-coded classified image was converted to a polygon layer using the Raster to Polygon tool. The area covered by each class was obtained using the Summary Statistics tool. For specific sections of the districts, the classification was clipped to the desired boundaries before running Summary Statistics.

Rate of Deforestation

To analyze Deforestation, the annual rate of change is calculated by comparing the area under forest cover at two contrasting times (FAO, 1996; Puyravaud, 2003). According to the methodology, the annual rate of forest change is derived from the compound interest formula which is as follows:

annual rate of deforestation:

$$r = (1/(t_2 - t_1)) \times \ln(a_2/a_1)$$

Where r is the annual rate of change, a_1 and a_2 are the forest cover estimates at time t_1 and t_2 , respectively.

Accuracy Assessment

An accuracy assessment was conducted to evaluate the reliability of the LULC classification produced for the 2024 reporting period. A stratified sample-based approach was applied using training data developed during the supervised classification process in ArcGIS Pro.

Training samples were divided into two subsets: approximately 80% of the samples for each LULC class were used to train the Random Forest classifier, while the remaining 20% were withheld for validation purposes. The validation samples were not used during model training and served as independent reference data for accuracy evaluation. The withheld validation samples were compared against the classified LULC map using the Accuracy Assessment tools in ArcGIS Pro, which generated a confusion matrix and associated accuracy statistics, including overall accuracy and Cohen's Kappa coefficient. Cohen's Kappa was used to assess the level of agreement between the classified output and reference samples while accounting for agreement occurring by chance.

The results indicate a high level of internal classification reliability, with strong agreement between reference samples and mapped LULC classes. Some misclassification was observed in transitional areas between forest, agriculture, and savanna, which is expected in heterogeneous landscapes. To address this, targeted pixel-level editing was applied where necessary to reduce classification noise and improve thematic consistency.

Change in Land-Use from 2023 to 2024 in Toledo District, Belize

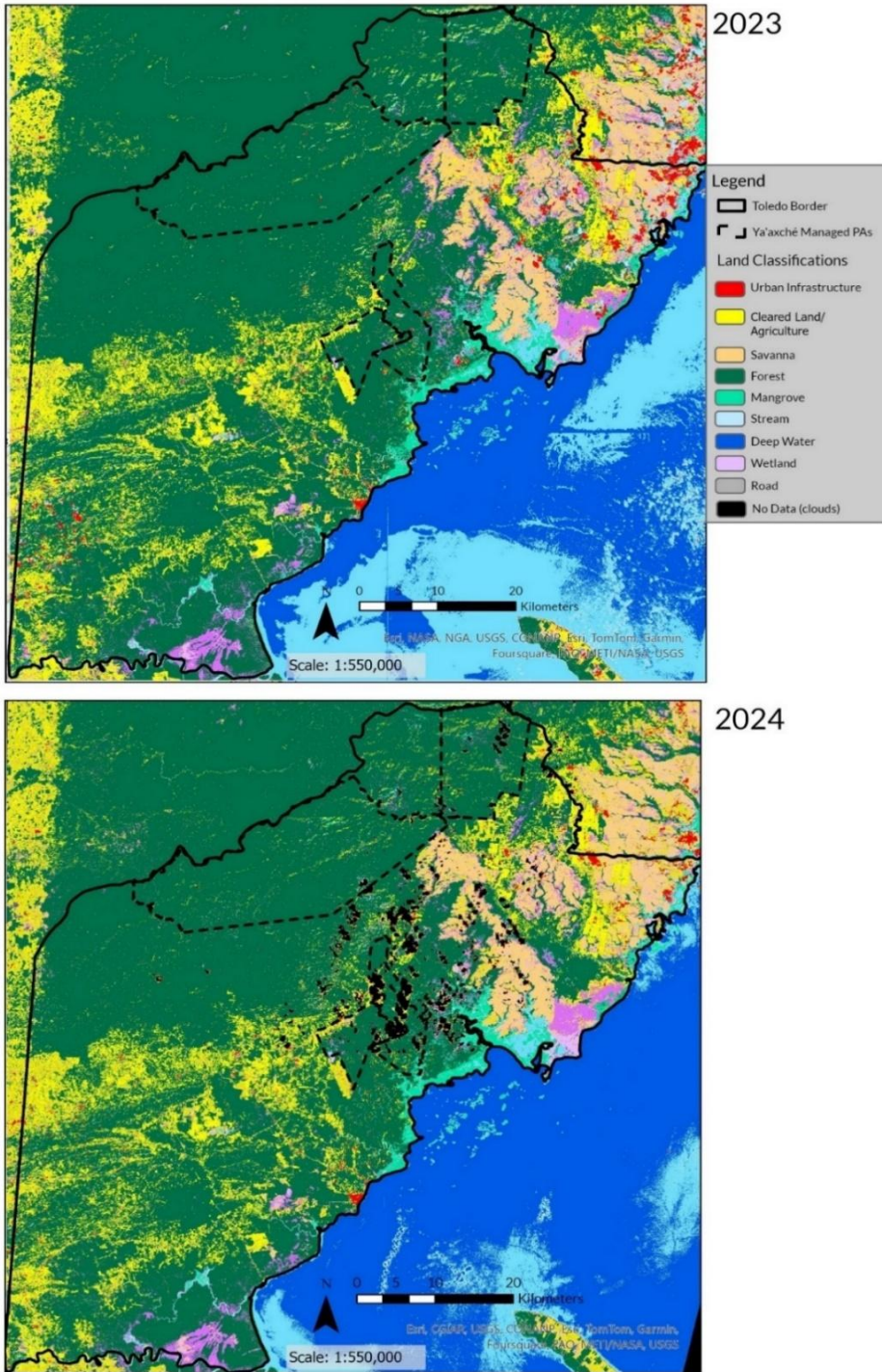


Figure 3A. LULC classification for the Toledo District for the years 2023 and 2024.

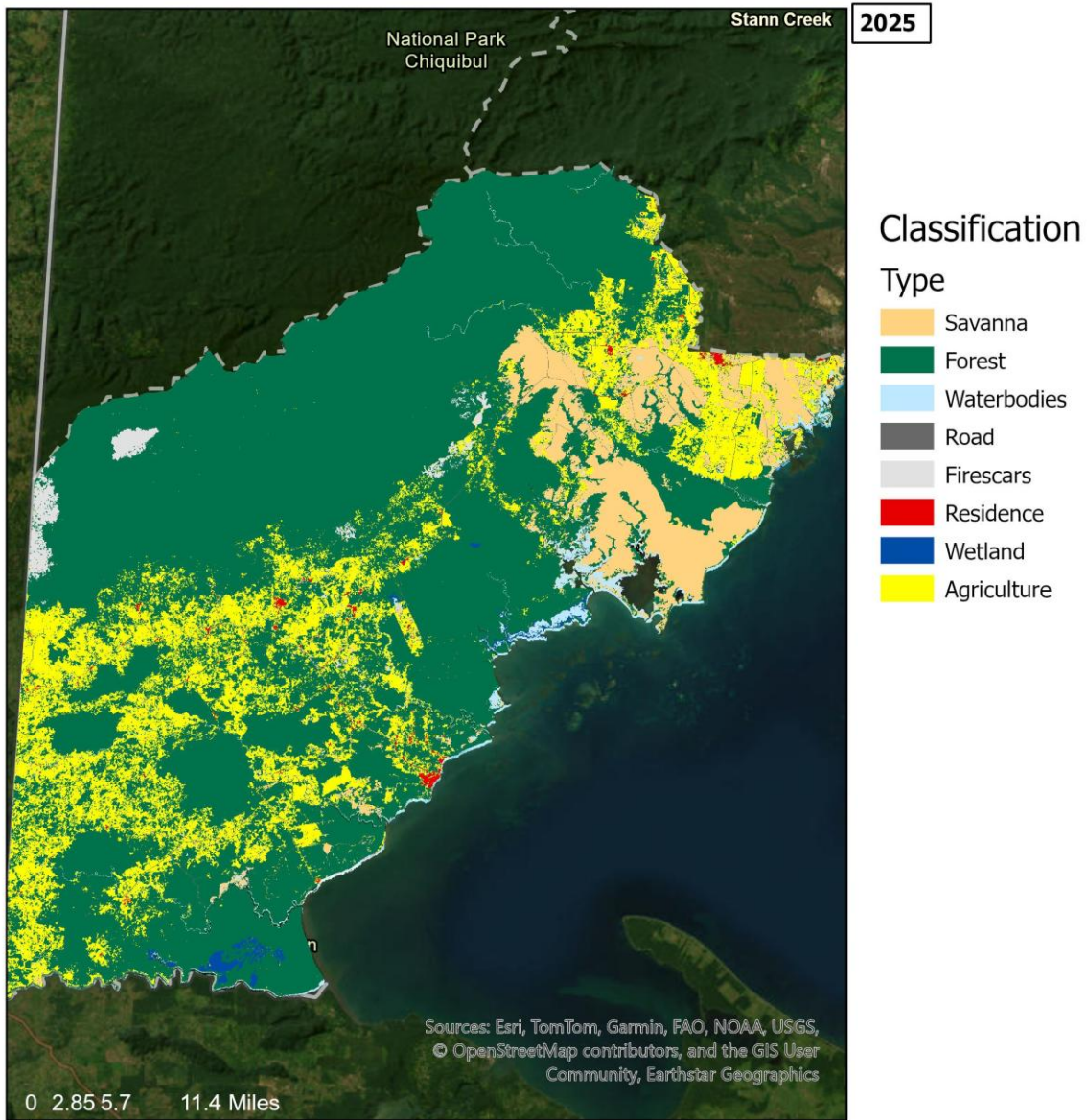


Figure 3B. LULC Classification for Toledo District, January 2024-2025.

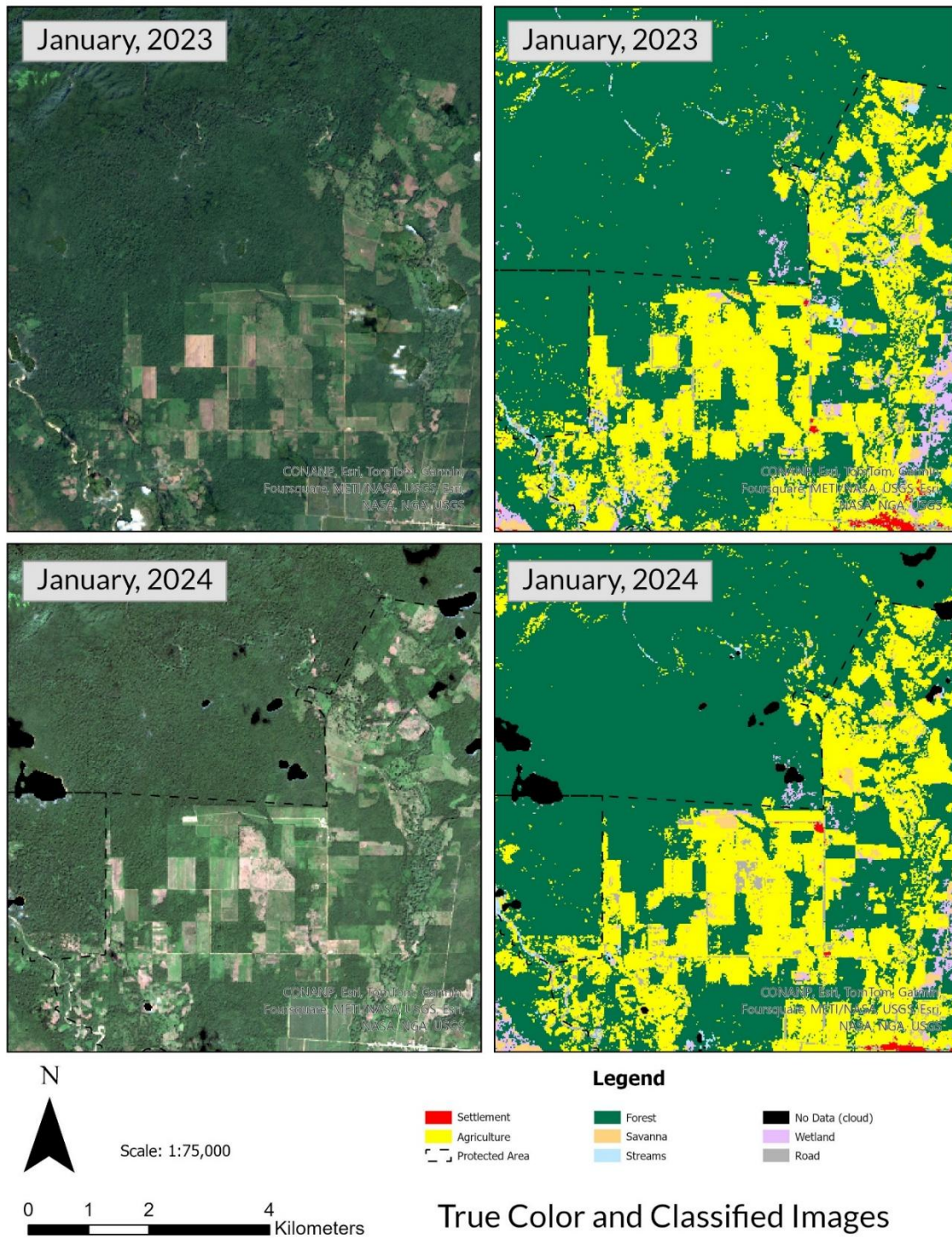


Figure 4A. 2023 & 2024

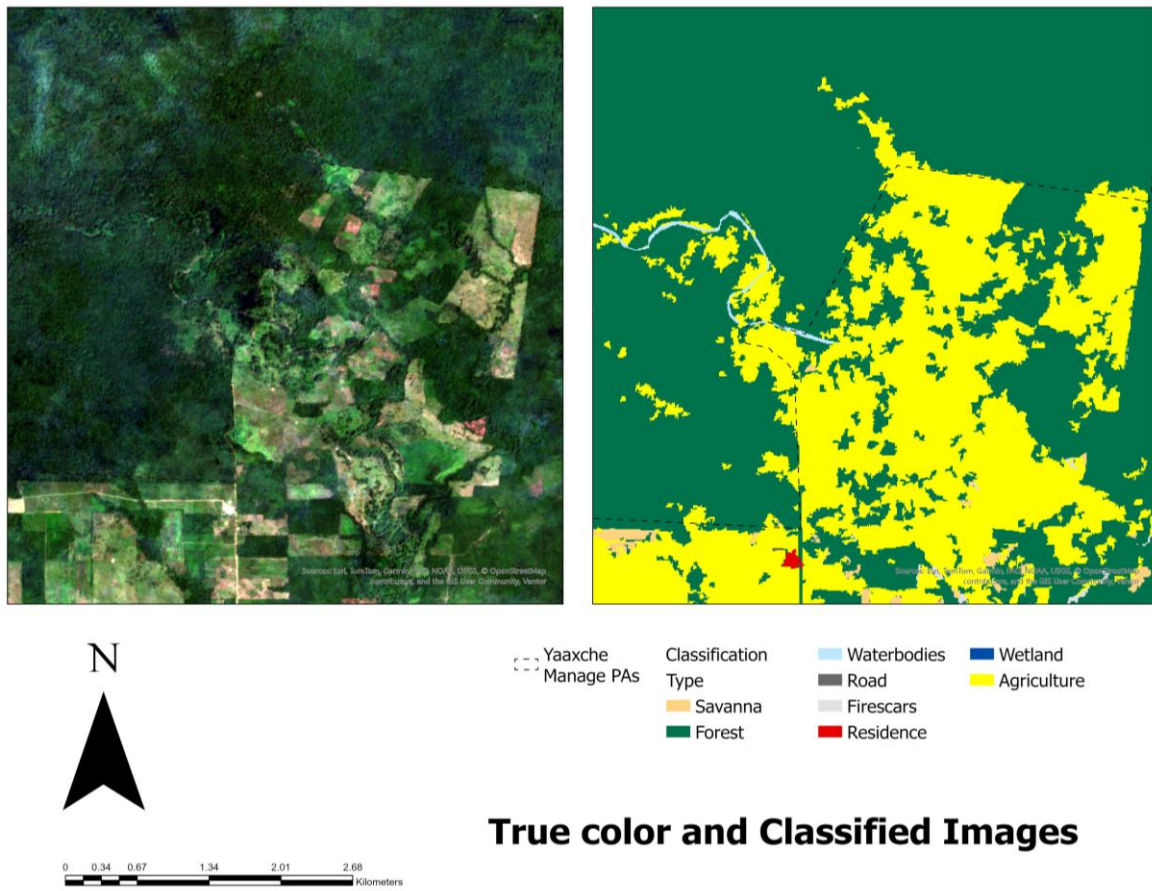


Figure 4. 2025

Figure 4A & Figure 4B. Comparison between natural colour composites (Sentinel-2) and LULC classification for the Toledo District, for the years 2023, 2024, 2025.

Results

Toledo

The Toledo District contains a diverse mosaic of forest, savanna, wetlands, water bodies, and anthropogenic land uses. For the January 2024 –January 2025 reporting period, forest remained the dominant land-cover class, covering 731,820 acres (69.69%) of the district (**Table 4**). This represents a net forest loss of 6,038 acres compared to January 2024, when forest cover totaled 737,858 acres (69.50%).

Using the FAO compound-interest formula for annual forest change, this reduction corresponds to an estimated annual deforestation rate of –0.82% for the Toledo District during the reporting period (**Table 5**).

Agriculture expanded substantially between January 2024 and January 2025, increasing from 161,102 acres (15.20%) to 197,769 acres (18.83%), a net gain of 36,667 acres. Savanna cover also increased from 54,125 acres (5.10%) to 83,627 acres (7.96%), representing an increase of 29,502 acres.

Fire scars covered 11,594 acres (1.10%) in January 2025 and were primarily concentrated along forest–agriculture and forest–savanna boundaries. Wetlands declined from 42,404 acres (4.00%) in January 2024 to 4,204 acres (0.40%) in January 2025, while water bodies decreased slightly from 15,612 acres (1.50%) to 14,453 acres (1.38%). These changes reflect a combination of seasonal variability and classification sensitivity.

In total, 1,050,039 acres were classified for the Toledo District during the January 2024–January 2025 assessment period. Land-cover classes exhibiting net increases included agriculture, savanna, and fire scars, while forest, wetlands, and water bodies showed net decreases over the same period (**Table 3**).

Table 3. Land Use/Land Cover Classes of the Toledo District with area and corresponding percentage cover per class per year.

LULC Classes	Jan-24 Acreage	Jan-24 Percentage	Jan-25 Acreage	Jan-25 Percentage	Percent Change
Settlement	23,722	2.2%	3,396	0.32%	–1.88%
Agriculture	161,102	15.2%	197,769	18.83%	+3.63%
Savanna	54,125	5.1%	83,627	7.96%	+2.86%
Forest	737,858	69.5%	731,820	69.69%	–0.82%
Water Body	15,612	1.5%	14,453	1.38%	–0.12%
Wetland	42,404	4.0%	4,204	0.40%	–3.60%
Roads	–	–	3,176	0.30%	–
Fire scars	–	–	11,594	1.10%	–

Table 4. Land Use/Land Cover classes of the Toledo District derived from January 2025. classification

Toledo District					
	Class	Frequency	Hectares	Acres	Percentage
1	Savanna	8097	33842.48	83626.59	7.96%
2	Forest	24403	296604.33	732925.26	69.80%
3	Waterbodies	1899	5855.27	14468.68	1.38%
4	Roads	2424	1285.20	3175.79	0.30%
5	Fire scars	3059	4691.84	11593.78	1.10%
6	Residence	1958	1374.21	3395.75	0.32%
7	Wetland	594	1701.48	4204.44	0.40%
8	Agriculture	12278	79581.01	196648.97	18.73%
			Total	1050039.26	100.00%

Forest Cover Change and Deforestation Rates

Forest cover change was further evaluated using the FAO annual rate of deforestation formula to compare forest area at the beginning and end of the reporting period (**Table 5**). Across the Toledo District, forest cover declined from 737,858 acres in January 2024 to 731,820 acres in January 2025, resulting in a net loss of 6,038 acres and an annual deforestation rate of -0.82%.

Table 5. Forest Cover (in acres) in the Toledo District, within protected areas, and outside of protected areas at the beginning and end of 2024 with annual rate of deforestation.

Area		Jan. 2024 Forest Cover (ac)	Jan. 2025 Forest Cover (ac)	Change 2024-2025 (ac)	Rate of Deforestation
Toledo District (Total)		737,858	731,820	-6,038	-0.82%
Within Protected Areas (Combined PAs)		160,525	159,950	-575	-0.35%
Outside Protected Areas		577,333	569,384	-7,949	-1.35%

Maya Golden Landscape

Within the Maya Golden Landscape (MGL), forest remained the dominant land-cover class during the reporting period, covering 492,633 acres (75.81%) of the total landscape area (**Table 6**). This

proportion is substantially higher than the district-wide forest cover, reflecting the concentration of protected and managed forest lands within the MGL.

Agriculture accounted for 66,099 acres (10.17%), while savanna covered 66,013 acres (10.16%), together representing the primary non-forest land uses within the landscape. Fire scars covered 10,754 acres (1.65%), indicating ongoing disturbance primarily along forest–agriculture and forest–savanna interfaces. Settlements and road infrastructure together accounted for approximately 0.42% of the MGL area. Wetlands and water bodies collectively covered 11,624 acres (1.79%) of the landscape. Between January 2024 and January 2025, the forest cover decreased from 498,805 acres to 492,633 acres, representing a forest loss of 6,172 acres (2497.72 hectares), or approximately 1.24% of the total forest area at the start of the reporting year.

Table 6. Land Use, Land Cover classes of the Maya Golden Landscape derived from the classification.

Maya Golden Landscape					
	Type	Frequency	Hectares	Acres	Percentage
1	Savanna	3028	26714.42349	66012.77767	10.16%
2	Forest	9619	199361.581	492633.1923	75.81%
3	Waterbodies	852	4240.709655	10479.02171	1.61%
4	Roads	875	558.549041	1380.20473	0.21%
5	Fire scars	1721	4352.138691	10754.36885	1.65%
6	Residence	698	549.449752	1357.719898	0.21%
7	Wetland	377	463.545275	1145.445313	0.18%
8	Agriculture	6633	26749.35634	66099.09864	10.17%
			Total	649861.8291	100.00%

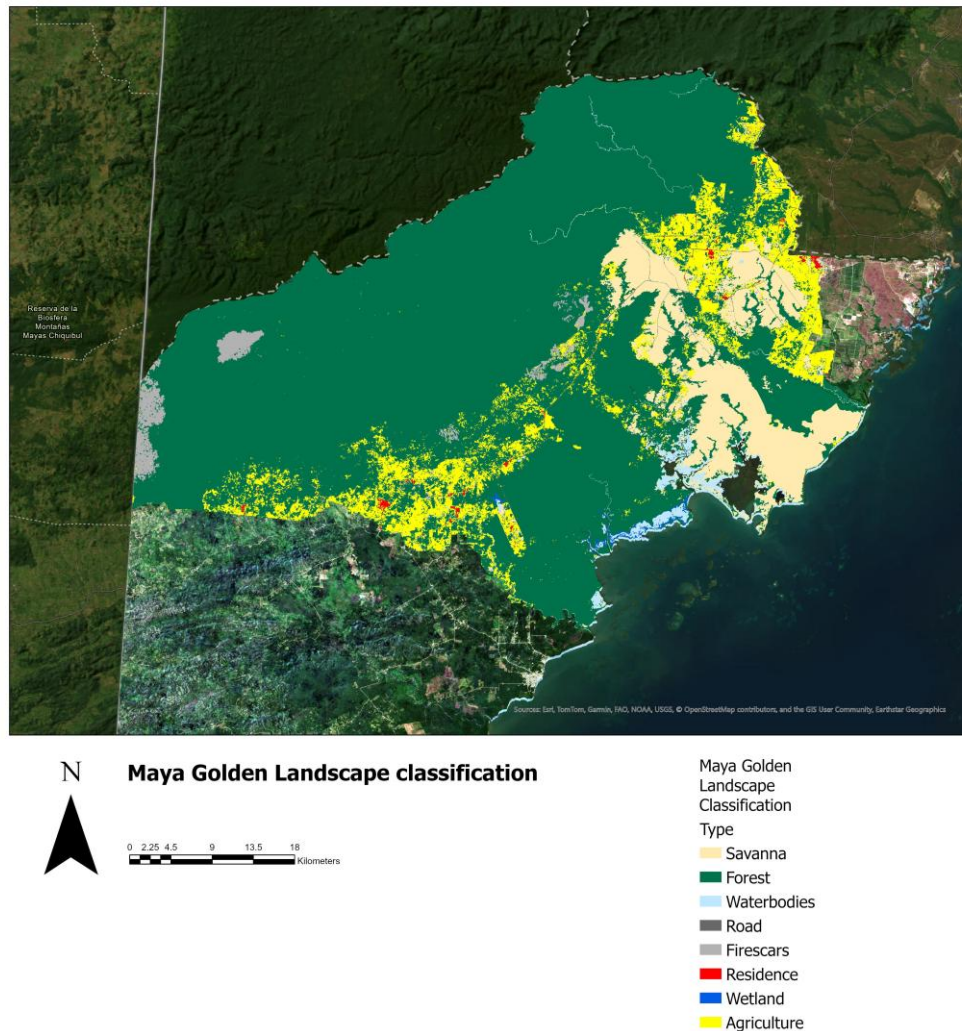


Figure 5. Land Use, Land Cover classification for the Maya Golden Landscape, January 2024-2025.

Ya'axché Managed PAs

Across the four protected areas managed by Ya'axché within the MGL (BNR, MMNFR, GSCP, and B CEP), forest cover remained high during the 2024 reporting period ([Table 7](#)).

Combined, these protected areas cover 403,020 acres, of which 398,185 acres ($\approx 96.0\%$) were classified as forest. Anthropogenic land uses—defined here as agriculture, settlements, and roads—covered approximately 1,105 acres ($\approx 0.3\%$) and were primarily concentrated along reserve boundaries.

BNR exhibited no mapped anthropogenic land use, with forest covering 99.80% of the reserve. MMNFR, GSCP, and BCEP showed limited anthropogenic presence, with anthropogenic cover ranging from 0.20% to 2.44% of total area.

Using the FAO annual deforestation rate formula applied to combined forest area estimates, forest loss within the protected areas totaled 575 acres during the reporting period, corresponding to an annual deforestation rate of -0.35% . In contrast, forest loss outside protected areas totaled 7,949 acres, with an annual deforestation rate of -1.35% , nearly four times higher than within protected areas.

Table 7. Forest and anthropogenic land cover within Ya'axché-managed Protected Areas in the Maya Golden Landscape.

Protected Area	Total Area (ha)	Total Area (ac)	Forest Area (ha)	Forest Area (ac)	Forest Cover (%)	Anthropogenic Area (ha)	Anthropogenic Area (ac)	Anthropogenic Cover (%)
BNR	98,528.91	243,540.70	98,347.88	243,060.29	99.80	0.00	0.00	0.00
MMNFR	35,504.46	87,739.45	35,156.47	86,871.79	99.06	69.79	172.19	0.20
GSCP	15,722.21	38,845.36	15,388.94	15,346.46	97.88	14.38	35.53	0.23
BCEP	13,312.36	32,894.68	12,270.14	30,317.21	92.17	701.36	1,733.06	5.27
PA's Combined	163,067.94	403,020.19	161,163.43	398,595.55	≈96.0	785.53	1,940.78	≈0.48

Baden Nature Reserve (BNR)

The 2024 land use and land cover classification for the BNR confirms that forest overwhelmingly dominates the reserve. Forest covers 99.80% of the total area (98,348 acres; 39,800 ha). Water bodies account for 0.12% (121 acres; 49 ha), while savanna covers 0.07% (73 acres; 30 ha). Agriculture, roads, fire scars, residences, and wetlands together account for less than 0.1% of the reserve area.

Anthropogenic land cover within BNR is negligible. Agriculture covers 0.18 ha (0.44 acres), while roads and residences are effectively absent. Detected fire scars total 0.04 ha (0.10 acres) and represent minor, temporary disturbance rather than land-use conversion.

No fire-related or anthropogenic disturbance was detected at a scale indicative of forest loss, and comparison of forest cover estimates between 2024 and 2025 indicates no measurable net loss of forest cover or conversion of forest to non-forest land uses.



Figure 6. Land Use Land Cover classification for the Bladen Nature Reserve, January 2024-2025.

Table 8. Land Use Land Cover classes of the Bladen Nature Reserve derived from 2024 classification.

Bladen Nature Reserve					
	Type	Frequency	Hectares	Acres	Percentage
1	Savanna	28	29.560441	73.04544006	0.07%
2	Forest	33	39799.97582	98347.8815	99.80%
3	Waterbodies	94	48.901117	120.837291	0.12%
4	Roads	7	0.15251	0.376860415	0.00%
5	Fire scars	15	0.041323	0.102111356	0.00%
6	Residence	0	0	0	0.00%
7	Wetland	0	0	0	0.00%
8	Agriculture	130	0.178765	0.441737933	0.00%
		Total		98542.68494	100.00%

Maya Mountain North Forest Reserve (MMNFR)

The 2024 land use and land cover classification for the MMNFR indicates that forest remains the dominant land-cover type, covering 99.06% of the reserve (35,156 acres; 14,227 ha). Water bodies represent 0.45% (160 acres; 65 ha), while agriculture accounts for 0.29% (104 acres; 42ha). All other land-cover classes individually represent less than 0.01% of the total area.

Agricultural land remains limited and spatially concentrated, consistent with historical land-use patterns along the reserve boundary. Roads, residences, and fire scars together account for less than 0.01% of the reserve and do not indicate expanding infrastructure or settlement pressure.

Although a small increase in the mapped extent of agricultural land is observed (0.20% to 0.29%), the change is negligible and does not indicate meaningful land-use change or encroachment within MMNFR. The establishment of the agroforestry concession in 2014 has contributed to the retention of forest cover and a reduction in forest loss.

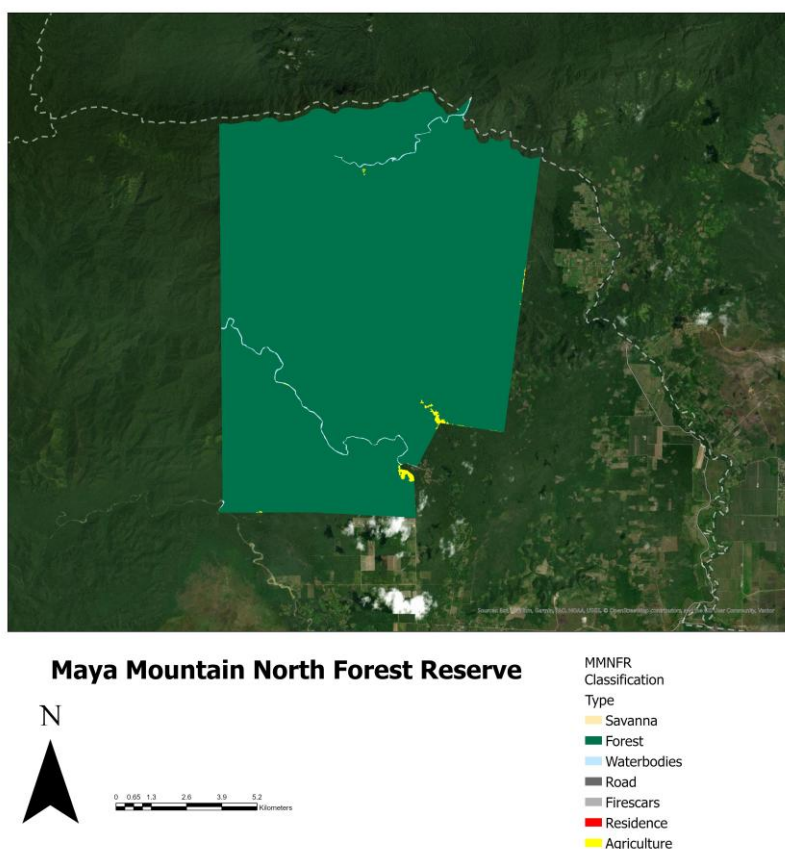


Figure 7. Land Use/Land Cover classification for the Maya Mountain North Forest Reserve,

January 2024-2025.

Table 9. Land Use Land Cover classes of the Maya Mountain North forest Reserve derived from the 2024 classification.

Maya Mountain North Forest Reserve					
	Type	Frequency	Hectares	Acres	Percentage
1	Savanna	13	0.304853	0.753308	0.00%
2	Forest	73	14227.317	35156.47	99.25%
3	Waterbodies	74	64.935419	160.4589	0.45%
4	Roads	3	0.06672	0.164869	0.00%
5	Fire scars	1	0.009526	0.023539	0.00%
6	Residence	1	0.133388	0.329609	0.00%
7	Wetland	0	0	0	
8	Agriculture	250	42.284562	104.4874	0.29%
		Total		35422.68	100.00%

Golden Stream Corridor Preserve (GSCP)

The 2024 land use and land cover classification for the Golden Stream Corridor Preserve (GSCP) shows that forest covers 97.88% of the preserve (15,388 acres; 6,227 ha). Wetlands represent 0.92% (144 acres; 58 ha), while water bodies account for 0.62% (98 acres; 40 ha). Fire scars were detected over 55.6 acres (22.49 ha; 0.35%), indicating localized, temporary forest disturbance during the reporting period.

Anthropogenic land use is minimal. Roads cover 0.21% (32.65 acres; 13.21 ha), residences 0.01% (0.92 acres; 0.37 ha), and agriculture 0.01% (1.96 acres; 0.79 ha). No expansion of agriculture or infrastructure into forested areas was observed. **Comparison of forest cover estimates between 2023 and 2024 indicates no net permanent deforestation within GSCP.**

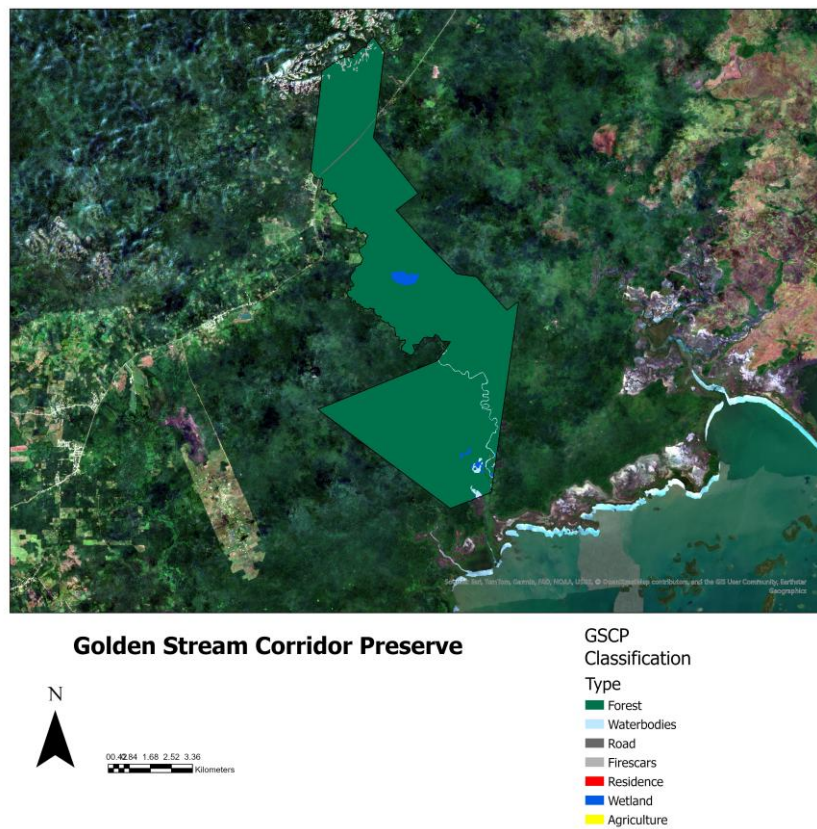


Figure 8. Land Use Land Cover classification for the Golden Stream Corridor Preserve, January 2024-2025.

Table 10. Land Use Land Cover classes of the Golden Stream Corridor Preserve derived from the 2024 classification.

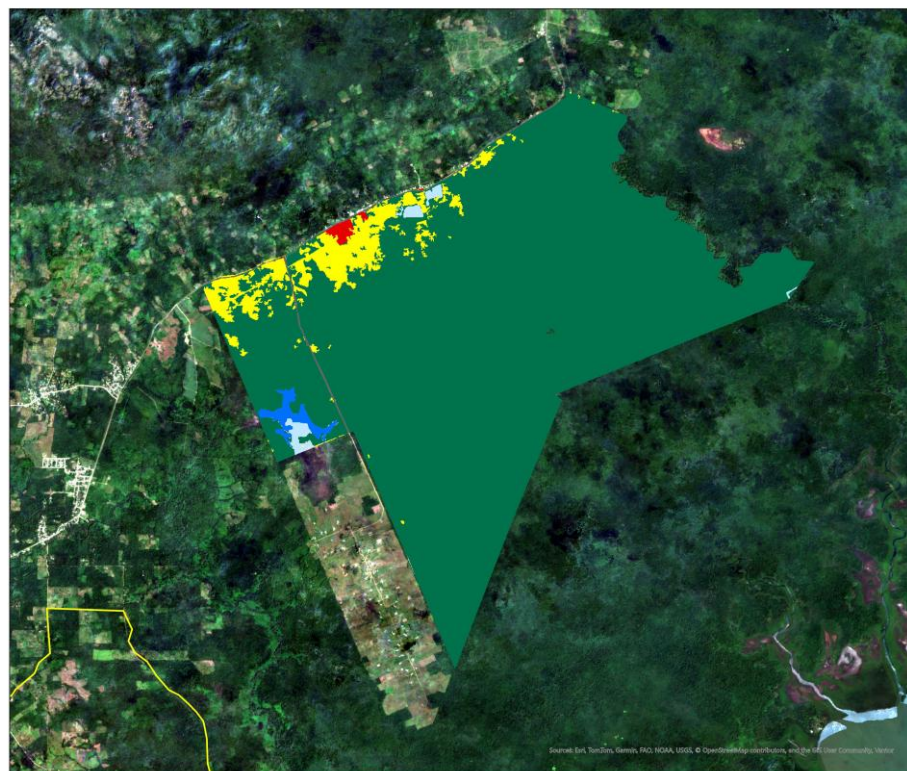
Golden Stream Corridor Preserve					
	Type	Frequency	Hectares	Acres	Percentage
1	Savanna	0	0	0	0.00%
2	Forest	48	6227.683773	15388.94	97.88%
3	Waterbodies	22	39.632183	97.93326	0.62%
4	Roads	1	13.213461	32.65117	0.21%
5	Fire scars	53	22.492672	55.5806	0.35%
6	Residence	2	0.372075	0.919417	0.01%
7	Wetland	19	58.368003	144.2305	0.92%
8	Agriculture	69	0.791912	1.956857	0.01%
		Toledo		15722.21	100.00%

Boden Creek Ecological Preserve

The 2024 land use and land cover classification for the Boden Creek Ecological Preserve (BCEP) indicates that forest remains the dominant land-cover type, comprising 92.17% of the preserve (12,270 acres; 4,966 ha). Agricultural land accounts for 5.34% (711 acres; 288 ha), while wetlands cover 0.86% (114 acres; 46 ha) and water bodies account for 0.70% (94 acres; 38 ha).

Anthropogenic land cover within BCEP includes roads (0.52%; 69 acres; 28 ha) and residential areas (0.35%; 46 acres; 19 ha). Fire scars were detected over 2.6 acres (1.1 ha; 0.02%), indicating localized, short-term disturbance rather than permanent forest conversion.

Comparison of forest acreage estimates between 2023 and 2024 indicates no net permanent deforestation within BCEP.



Boden Creek Ecological Preserve



0 0.380.71 1.43 2.15 2.86
Kilometers

BCEP

Type

Savanna

Forest

Waterbodies

Road

Firescars

Residence

Wetland

Agriculture

Figure 9. Land Use Land Cover classification for the Boden Creek Ecological Preserve, January

2024-2025.

Table 11. Land Use Land Cover classes of the Boden Creek Ecological Park derived from the 2024 classification.

Boden Creek Ecological Park					
	Type	Frequency	Hectares	Acres	Percentage
1	Savanna	100	2.262103	5.5897782	0.04%
2	Forest	199	4965.551	12270.144	92.17%
3	Waterbodies	10	37.97659	93.842197	0.70%
4	Roads	31	28.068042	69.357642	0.52%
5	Fire scars	69	1.059343	2.6176935	0.02%
6	Residence	31	18.628699	46.032517	0.35%
7	Wetland	1	46.112016	113.94527	0.86%
8	Agriculture	118	287.66438	710.83415	5.34%
			Total	13312.363	100.00%

Case Studies

Areas of Interest

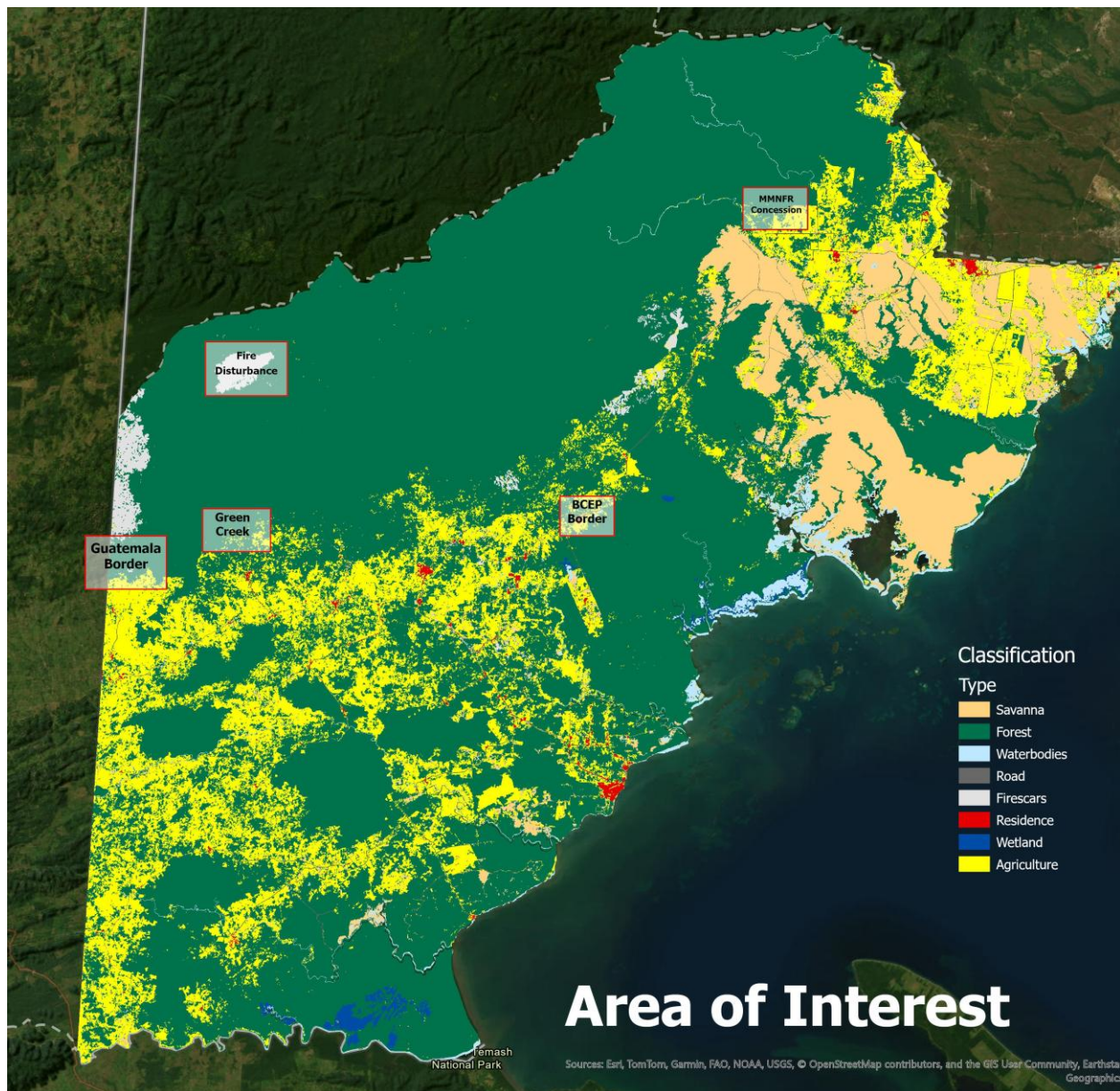


Figure 10. Areas of Interest in Toledo for Case Studies. From left to right: 1, the section of the Belize-Guatemala border adjacent to the Columbia River Preserve; 2, The Green Creek Farmers' Cooperative in San Jose village; 3, The northern border of Boden Creek Ecological Preserve adjacent to Indian Creek village; 4, the southern portion of the Maya Mountain North Forest Reserve covering the agroforestry concession and the de-reserved area, 5, the fire disturbance in Columbia River Forest Reserve.

Boden Creek Ecological Preserve

Land-cover change within BCEP remains concentrated along the northern boundary near Indian Creek Village, in areas historically used for agriculture and now largely recovering as secondary vegetation. Forest remains the dominant land-cover type, accounting for $\approx 92.17\%$ of the preserve (12,270 acres / 4,966 ha; **Table 11**), while agriculture and other anthropogenic activity occupy $\approx 5.7\%$ of the area (≈ 701 acres / 288 ha), primarily along the northeastern and southeastern edges.

Comparison with the previous reporting period indicates no significant expansion of agricultural clearing into the preserve, though small increases in clearing are visible in the southeast (**Figure 11**), reflecting localized, ongoing management of existing agricultural plots. Minor fluctuations in mapped forest cover are likely linked to seasonal hydrological changes, where waterlogged forest areas were classified as wetland ($\approx 1.6\%$; 203 acres / 82 ha) in the 2024–2025 imagery. Areas showing apparent forest gain are mostly within previously disturbed zones undergoing natural regeneration. Increased settlement-related activity was observed in Indian Creek Village but remained outside the BCEP boundary.

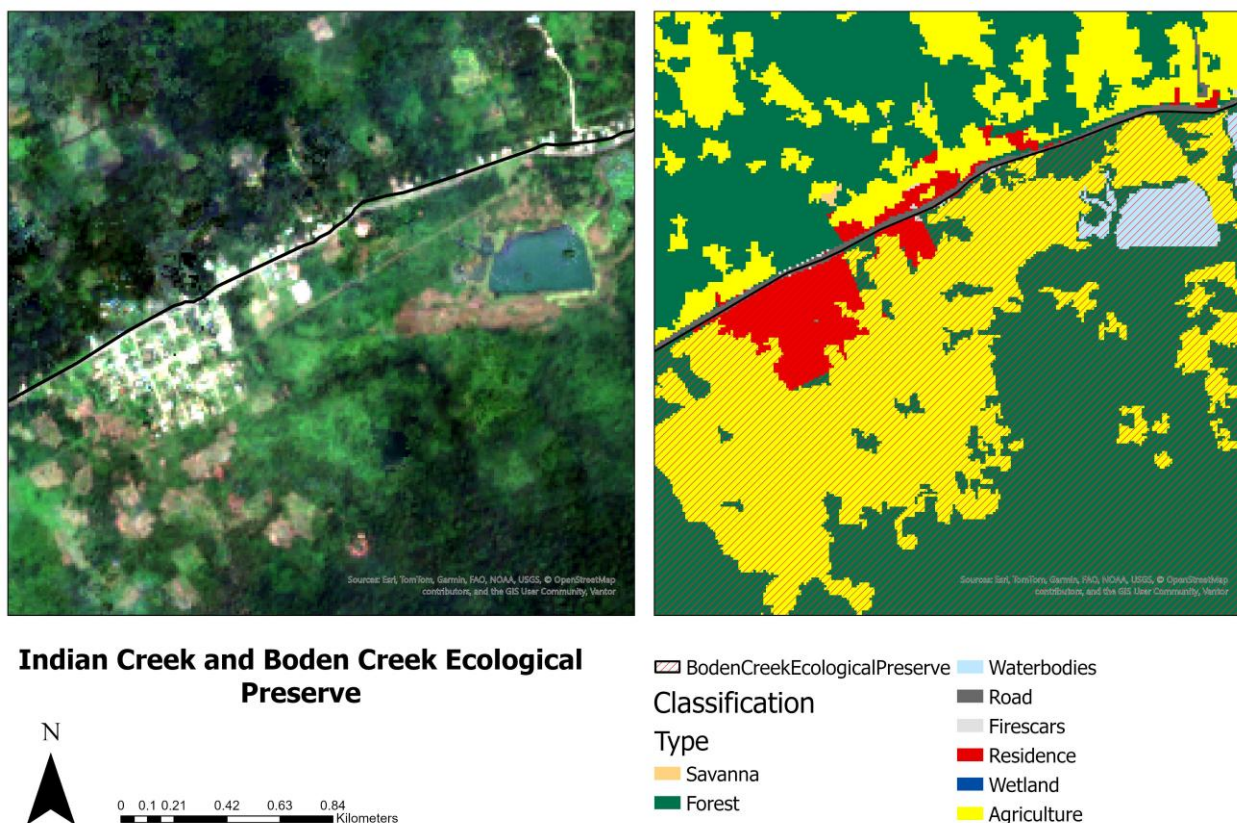


Figure 11. Land-use change along the northern boundary of the Boden Creek Ecological Preserve adjacent to Indian Creek Village, January 2024- 2025.

Maya Mountain North Forest Reserve

Forest cover within MMNFR remains largely intact, with $\approx 99.25\%$ of the reserve classified as forest (35,156 acres / 14,227 ha; [Table 9](#)). Minor localized disturbance was observed during the reporting period, primarily along the southern and eastern boundaries near de-reserved areas and buffering communities. Small increases in disturbed land were mainly associated with areas previously classified as wetland, suggesting reclassification rather than new clearing. Agricultural expansion within the cacao agroforestry concession and cultivated areas remained limited, though continued monitoring is recommended to ensure compliance with land-use boundaries.

Within MMNFR Anthropogenic land uses, including agriculture, roads, and settlements, accounts for $\approx 0.29\%$ of the reserve (≈ 172 acres / 70 ha), confirming the reserve's high forest integrity.

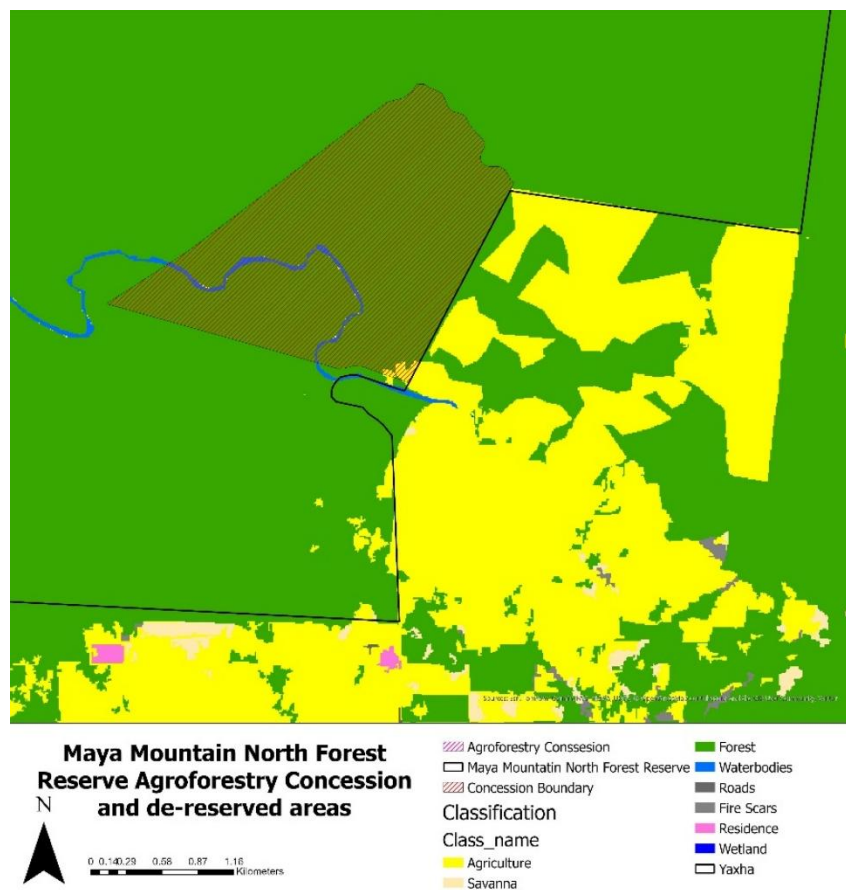


Figure 12. Land-use patterns within the Maya Mountain North Forest Reserve agroforestry concession and de-reserved areas, January 2024-2025.

Green Creek at San Jose Village

The Ya'ax Ha Livelihood Area (Green Creek), a locally recognized Indigenous Community Conserved Area (ICCA), continues to be managed by the Green Creek Farmer's Cooperative (GCFC) under traditional farming systems, including cacao agroforestry and subsistence agriculture. The 2024 classification indicates that forest cover remains the dominant land cover, accounting for 757.99 hectares (1873 acres, 86.07%). Agricultural land covers 122.33 ha (302.3 acres, 13.89%), primarily within the cultivation zone, reflecting continued traditional farming practices rather than large-scale forest conversion. comparison with the previous reporting period shows a modest increase in cultivated land, accompanied by stable forest cover within conservation areas, reflecting continued community management rather than large-scale forest conversion.

Ya'ax Ha Livelihood Area

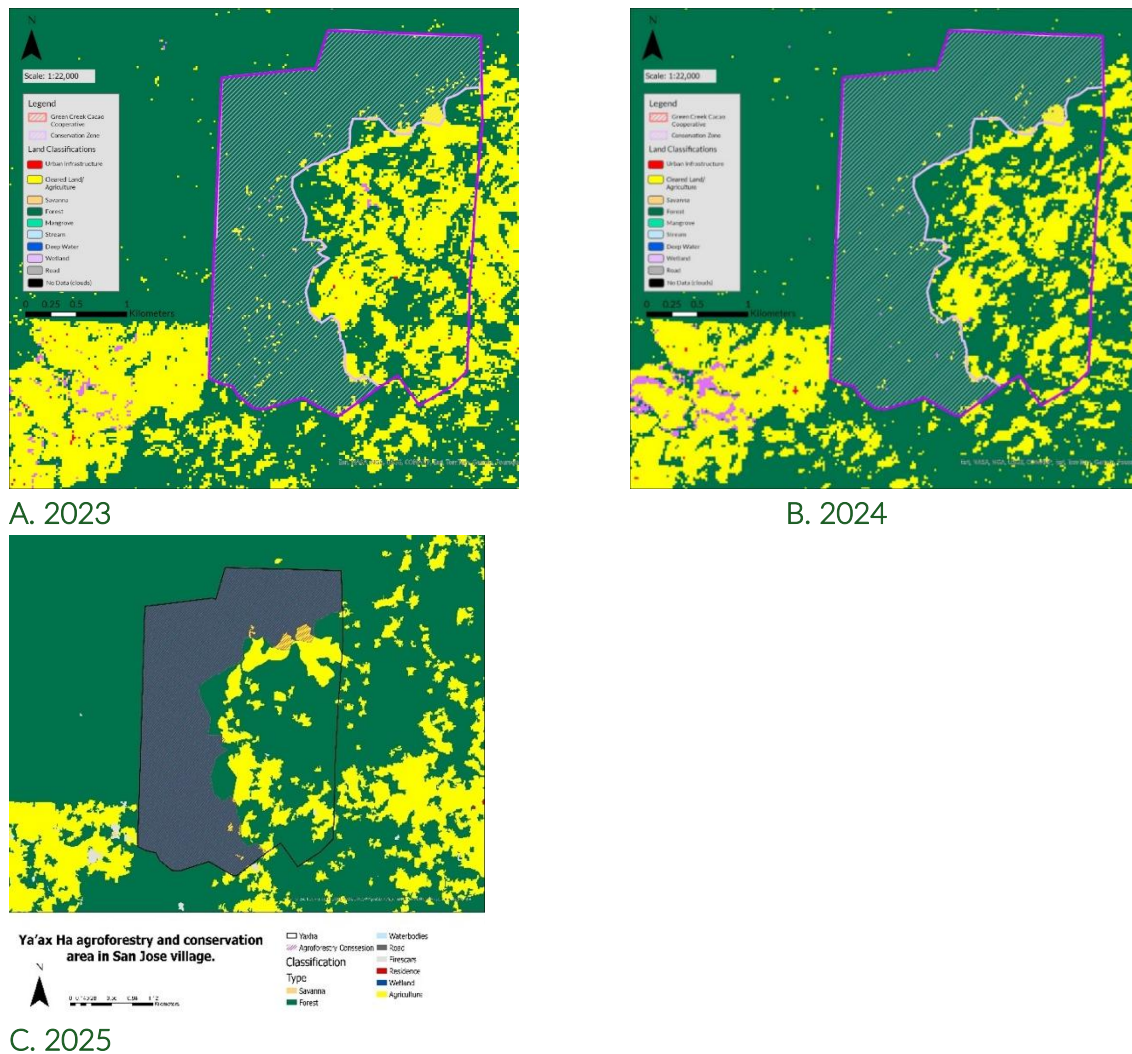
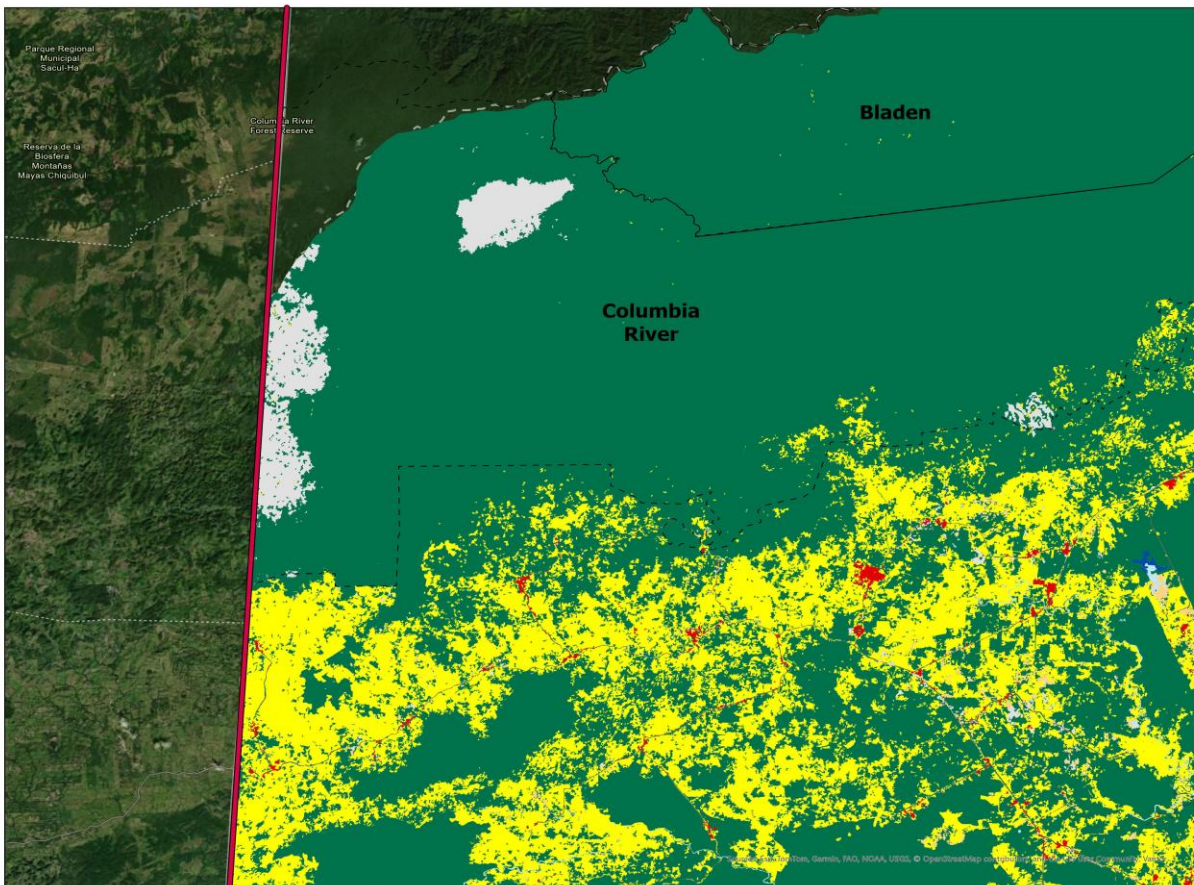


Figure 13 A, B, C. Land-use patterns within the Ya'ax Ha Livelihood Area (Green Creek) agroforestry and conservation area, San Jose Village, for the years 2023, 2024 and January 2025.

Columbia River Forest Reserve (CRFR – Agricultural Incursions)

CRFR continues to experience significant anthropogenic pressure, particularly along its western and southern boundaries. Illegal agricultural expansion, cattle grazing, and resource extraction largely associated with cross-border access from Guatemala remain the primary drivers of forest loss. The presence of multiple access routes into the reserve facilitates continued encroachment and highlights the need for strengthened monitoring and enforcement along these borders.



Guatemalan Border along the Columbia River Forest Reserve



Classification Type

- Savanna
- Forest
- Waterbodies
- Road

- Firescars
- Residence
- Wetland
- Agriculture
- Columbia River Forest Reserve
- Protected Areas
- Belize/Guatemala Border

Figure 14. Land-use change along the Belize–Guatemala border within the Columbia River Forest Reserve highlighting agricultural incursions, as of January 2024-2025.

Columbia River Forest Reserve (CRFR – Fire Disturbance)

During the 2024 dry season, a discrete patch of forest within the CRFR was affected by fire, resulting in forest loss totaling 3,431.16 ha (8,478.59 acres), equivalent to 6.11% of the reserve. This disturbance represents a direct reduction in forest cover rather than a classification artifact. While limited to extent relative to the total reserve area, the fire-affected zone warrants continued monitoring to assess forest recovery and to evaluate potential interactions between fire occurrence and adjacent land-use activities.

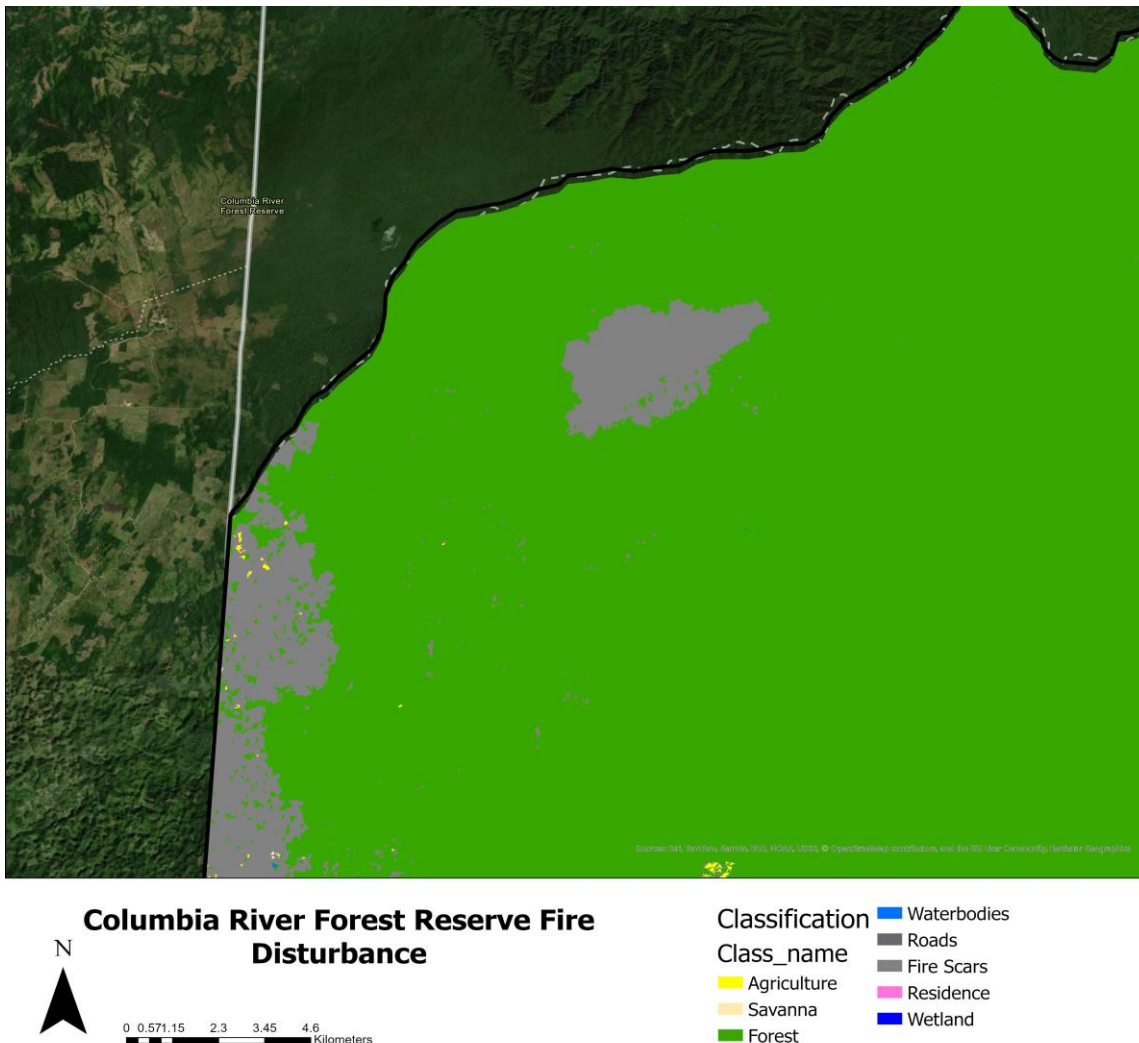


Figure 15. Fire-affected area within the Columbia River Forest Reserve detected during the 2024 dry season.

Discussion

Toledo

The Toledo District remains one of the most forested districts in Belize, with approximately 731,820 acres ($\approx 296,140$ ha; 69.69%) of its land area under forest cover during the January 2024–January 2025 reporting period (**Table 3**). Despite this high level of forest cover, the results indicate continued forest loss driven primarily by agricultural expansion, settlement development, and fire-related disturbance (**Figures 5–6**). These drivers are consistent with national and regional assessments of land-use change in southern Belize.

Smallholder agriculture remains the dominant land-use system within Toledo, particularly within predominantly Indigenous communities where subsistence and mixed-use farming practices are common. While most agricultural activity occurs outside protected areas, the results show localized illegal agricultural incursions within some Protected Areas, contributing to forest degradation along reserve boundaries. Fire scars mapped during this reporting period covered 11,594 acres (1.10%), primarily along forest–agriculture and forest–savanna edges (**Table 3**), indicating that fire is an increasingly important driver of forest loss, consistent with regional observations (WWF, 2022).

To place Toledo's deforestation in a broader regional context, the district's annual deforestation rate remained -0.82% , lower than reported rates for Petén, Guatemala ($>1.5\%$ annually). However, similar drivers—including cattle ranching, smallholder farming, and fire—suggest that without continued management and enforcement, Toledo could experience accelerated forest loss comparable to other Mesoamerican deforestation frontiers (WWF, 2021).

Maya Golden Landscape

Deforestation rates within the Maya Golden Landscape were lower than district-wide values, reflecting the higher proportion of protected and actively managed lands within the MGL. Forest remained the dominant land-cover type, accounting for 492,633 acres ($\approx 199,362$ ha; 75.81%) of the landscape (**Table 6**), with agriculture, savanna, and fire scars comprising the majority of non-forest land-cover classes.

Fire-related disturbance accounted for a measurable portion of recent forest loss within the MGL. Unlike previous reporting periods, fire scars identified in the 2024 analysis represent real forest cover loss, contributing directly to the observed deforestation rate. Fire-driven degradation is increasingly recognized as a key threat to tropical forest integrity, particularly in mosaic landscapes where forest edges are expanding (FAO, 2022).

Although the overall deforestation rate in the MGL remains lower than that of the Toledo District as a whole, results indicate that protected status alone does not eliminate forest loss. Continued pressure from agriculture, combined with recurring fire disturbance, poses

a long-term risk to forest structure and connectivity if not addressed through integrated landscape-level management approaches (FAO, 2018).

Protected Areas

Across the four Protected Areas managed by Ya'axché within the MGL, forest cover remained exceptionally high, exceeding 96% of total PA area (**Table 7**). The combined annual deforestation rate for these PAs was low relative to surrounding unprotected lands, reinforcing evidence that protected-area management is effective in reducing large-scale forest conversion (FAO, 2020).

Bladen Nature Reserve (BNR)

BNR remained almost entirely forested during the reporting period, with $\approx 98,348$ acres ($\approx 39,718$ ha) of forest (**Table 8, Figure 6**). No evidence of permanent forest loss, agricultural expansion, or fire-related disturbance was detected. Minor non-forest classifications within the reserve reflect natural variability and topographic complexity, not land-use conversion.

Maya Mountain North Forest Reserve (MMNFR)

Forest cover remained high at $\approx 35,156$ acres ($\approx 14,227$ ha) (**Table 9, Figure 7**). Localized forest loss and agricultural pressure were concentrated along the eastern boundary. Agriculture, roads, and settlements together represent $\approx 0.2\%$ (≈ 70 ha; 172 acres) of the reserve. Existing clearings and fire scars indicate continued vulnerability to edge-related degradation, consistent with trends observed in other multiple-use forest reserves.

Golden Stream Corridor Preserve (GSCP)

GSCP retained a high proportion of forest cover ($\approx 15,388$ acres; $\approx 6,228$ ha; 97.88%) with no evidence of agricultural expansion into forested areas (**Table 10, Figure 8**). Fire scars were detected within the preserve, covering ≈ 56 acres (≈ 23 ha; 0.35%), indicating localized forest disturbance. These repeated disturbances, while not causing widespread deforestation, may reduce forest resilience over time, particularly in corridor habitats critical for landscape connectivity.

Boden Creek Ecological Preserve (BCEP)

BCEP exhibited the highest proportion of non-forest land cover among the four PAs, largely due to agriculture and wetlands along its boundaries (**Table 11, Figure 9**). Forest remained dominant at $\approx 12,270$ acres ($\approx 4,966$ ha; 92.17%), with anthropogenic areas (agriculture, roads, settlements) covering $\approx 1,037$ acres (≈ 420 ha; 7.8%). Fire-related forest loss was detected but at very limited spatial extent, and no net permanent deforestation occurred during the reporting period.

Conclusion

The 2024 Land Use and Land Cover (LULC) assessment provides an updated overview of land-cover patterns and forest dynamics across the Toledo District, the Maya Golden Landscape (MGL), and Ya'axché-managed Protected Areas. Using consistent ArcGIS-based classification methods and FAO-aligned deforestation metrics, this assessment establishes a reliable baseline for monitoring land-use change during the January 2024 to January 2025 reporting period.

Results indicate that forest remains the dominant land-cover type across all spatial scales assessed. Toledo District continues to retain a high proportion of forest cover, although measurable forest loss persists, driven primarily by agricultural expansion, smallholder farming, settlement growth, and fire-related disturbance. These pressures remain concentrated along forest edges, road corridors, and community boundaries.

Within the Maya Golden Landscape, forest cover remains proportionally higher and deforestation rates lower than the district average, reflecting the influence of protected areas and landscape-level conservation planning. Despite this, agricultural expansion and fire scars continue to contribute to localized forest loss and degradation, underscoring the need for continued management attention.

Ya'axché-managed Protected Areas demonstrated strong forest retention during the reporting period, with forest cover exceeding 96% across the combined network. Observed forest loss within these areas was limited and localized, primarily associated with boundary pressures and fire disturbance rather than widespread land-use conversion. The substantially lower deforestation rates within Protected Areas compared to unprotected lands highlight the effectiveness of active management and protection.

Recommendations

Future land use land cover (LULC) assessments should continue using a standardized and replicable classification approach, such as the Random Trees (Random Forest) supervised classification applied in this report. A consistent LULC framework allows reliable comparison across years and management areas. The classification scheme should remain generalized, with key classes such as forest, agriculture, savanna, wetland, settlements, roads, fire scars, and water bodies. In this study, forest sub-types were intentionally grouped into a single "Forest" class to reduce classification error and improve interpretation of deforestation trends. While the FAO Land Cover Classification System is valuable for carbon accounting, it was not applied here as its detailed forest categories are not required for district- or landscape-level forest change analysis.

Cloud cover remains a major limitation for optical satellite imagery in southern Belize. Future analyses should apply robust cloud-masking and image mosaicking techniques to minimize cloud and shadow effects. The use of Google Earth Engine for cloud masking is recommended, as standard Sentinel-2 cloud products alone were insufficient to fully remove cloud contamination in this study.

This analysis requires substantial time and technical effort, particularly for image preprocessing, training data development, classification, post-processing, and validation. Future reporting cycles should allocate sufficient time for these steps and maintain clear documentation of the workflow. Training samples should be evenly distributed across the landscape, with a similar number and size of samples per class. Large imbalances in training data can result in noisy classifications and reduced accuracy.

All spatial analyses and area calculations should be conducted in a projected coordinate system using meters. We recommend standardizing all datasets to **NAD 1983 UTM Zone 16N** prior to classification and area analysis to ensure accurate acreage and hectare estimates.

Limitations

The land use and land cover (LULC) classification methodology applied in this assessment was consistent with that used in the previous reporting period, and efforts were made to closely follow the procedures, class definitions, and analytical workflow of earlier reports. This consistency supports comparability between reporting periods; however, some level of uncertainty remains inherent to LULC analysis.

Natural ecosystems in Toledo are highly dynamic, and transitions between forest, savanna, agriculture, and wetlands are often gradual rather than distinct. Seasonal variation, particularly in precipitation, can influence spectral reflectance and affect class assignment from year to year. As a result, certain land-cover changes may reflect environmental variability rather than permanent land-use conversion.

Cloud cover in Sentinel-2 imagery continues to be a limiting factor, despite the use of cloud masking and careful image selection. Residual cloud and shadow effects required interpolation and manual editing in localized areas, introducing additional assumptions into the analysis. Time constraints, limited access to previously classified raster datasets, and the absence of field-based ground truthing further contribute to uncertainty.

Finally, while methodological consistency was maintained, minor variations in interpretation, training sample selection, and data handling between reporting periods and analysts may influence classification outcomes. These uncertainties are acknowledged, and results should be interpreted as best estimates of land-cover conditions and trends during the reporting period rather than exact measurements.

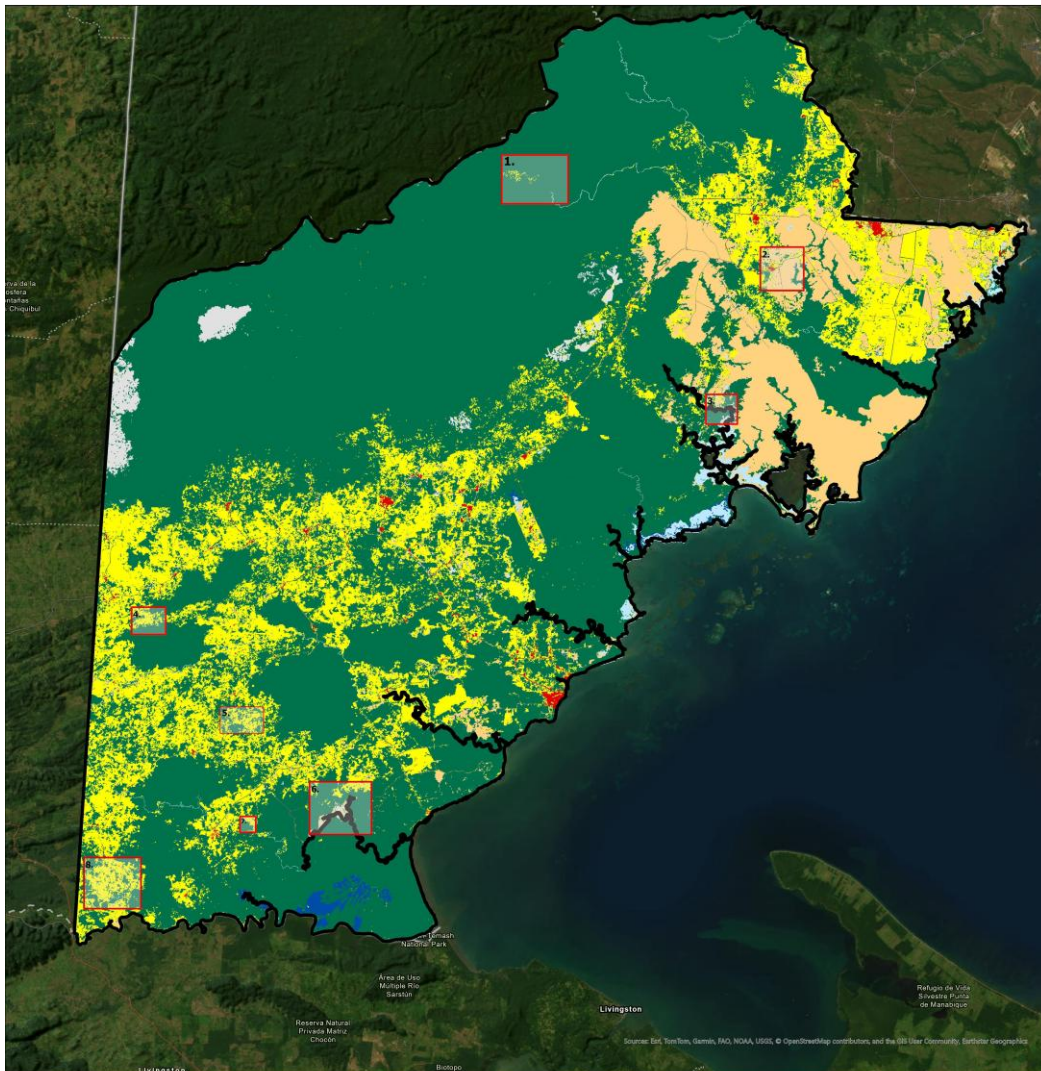
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Appendices

Appendix 1



Classification Anomalies

Toledo District	Waterbodies
Classification	Road
Type	Firescars
Savanna	Residence
Forest	Wetland
	Agriculture

Cloud residue:

Despite the application of an advanced cloud and cloud-shadow masking workflow in Google Earth Engine, residual cloud edges and shadows remained in the imagery. These features were insufficiently reflective to be captured by the masking threshold and were therefore misclassified as settlement, agriculture, or water features. Affected pixels were manually corrected using contextual interpretation and reference imagery to assign the most probable land-cover class, thereby minimizing bias in area estimates.

Ridgeline effects:

Topographic variation and associated vegetation types produced spectral responses that differed from surrounding forest cover. Certain vegetation types exhibited reflectance characteristics similar to agricultural land, while terrain-induced shadows were frequently misclassified as water features. These areas were reclassified as forest during post-processing to prevent overestimation of anthropogenic land cover.

Mixed-class artifacts:

Isolated areas displayed simultaneous assignment to multiple land-cover classes due to spectral ambiguity and landscape heterogeneity. These artifacts were resolved by reassigning the affected pixels to a single, ecologically appropriate class based on visual interpretation and contextual consistency.

Waterlogged forest misclassification:

Heavily saturated forest areas exhibited spectral signatures similar to wetlands or mangrove vegetation, resulting in misclassification. These areas were reclassified as forest using reference basemaps, local ecological knowledge, and comparison with historical imagery to ensure consistency across reporting periods.

Transitional savanna–forest zones:

Gradual transitions between savanna and forest produced mixed spectral signals that were occasionally classified as wetland. These transition zones were reviewed and corrected during post-classification editing to better reflect actual land-cover conditions.

High-reflectance agriculture and aquaculture:

Certain agricultural and aquaculture features displayed high reflectance values similar to built surfaces, leading to misclassification as settlement or urban land. Where identified, these features were reclassified as agriculture using high-resolution satellite imagery to confirm the absence of permanent structures. Aquaculture features with limited spatial extent were retained as classified, as they did not influence focal analyses.



Land Use/Land Cover change in Toledo and the Maya Golden Landscape 2024-2025



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