



Toledo Fire Report

Annual Change and Burned Areas in the Toledo District 2025



Karen Zambrano
Protected Areas Geospatial Monitoring Officer

Said Gutierrez
Protected Areas Program Director



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Report Prepared by:

Karen Zambrano

Protected Areas Geospatial Monitoring Officer

Said Gutierrez

Protected Areas Program Director

Revised by:

Marvin Vasquez

Contents

Contents	i
List of acronyms	ii
Summary	1
Introduction	2
Goals and Objectives	3
Methodology.....	3
Study Area	3
Remote Sensing Data Collection	4
Exporting and Preparing Indexed Images	4
Constructing the dNBR Index Rasters	5
Accuracy Assessment.....	6
Results	7
Toledo	7
Discussion	12
Toledo /MGL.....	12
Ya'axché-Managed Protected Areas	13
Conclusion	14
Limitations	16
Reference.....	17

List of acronyms

BA	Burned Area
BCEP	Boden Creek Ecological Preserve
BERDS	Biodiversity & Environmental Resource Data System of Belize
BFREE	Belize Foundation for Research and Environmental Education
BNR	Bladen Nature Reserve
CRFR	Columbia River Forest Reserve
dNBR	Difference Normalized Burn Ratio
FAO	Food and Agriculture Organization
FD	Forest Department
GEE	Google Earth Engine
GIS	Geographic Information System
LULCC	Land Use Land Cover Change
GSCP	Golden Stream Corridor Preserve
MGL	Maya Golden Landscape
MMNFR	Maya Mountain North Forest Reserve
MODIS	Moderate Resolution Imaging Spectroradiometer
NBR	Normalized Burn Ratio
NIR	Near Infrared Radiation
NPAS	National Protected Areas System
PA	Protected Area
PPA	Privately Protected Area
SWIR	Short-wave Infrared Radiation
Ya'axché	Ya'axché Conservation Trust

Summary

Fire is an integral component of land-use practices and ecological processes across southern Belize, particularly within smallholder agriculture, cattle ranching systems, and savanna ecosystems of the Toledo District. Increasing pressures from population growth, agricultural expansion, and climate variability have raised the risk that routine fires may escalate into uncontrolled and damaging fire events. Understanding the spatial and temporal extent of fire is therefore critical for effective land management and conservation planning especially in the context of traditional indigenous farming and the adoption of climate smart practices.

This report quantifies Burned Areas (BA) across the Toledo District and the Maya Golden Landscape (MGL) for the 2025 fire seasons using the Difference Normalized Burn Ratio (dNBR) derived from Sentinel-2 satellite imagery. Pixels with dNBR values greater than 0.2 were classified as burned, capturing areas affected by low to high fire severity. BA estimates were calculated directly from pixel counts using an average spatial resolution of approximately 20 m × 20 m, ensuring consistent, reproducible, and spatially explicit results across years and scales.

Previous years, 2022 and 2023 documented relatively low levels of burning across both the Toledo District and the MGL. In contrast, 2024 showed severe fire activity exceeding the combined burned area of several preceding years (Place & Gutierrez 2024). 2025, fire activity declined from the 2024 peak but remained elevated relative to earlier low-burn years. In 2025 alone, approximately 24,396 ha (7.7%) of the Toledo District and 14,372 ha (4.5%) of the MGL were affected by fire, indicating moderate but widespread fire impacts at the landscape scale.

At finer spatial scales, fire activity within Ya'axché Conservation Trust's (Ya'axché) protected areas remained minimal throughout the study period. Forest cover across these protected areas remained high, underscoring the effectiveness of conservation management practices in limiting fire spread and protecting forested ecosystems.

Overall, these findings demonstrate that while fire remains a recurring feature of the Toledo landscape, its impacts vary considerably year by year and are strongly influenced by climatic conditions and land management. The concentration of fire activity outside protected forests suggests that management interventions are effective where consistently applied. However, the sharp increase in BA during extreme years highlights the need for fire risk mitigation. This report recommends strengthening early fire warning systems, improving access to fire risk information, and promoting adaptive fire management strategies to reduce the likelihood that routine agricultural burning escalates into large-scale, damaging wildfires particularly during dry and climatically extreme years.

Introduction

Ya'axché's main goal is to promote the sustainable use and management of forest resources and biodiversity conservation in southern Belize through collaborative efforts with local communities, government agencies, and other stakeholders. Its focus is primarily within the MGL, an area of 780,200 acres found in the Toledo District. Within the MGL, there are 28 Protected Areas (PAs) of which Ya'axché manages or co-manages four: the Bladen Nature Reserve (BNR), Boden Creek Ecological Preserve (BCEP), Golden Stream Corridor Preserve (GSCP), and Maya Mountain North Forest Reserve (MMNFR), encompassing approximately 165,300 acres, or 15% of the Toledo District and 21% of the MGL.

The BNR is the largest nature reserve in Belize with the highest level of protection under the NPAS Act. Encompassing roughly 100,000 acres in the core zone of the Maya Mountain Massif, the nature reserve benefits from its remote location, which provides a natural barrier against most human-induced disturbances affecting other PAs (Gutierrez et al., 2023). Ya'axché shares co-management of the reserve with the Government of Belize, with the former assuming significant responsibility for day-to-day operational activities. This collaborative approach promotes effective management and conservation efforts, which will contribute to long-term protection of this ecologically significant area.

The BCEP is a Privately Protected Area (PPA) in the Toledo District. This preserve has been privately owned well before the 1960's and was predominantly used for agriculture in many forms, including citrus, banana, and cattle (Bowen-Jones 2001). It currently covers an area of approximately 12,876 acres along the Southern Highway adjacent to the village of Indian Creek. As with the adjacent GSCP, the property was acquired in tandem for conservation purposes in the late 90's and established as the BCEP circa 2007 under continued private ownership and management. Since 2007 the area has been managed as the BCEP under different owners culminating in 2021 with the acquisition of the property by Fauna & Flora and final transfer of ownership Ya'axché in 2024. Combined with the GSCP, these two form an integral part of the southern biological corridor.

The GSCP is a PPA situated in the Toledo District of Belize. It was established in 1998 through the collective efforts of Ya'axché, a consortium comprising local community members and both national and international conservation experts. The PPA spans about 15,070 acres, comprising lowland broadleaf forests serve as a vital ecological corridor linking the Maya Mountains' foothills to the coastal lowlands of the Toledo District (Lenox et al., 2020).

The MMNFR is an extractive reserve in the Toledo District. Historically, the reserve lacked management presence until 2015 when Ya'axché undertook co-management responsibilities. The PA spans over 37,700 acres, with most of its land characterized by rugged terrain that predominantly remains a forested landscape. Presently, there is an agroforestry concession that is closely monitored by the Belize Forest Department (FD) and managed by Ya'axché on behalf of a community group from Trio Village (Garcia et al, 2014).

In this report GIS & Remote Sensing analysis methods are used to measure and provide extensive data on the location and intensity of fire over time by detecting, characterizing, and monitoring BA.

Goals and Objectives

The goal of this study is to use Remote Sensing Technology and Sentinel-2A imagery to study fire patterns in Toledo, Belize, for the dry season period February-June 2025. Our objectives are as follows:

- Estimate the amount of land burned each year
- Identify dNBR thresholds for burned land
- Identify any fire hotspots in Toledo

Methodology

Study Area

Toledo is the southernmost and least populated Belizean district. The average annual maximum temperature is 85° Fahrenheit (30° Celsius). The average annual minimum temperature is 73° Fahrenheit (23° Celsius). Toledo comprises 1,064,547 acres of terrestrial and inland aquatic ecosystems; this area is bounded by 16°15'36" N latitudes to 89°12'0" W longitudes, 16°28'12"N latitude to 89°11'24"W longitudes, 16°42'0"N latitudes to 88°33'36"W longitudes, 16°12'0"N latitudes to 88°28'48"W longitudes, and 16°7'48"N latitudes to 88°36'0"W longitudes. The MGL is the portion of Toledo in which Ya'axché focuses on its conservation and community development. The MGL consists mainly of forest, savanna, mangrove, wetland, ocean, and agriculture land cover, and contains twenty-four small communities.

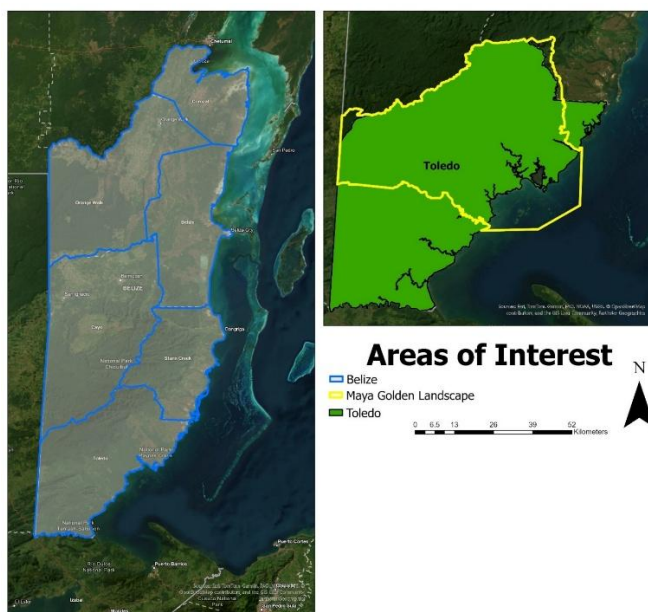


Figure 1. Map of the study area found within Belize

The data collected and used for this study include Sentinel-2 satellite data, a base map for Belize, a Belize PAs map, and the MGL boundary. The Belize base map and PAs map were created using geospatial data files obtained from the Biodiversity and Environmental Resource Data System for Belize (BERDS) (Meerman, 2013; Meerman, 2017). The MGL map was obtained internally from Ya'axché's geodata sets. Maps and Indices used for analyzing BA were created through the supervised classification of the Sentinel 2 multi-Spectral instrument 2A images, with a total 3 spectral bands spanning from the visible and the near infrared to the short-wave infrared. The spatial resolution of this analysis is 20m.

Remote Sensing Data Collection

This study used Sentinel-2 Level-2A (S2MSI2A) satellite imagery obtained from the European Union's Copernicus Programme. Sentinel-2 provides atmospherically corrected surface reflectance data suitable for vegetation and fire-related analyses, with spatial resolutions ranging from 10 m to 60 m. For this analysis, imagery was accessed and processed using Google Earth Engine (GEE).

Sentinel-2 images were filtered spatially to the Toledo District boundary and temporally to capture conditions before and after the 2025 fire season. Images with cloud cover greater than 70% were excluded. Cloud contamination was further reduced using the QA60 quality assurance band, which masks pixels affected by clouds and cirrus. All reflectance values were scaled to surface reflectance by dividing digital numbers by 10,000.

To represent pre-fire and post-fire conditions, two cloud-robust (Cloud-Minimized) composite images were created using a median reducer:

- Pre-fire composite: February 15 – March 31, 2025
- Post-fire composite: May 1 – June 15, 2025

All composite images were clipped to the Toledo District boundary. The spatial resolution of the analysis was standardized to twenty meters, corresponding to the native resolution of the Near Infrared (NIR) and Short-Wave Infrared (SWIR) bands used in the burn analysis.

In addition to Sentinel-2 imagery, active fire point data from the Fire Information for Resource Management System (FIRMS) were used to support interpretation of BA and confirm the timing and spatial distribution of fire activity within the study area (NASA FIRMS 2025).

Exporting and Preparing Indexed Images

Sentinel-2 imagery includes twelve spectral bands; however, this study focused on bands relevant to fire detection and vegetation response. Bands 8A (NIR) and 12 (SWIR 2), both at 20-meter resolution, were used to generate fire indices (Table 1). Band 4 (Red) was used in combination with bands 8A and 12 to produce false-colour composites highlighting BA and vegetation condition.

After cloud masking and compositing in GEE, indexed raster layers were generated and prepared for export. True-colour and false-colour composites were created for visual inspection, while the dNBR raster and BA mask were exported as GeoTIFF files. All exported rasters were clipped to the Toledo District boundary, kept at 20-meter spatial resolution, and prepared for further visualization and spatial analysis in ArcGIS Pro.

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

Band	Resolution (m ²)	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 Edge 3
B8	10	842	Near Infrared (NIR)
B8A	20	865	Near Infrared (NIR) focused
B9	60	940	Water Vapor
B11	20	1610	Short-Wave Infrared (SWIR) 1
B12	20	2190	Short-Wave Infrared (SWIR) 2

Following image collection and compositing, indexed images were generated in GEE to support fire analysis. NBR was calculated for both pre-fire and post-fire composite images using the NIR and SWIR bands. The dNBR was then derived by subtracting post-fire NBR values from the pre-fire baseline, allowing for the identification of fire-affected areas.

All index calculations were performed on cloud-masked, median-composited imagery to minimize atmospheric and cloud-related artifacts. The resulting NBR and dNBR images were clipped to the Toledo District boundary and exported at a spatial resolution of 20 m for subsequent burned area and severity analysis.

Constructing the dNBR Index Rasters

The NBR and dNBR were used to identify and map BA within the Toledo District. The NBR is a widely used spectral index that exploits the contrast between NIR and SWIR reflectance to detect vegetation damage and fire effects. Alcaras et al summarize the value of this index well in their 2022 paper: “The Near Infrared (NIR) and Shortwave Infrared (SWIR) spectral regions are relevant for detecting burned areas: NIR highlights changes in canopy cover and brightness of leaf burn, whereas SWIR detects changes in landscape dryness (Alcaras et al. 2022).

The NBR was calculated for both pre-fire and post-fire composites using the formula:

$$NBR = \frac{(NIR - SWIR)}{(NIR + SWIR)}$$

where NIR corresponds to Sentinel-2 Band 8A and SWIR corresponds to Band 12. The dNBR raster was then calculated by subtracting the post-fire NBR from the pre-fire NBR:

$$dNBR = NBR_{pre-fire} - NBR_{post-fire}$$

Higher dNBR values indicate greater change in vegetation structure and moisture associated with fire disturbance. Following established practices, a threshold of dNBR ≥ 0.20 was applied to delineate BA. Pixels meeting or exceeding this threshold were classified as burned, while lower values were excluded. This threshold-based approach allows for consistent BA mapping without the use of supervised classification or training samples. At this stage of the study, training samples were not incorporated and are planned for use in future validation of the burned area BA results.

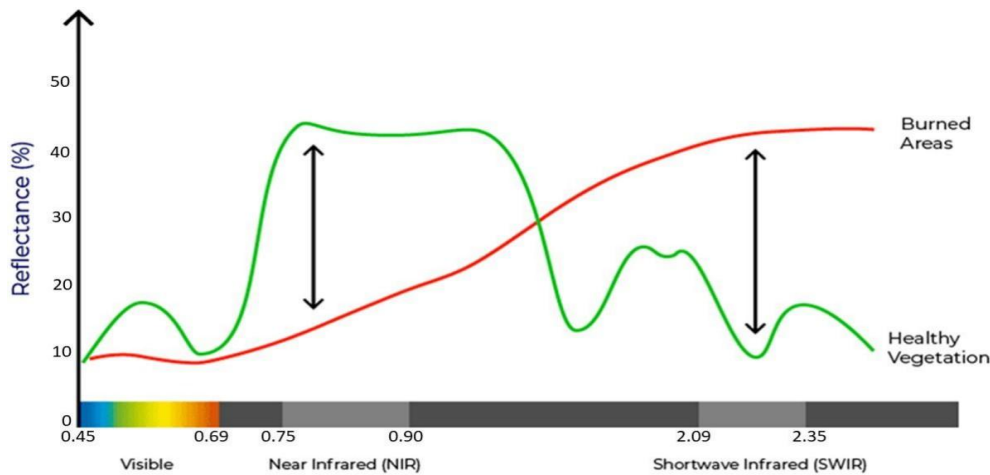


Figure 2. Graph showing the percent reflectance of healthy vegetation and burned areas at different points along the visible and infrared light spectrum (in micrometers). From Alcaras et al, 2022.

Accuracy Assessment

Table 3. Confusion matrix and accuracy statistics for burned area classification (2025)

Reference \ Classified	Not Burned	Burned	Total	User's Accuracy (%)
Not Burned	92	8	100	92.0
Burned	11	89	100	89.0
Total	103	97	200	
Producer's Accuracy (%)	89.3	91.8		

Overall Accuracy:

$$(92 + 89)/200 = 90.5\%$$

Cohen's Kappa (κ): 0.81

To verify the level of accuracy of the BA classification for the 2025 reporting period, a confusion matrix was constructed, and Cohen's kappa statistic was calculated. Cohen's kappa allows for the evaluation of classification performance beyond chance agreement and provides a robust metric for determining whether the model performs better than a random classification. As noted by

Czodrowski (2014), the kappa statistic enables a quantitative comparison between the trained model and a hypothetical random model. The accuracy assessment was conducted using a subset of reference points derived from Moderate Resolution Imaging Spectroradiometer (MODIS), FIRMS active fire detections and randomly generated non-burned points. Using the ArcGIS Pro Accuracy Assessment protocol, a confusion matrix (Table 3) was generated to evaluate the agreement between the BA classification derived from the dNBR raster and the reference data. Cohen's kappa represents the proportion of correctly classified samples while accounting for agreement occurring by chance.

The resulting overall accuracy of the classification was 90.5%, with a Cohen's kappa value of 0.81, indicating almost perfect agreement between the classified BA map and the reference data. Kappa values greater than 0.81 are widely considered to reflect strong model performance and reliability in remote sensing classification studies (Czodrowski 2014). Once the BA classification was validated, the raster dataset was clipped to multiple spatial extents to quantify BA within specific regions of interest. Cloud-affected pixels were masked using cloud cover information to reduce classification errors associated with atmospheric interference. This approach ensured that BA estimates were derived from high-confidence observations and allowed for more accurate quantification of BA across the Toledo District.

Results

BA across both the MGL and Toledo District were quantified directly from pixel counts of the severity raster, using an average pixel size of approximately 20 m × 20 m at the study latitude. This approach provides accurate and reproducible estimates of fire-affected hectares, clearly illustrating the spatial distribution and magnitude of fire at both the landscape and protected area scales. These results offer robust, data-driven insights to support effective fire management and conservation planning across the region.

Toledo Brun Assessment

Burn severity across the Toledo District was assessed using the differenced Normalized Burn Ratio (dNBR), with pixels exceeding 0.2 classified as burned, representing areas of low to high fire severity. Total burned area (BA) within the district was estimated at approximately 24,396 ha (60,289 acres), corresponding to 7.7% of the district's total area. These results indicate widespread fire activity across Toledo during the 2025 fire season, reflecting the broader regional fire dynamics (Table 4). High-severity burn scars are most apparent within savannah and mixed land-use landscapes, particularly in areas that are known to experience recurring fires. By focusing exclusively on high-severity burns, this analysis provides a conservative and robust estimate of the most ecologically impactful fire events, reducing uncertainty associated with low-severity burns and seasonal vegetation variable.

Maya Golden Landscape Burn Assessment

Burn severity within the MGL was assessed using the dNBR. Areas with a dNBR value greater than 0.2 were classified as burned, representing low to high severity fire effects. The analysis identified approximately 14,372 ha or 4.5% of BA within the MGL. BA was estimated based on pixel counts derived from the severity raster, assuming an average pixel size of approximately 20 m × 20 m at the study latitude.

Within the Maya Golden Landscape, burned area was lower than in the broader district. Approximately 14,372 ha were affected by fire, representing 4.5% of the MGL. Compared to the district-wide results, fire impact within the MGL was moderate, suggesting more localized fire activity. This pattern may reflect differences in land use, vegetation cover, and the influence of management practices across the landscape (Table 4).

Ya'axché Protected Areas Burn Assessment

At the finer scale of Ya'axché-managed protected areas, fire activity remained minimal. In B CEP, BA covered only 1.06 ha (0.02% of the reserve), which is forested (92.17%). The MMNFR exhibited no fire impact, with BA of 0.01 ha (0.00%) and forest comprising 99.25% of the reserve. The GSCP showed 22.49 ha (0.35%) of fire scars, in cleared areas, while forest dominated the reserve (97.88%). Overall, these findings confirm that fire activity within Ya'axché-managed protected areas is confined to non-forest areas, highlighting the effectiveness of conservation management in limiting the spread of fires (Fig. 3).

Table 4. Comparison of burned area extent in the Toledo District and Maya Golden Landscape (MGL) from 2021 to 2025

Year	Toledo Burned Area (ha)	% of Toledo	MGL Burned Area (ha)	% of MGL
2021	10,358	2.4%	10,107	1.9%
2022	4,210	1.0%	2,790	0.2%
2023	13,354	3.1%	3,879	1.2%
2024	43,992	10.2%	25,360	8.0%
2025	24,396	7.7%	14,372	4.5%

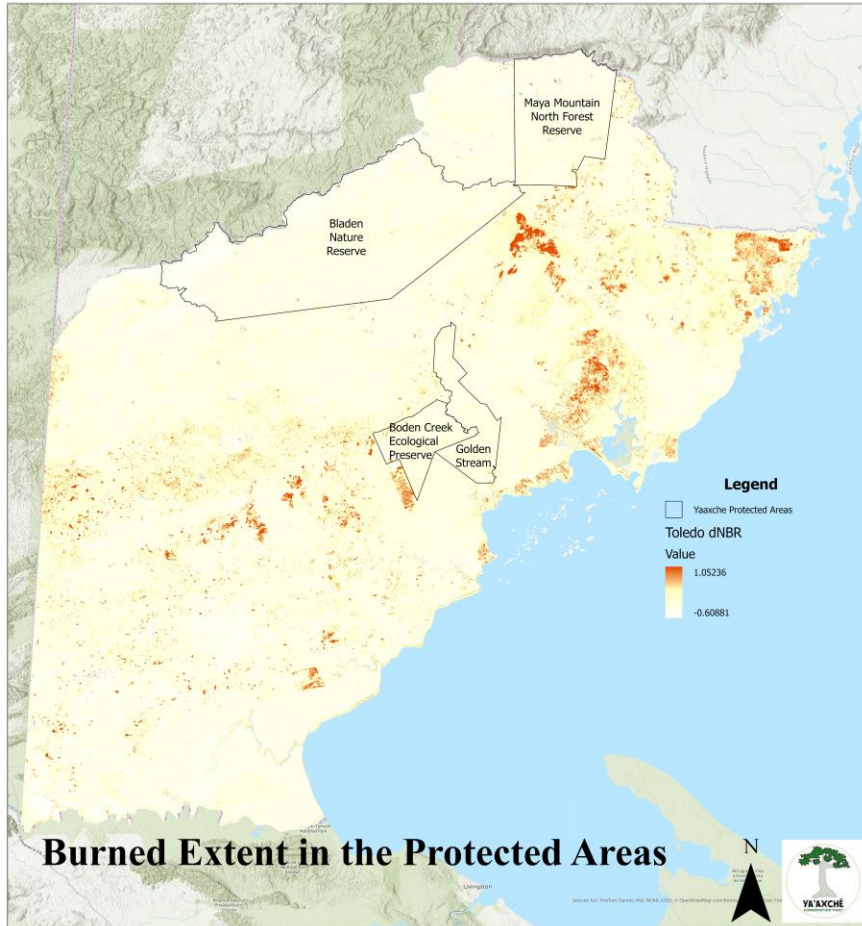


Figure 3. BA in Ya'axché-Managed Protected Areas, Toledo District.

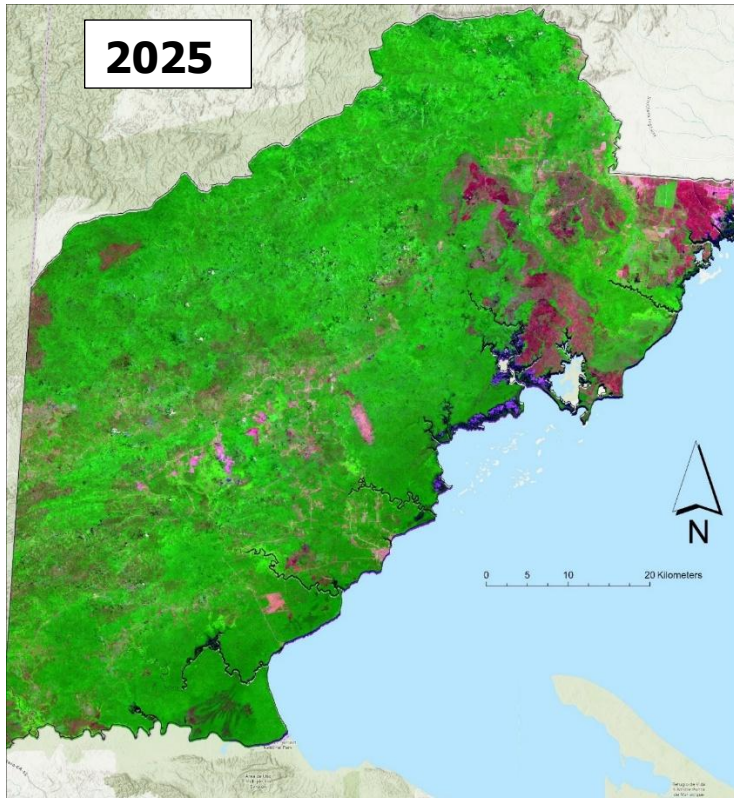


Figure 4. False-color mosaic image of Toledo between February 15, 2025 – May 1, 2025 highlighting BAs, bare ground and healthy vegetation.

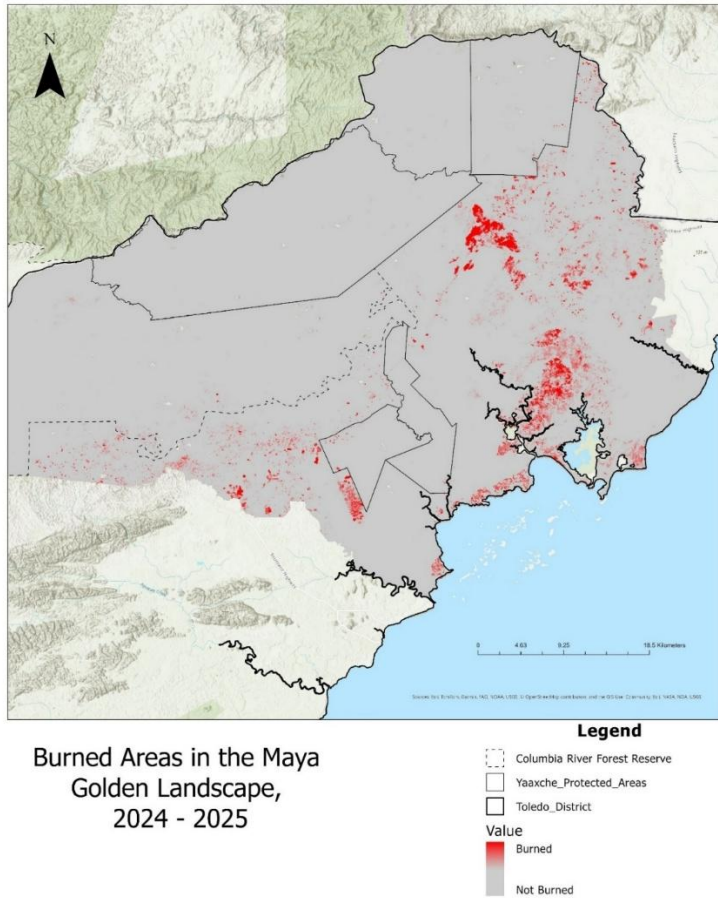
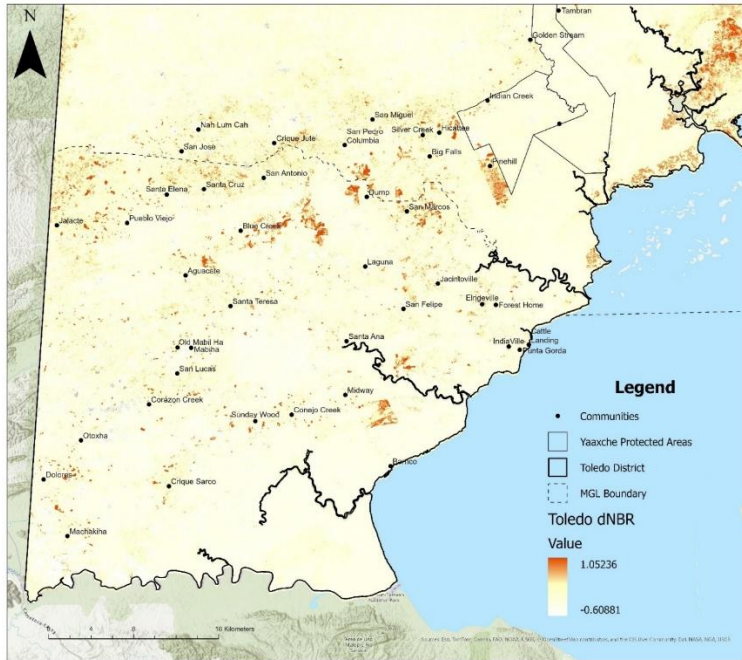


Figure 5. Areas burned In the MGL highlighted in red



Burn Extent in Southern Toledo

Figure 6. Map of Southern Toledo and MGL in 2024 showing BA and severity and communities closest to the largest burns.

Discussion

Toledo

Fire activity in the Toledo District shows clear interannual variability driven largely by climatic conditions. The extreme 2024 fire season, which burned 43,992 ha (10.2% of the district), demonstrates how unusual dry-season events can substantially amplify both the extent and severity of fires. Although 2025 saw a reduction in BA (24,396 ha; 7.7%), levels remained elevated compared to pre-2024 years, highlighting continued landscape vulnerability. These patterns indicate that while fires are an expected seasonal occurrence, extreme climate conditions can exacerbate their impact, creating significant challenges for landscape-level fire management.

Maya Gloden Landscape

Within the Maya Golden Landscape, fire trends generally mirror those of the wider Toledo District but at lower absolute and proportional levels. Peak burned area occurred in 2024 (25,360 ha; 8.0% of the MGL) and declined in 2025 (14,372 ha; 4.5%). The smaller proportional impact relative to the district suggests that local factors—such as landscape

composition, land-use patterns, and management practices—may help moderate fire spread. Nevertheless, elevated burned areas in 2024 and 2025 compared to earlier years indicate that the MGL remains susceptible to broader climatic pressures, reinforcing the importance of proactive fire management and conservation planning.

Ya'axché-Managed Protected Areas

Fire activity within Ya'axché-managed PAs remained low from 2025, especially when compared to the wider Toledo District and the MGL. The 2025 results confirm that these reserves continue to function as effective buffers against fire spread. However, the extreme 2024 fire season proved that even well-protected areas can be affected under severe dry conditions. The interpretation of fire patterns in 2025 should also be considered alongside findings from the Land Use Land Cover Change (LULCC) Report 2024, which provides added context on vegetation cover and landscape change (Zambrano & Gutierrez 2025). Although 2025 conditions were not severe, the repeated occurrence of small boundary fires highlights the importance of continued coordination with nearby communities, particularly during predicted dry seasons.

BCEP

BCEP recorded 1.06 ha burned in 2025 (0.02% of the reserve), a major decrease from 2024. As in previous years, BA were limited to already cleared lands along the northern boundary near Indian Creek Village and the Southern Highway. Since BCEP is largely forested 92.17% (Zambrano & Gutierrez, 2025) , and fires did not spread into intact forest, ecological impacts are considered minimal.

BNR

BNR experienced no classified burned area in 2025. The reserve remains predominantly forested, with 99.80% of intact forest cover. While some pixels along river channels were flagged in remote sensing analyses, these reflect misclassification due to water reflectance or edge effects rather than actual fire. Ecological impacts from fire in 2025 were negligible.

GSCP

GSCP recorded 22.49 ha burned in 2025 (0.35% of the reserve), which is significantly lower than the extent observed in 2024. In 2024, unusually dry conditions allowed fires to spread into secondary forest areas that have been regenerating since Hurricane Iris in 2001. In 2025, BA were more localized and largely confined to cleared or non-forest areas. GSCP is predominantly forested (97.88%), and under normal conditions, its seasonally flooded lowland broadleaf ecosystem limits fire spread. The reduction in BA in 2025 suggests that fire severity in GSCP is strongly linked to climate conditions and the spread of agricultural fires from outside the reserve.

MMNFR

MMNFR experienced almost no fire impact in 2025, with only 0.01 ha (0.00%) burned. The reserve is still 99.25% forested, and intact broadleaf forest is not naturally prone to frequent fire, like previous years. As noted in the LULCC Report for 2024, surrounding areas that have undergone land-use change are more susceptible to fire (Zambrano & Gutierrez, 2025). The contrast between intact forest inside MMNFR and adjacent agricultural lands proves how land conversion increases fire risk. This pattern highlights the importance of maintaining forest cover and carefully considering land-use decisions around PA boundaries.

Overall, fire activity within Ya'axché-managed protected areas in 2025 remained low and was largely restricted to non-forest areas. This pattern, consistent with observations in the LULCC Report for 2024, indicates that intact forest cover and active management contribute significantly to reducing the spread of fires. Although climatic variability and extremes are beyond the control of management, there are approaches that can improve fire suppression in protected areas. Ranger presence, fire risk monitoring, and rapid response to fires play a key role in limiting fire incursions. Strengthening collaboration with neighbouring communities and integrating seasonal climate information into fire planning will be essential to maintaining the resilience of these reserves.

Conclusion

This assessment of BA across the Toledo District, the MGL and Ya'axché-managed protected areas for 2025 highlights the impact of fire use in Southern Belize. While seasonal burning remains a common feature of the dry season, the scale and severity of fire can vary significantly year to year as was presented in the 2024 report. Although 2025 showed a reduction in BA compared to 2024, fire extent remained elevated relative to earlier years, indicating continued landscape vulnerability to fire use and misuse.

At the district and landscape scales, most fires are linked to agricultural practices, particularly slash-and-burn systems and seasonal savannah burning. Under typical conditions, these fires remain contained within intended areas. However, during hotter and drier years, such as those associated with El Niño conditions, fires are more likely to escape and spread into forested lands. Savannah habitats are fire dependent habitats but in recent years, fires in the savannahs of the Toledo district are burning with increased frequency and scale which may not always be attributed to natural fire occurrences. The sharp increase in BA observed in 2024, and the sustained levels in 2025, demonstrate how climate extremes can amplify existing land-use pressures.

Within the MGL, BA trends followed a similar pattern but at lower proportional levels than the wider Toledo District. This suggests that landscape composition, forest cover, and conservation management contribute to moderating fire spread with the exception being the 2024 fire season. Findings from this 2025 report should be considered alongside the LULCC Report for 2024 to reinforce the importance of maintaining forest integrity and managing land-use change to reduce fire risk and susceptibility.

Ya'axché-managed protected areas experienced minimal fire impact throughout the reporting period. BA were largely confined to previously cleared or non-forest lands, with intact broadleaf forest showing strong resistance to fire spread. Active ranger presence, fire risk monitoring, and rapid response capacity appear to be effective in limiting fire incursions and should be continuously strengthened.

Recommendations

Our principal recommendation is the collection of additional data to further strengthen this study. While we were able to establish a dNBR threshold to identify BA across multiple years, the inclusion of further field-based data would allow for the calibration of multiple dNBR thresholds to measure burn severity. Ground surveys of burned areas summarizing burn severity through the proportion of vegetation lost would be sufficient for this purpose. Using these data points, it would be possible to identify which NBR values correspond to specific burn severity levels and to estimate burn severity across the district as soon as satellite imagery becomes available. This would provide a completer and more accurate picture of fire patterns in Toledo and allow burn severity in remote areas to be assessed immediately through remote sensing, reducing, or eliminating the need for staff to spend extended periods trekking to inaccessible sites.

We further recommend expanding fire monitoring efforts through the combined use of satellite imagery and drone-based surveillance in areas identified as particularly vulnerable to fire. High resolution drone imagery would complement satellite data by allowing for rapid validation of BA, assessment of fire impacts on vegetation, and improved detection of small or understory fires that may not be captured in coarser-resolution imagery. Prioritizing monitoring in historically fire-prone and ecologically sensitive areas would improve early detection and response capacity.

In addition, we recommend the systematic integration of NASA's FIRMS into Ya'axché's fire monitoring workflow. FIRMS provides near real time active fire detections from MODIS and VIIRS sensors and could be used to rapidly identify emerging fire activity across Toledo. Coupling FIRMS alerts with existing dNBR-based analyses would enhance both early detection and post-fire assessment, enabling faster response times and better-informed decision-making.

Looking beyond Belize for fire mitigation strategies, we note that in tropical northern Australia, farmers and land managers are encouraged to burn early in the dry season and strongly discouraged from burning later in the season, when vegetation is drier and fires are more difficult to control (Philipps & Levick, 2019). In Belize, a comparable strategy would involve encouraging and incentivizing burning during March and April while discouraging burning in May. Given that the most severe and uncontrolled fires during the 2024 fire season were largely anthropogenic and occurred primarily in May, a temporal shift in burning practices could substantially reduce fire severity.

Implementation of this strategy would need to differ from the government-led approach used in Australia due to potential community resistance. However, village Alcaldes and Chairmen could play a critical role in promoting early-season burning if the economic and safety benefits are clearly communicated.

We also recommend targeted capacity-building and training for officers responsible for fire monitoring and response. Training should focus on the interpretation of satellite-derived fire products (including dNBR and FIRMS data), drone operation and image analysis, and the use of geospatial tools for rapid fire assessment. Strengthening technical capacity among monitoring officers would ensure that available data are effectively used and that monitoring efforts are both consistent and sustainable.

Limitations

An additional limitation of this study is that all analyses were conducted in-office using remote sensing techniques, with no field verification during the reporting period. While satellite-derived indices such as dNBR are well established for identifying BA, the absence of ground-truth data limits our ability to validate burnt extent and severity on the ground. Factors such as understory burning, partial canopy scorch, or small agricultural fires may be under- or overestimated when relying solely on remotely sensed data. Field observations would strengthen future analyses by improving calibration of burn severity thresholds and increasing confidence in BA estimates, particularly in heterogeneous landscapes and remote areas of the district.

Reference

Alcaras, E., Costentino, D., Guastafero, F., Parente, C., Pepe, M. (2022). Normalized Burn Ratio Plus (NBR+): a new index for Sentinel-2 imagery. *Remote Sensing*.

Bowen-Jones, E. 2001. Belize Lodge Excursions Biodiversity Assessment. Fauna and Flora International.

Czodrowski, P. (2014). Assessing classification accuracy in remote sensing: Kappa statistics and beyond. Springer.

García C., Ruscalleda J., Mcloughlin L., Cal K., (2014). Agroforestry Concession Management Plan Maya Mountain North Forest Reserve 2014-2019. Ya'axché Conservation Trust.

Gutierrez S., García C., García D., Dorgay B., Vasquez M., (2023). Bladen Nature Reserve Management Plan 2023-2027.

Lenox, L., Rodriguez, S., Gutierrez, S., Solomon, J., Ack, M., Chub, J., Dorgay, E., Garcia, C., & Requena, G. (2020). Golden Stream Corridor Preserve Management Plan 2020-2025 Ya'axché Conservation. In *GSCP Management Plan team*.

Meerman, J. (2013). Belize Basemap. Biodiversity and Environmental Resource Data System of Belize (BERDS)

Meerman, J. (2017). Belize Protected Areas. Biodiversity and Environmental Resource Data System of Belize (BERDS).

Miller, J. D., & Thode, A. E. (2007). Quantifying burn severity in a heterogeneous landscape with a relative version of the delta Normalized Burn Ratio (dNBR). *Remote Sensing of Environment*, 109(1), 66–80. <https://doi.org/10.1016/j.rse.2006.12.006>

NASA FIRMS. (2025). Fire Information for Resource Management System (FIRMS). National Aeronautics and Space Administration. <https://firms.modaps.eosdis.nasa.gov>

Philipps, R., & Levick, S. R. (2019). Early dry-season burning as a fire management strategy in northern Australia. *International Journal of Wildland Fire*, 28(5), 331–344. <https://doi.org/10.1071/WF18110>

Place M. R. & Gutierrez S.M., 2024. Toledo Fire Report, Annual Change and Burned Areas in the Toledo District, March 2021 to June 2024. Ya'axché Conservation Trust

Place, M. R., & Gutierrez, S., (2024). Land use/land cover change in the Maya Golden Landscape, 2023. Ya'axché Conservation Trust.

Roy, D. P., Boschetti, L., Justice, C. O., & Ju, J. (2008). The collection 5 MODIS burned area product—Global evaluation by comparison with the MODIS active fire product. *Remote Sensing of Environment*, 112(9), 3690–3707. <https://doi.org/10.1016/j.rse.2008.05.013>

USGS. (2023). Normalized Burn Ratio (NBR). U.S. Geological Survey.
<https://www.usgs.gov>

Zambrano K., & Gutierrez, S., (2025). Land use/land cover change in Toledo and the Maya Golden Landscape, January 2024- January 2025. Ya'axché Conservation Trust.



Toledo Fire Report

Annual Change and Burned Areas in the Toledo District

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Karen Zambrano
Protected Areas Geospatial Monitoring Officer
karen.zambrano@yaaxche.org

Said Gutierrez
Protected Areas Program Director
said.gutierrez@yaaxche.org