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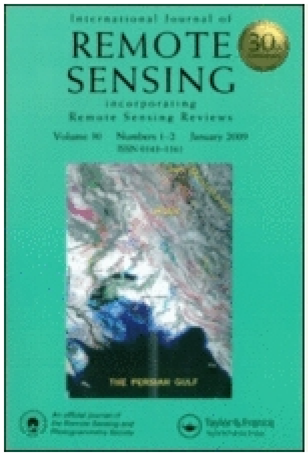

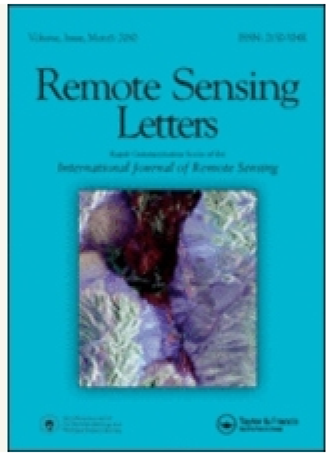

Tracking Forest Dynamic Trends in Belize: The Role of Protected Areas, Agriculture, and Fire in the South Eastern Selva Maya

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Tracking Forest Dynamic Trends in Belize: The Role of Protected Areas, Agriculture, and Fire in the South Eastern Selva Maya

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Abstract

The Selva Maya represents the largest expanse of tropical forest in Mesoamerica, encompassing parts of Belize, northern Guatemala, and south-eastern Mexico. Patterns and processes of forest loss in Belize are less comprehensively studied than other regions in the Selva Maya. Hence, this research tracks twenty years of forest loss in relation to Protected Areas (PAs) and transborder activity in the country. Results show that since 2000, Belize lost 11% of its forest cover. In that same period, 39.7% of this loss has seen forest recovery, predominantly in southern portion of the country, and within PAs. Ongoing forest loss in the north has expanded towards central and southern Belize. Forest loss in PAs account for 14.3% of overall loss nationwide, with fires and agricultural expansion playing a prominent role in the encroachment on forestland. A better understanding of forest loss in Belize reinforces distinctions between forest loss in the north and the south of the country and demonstrates the need for enhanced forest protection. This research provides new information to conservation planners to better understand the dynamics and drivers of forest loss and regrowth in the Selva Maya region.

1 Introduction

A jaguar nicknamed "short-tail" was recently captured on camera in both Belize and Guatemala for the first time, highlighting the degree to which threatened species' habitats transcend national boundaries (Garcia-Anleu et al. 2020). As the largest contiguous tropical broadleaf forest remaining in Central America (Carr 1999), the Selva Maya is ecologically significant. Its transboundary nature, spanning multiple bordering countries, offers a unique opportunity to examine the role of different institutional contexts in confronting forest loss pressures. This study adds to the growing body of literature surrounding degradation, deforestation, and conservation policy in the Selva Maya region (e.g., Ellis et al., 2020; Ramírez-Delgado et al., 2014), which extends over Belize, northern Guatemala, and southeastern Mexico. Prior research shows continued forest loss in northern Guatemala and south-eastern Mexico, through crop expansion, and associated forest fires (Ellis 2015) and transportation infrastructure (Ovando 2008).

Despite research documenting Belize's forests as globally significant within the Selva Maya for biodiversity and habitat protection (Anderson et al. 2008; Bridgewater 2012), many agree that forest loss is a tangible threat. Some studies on forest loss exist (Cherrington et al. 2010; Meerman and Cherrington 2005), yet previous research is sparse, with the most recent comprehensive analysis in 2010 finding that annual forest loss is above 100 km^2 annually and agriculture, in particular, appears to be a primary driver of forest loss nationwide, especially in the north, although increasingly in the south (Folkard-Tapp 2020; Kunen 2001). Doyle et al. (2021) revealed significant losses of forest and wetlands in Belize's Orange Walk district to Mennonite industrial agriculture and highlighted complexities in harmonizing forest conservation with agricultural needs and food security. Current literature lacks focus on the intersection between transborder activity (i.e., Belize and Guatemala) and protected areas (PAs), with forest loss and needs updating. In light of increasing pressure in Belize from forces such as agricultural expansion, there is a need to understand forest cover dynamics to determine how effective conservation efforts can be maintained.

This study focuses on 2000 – 2019, during which time government policies have influenced forest loss nationwide. For example, in 2015, Belize authorised the National Protected Area Systems Act (Young 2015), establishing a public-private network of PAs and enhancing the government's agency in environmental law enforcement. This legislation ensured official recognition of private PAs and enhanced government agency in PA law enforcement. In 2020, the declaration of a new wildlife corridor connecting Shipstern Nature Reserve with Honey Camp National Park and Freshwater Creek Forest Reserve (Government of Belize 2020) also signaled a national shift towards enhanced protection of natural spaces. As the country faces increased pressure for habitat protection, this research sits at the confluence between conservation policy, forest loss, and transborder activity in Belize over the past two decades. This study employs a global forest change dataset, global forest canopy height map, and the Moderate Resolution Imaging Spectroradiometer (MODIS) collection-6 active fire dataset to examine how forest loss dynamics intertwine with discussions surrounding government policy and transborder activity. Forest loss trends and active fire frequency and distribution are used to address the following questions:

1) What are the trends in forest loss in Belize between 2000 and 2019, and where has loss been replaced by forest recovery?
2) What are the key drivers of forest loss and does this differ across regions within the country?

2 Study Area

Belize sits on the east coast of Central America, defined by borders with Guatemala to the west, Mexico to the north, and the Caribbean Sea to the east. This study divides analysis into two regions: Northern Belize, consisting of Orange Walk, Cayo, Belize, and Corozal districts, and Southern Belize, consisting of Stann Creek and Toledo districts (Figure 1). There are 59 PAs in the North (38% area) and 41 in the South (49% area). This division is based on the two southern districts being predominantly Mayan inhabited, and more isolated from large scale infrastructure, as well as the topographical border formed by the Maya mountains. Forest is therefore impacted by differing agricultural techniques in these districts, versus the Mennonite and industrial farming practices seen further north, which have a linear spatial pattern, and occur across much larger areas. Agriculture and tourism are the most significant industries in Belize (World Bank 2017); the most prominent crop is sugar cane, employing 10% of the country's labor force (Chi et al. 2017). Belize is the most forested country in Central America, with 62.7% of its land area covered by forest (Cherrington et al., 2010).

3. Data

The 30 m Global Forest Change dataset captures canopy cover (defined as vegetation ≥ 5 m) and forest loss events across Belize. The moderate spatial resolution of this product is reportedly unable to detect fine-scale disturbances and has a false positive rate of 13%, and a false negative rate of 12.2% (Hansen et al. 2013) when detecting forest presence. Validation of Belize forest cover was conducted on the 2019 Hansen data using a random sample of 200 points and using Google Earth imagery for interpretation purposes. The 2019 forest cover map had an overall accuracy of 82% with a 10% omission error and 1% commission error. The 2019 30 m global forest canopy height map (Potapov et al. 2021) facilitated assessment of forest gain to address post-disturbance recovery over the two decades. These data combine the International Space Station GEDI Lidar instrument with Landsat data to create global forest canopy height measurements. At a 5 m threshold, such as that used in the Hansen forest loss product, assessments report 88% accuracy in forest presence detection (Potapov et al. 2021). NASA's Fire Information for Resource Management System provides active fire data from the MODIS sensor to show the spatial and temporal distribution of active fires. Researchers use the MODIS MOD14/MYD14 fire and thermal anomalies algorithm to detect fires 1000 m^2 or larger in typical conditions (Pagan et al. 2021).

4 Methods

This study uses annual forest loss data between 2000 and 2019 in conjunction with PA and county boundaries to compare forest loss within and outside PAs and in the northern and southern regions of the country. The year 2000 was chosen since it is the earliest extent of the dataset available. After reprojecting the data into NAD 1927 UTM Zone 16N, the total area of forest was calculated to measure annual forest loss. Forest loss divides into protected and non-protected areas, and north and south Belize. Forest loss between 2000 and 2019 was compared with the 2019 forest cover map (Potapov et al. 2021). For each region and for PAs, the percentage of the recovered forest, i.e., forest cover that was lost previously, but mapped as forest cover in 2019, was calculated by measuring the total overlapping area between the forest loss image and the 2019 forest cover image. The 1 km MODIS active fire product enables exploration of the association between annual forest loss and forest fire occurrence. A linear regression analysis was run between aggregate fires and forest loss in each year for the north and south to quantify the degree to which fires can explain variation in forest loss.

5 Results

5.1 Trends in Forest Loss

Nationwide, forest cover decreased by 11% between 2000 and 2019. The annual rate of forest loss is 130.4 km^2, rising by an average of 6.3 km^2 every year. These results are higher than previous reports, which found annual loss to be 100 km^2 between 1980 and 2010 (Cherrington et al. 2010) and 73.6 km^2 between 1986 and 2018 (Folkard-Tapp 2020). Evaluation alongside data from the Global Forest Watch shows countries across Central America are exhibiting similar amounts of forest loss ranging between 6.5% in Costa Rica and 21.0% in Guatemala (Hansen et al. 2013). Comparison with the 2019 global forest cover map (Potapov et al. 2021) highlights that 39.7% of forest loss between 2000 and 2019 had recovered. PAs account for 62.1% of the total land area in the country. However, the amount of forest loss in PAs, relative to their extent, is low, accounting for 14.3% of nationwide forest loss between 2000 and 2019. Furthermore, only 3.7% of permanent forest loss occurred in PAs. Of forest lost in PAs, 74.8% saw forest regrowth, and the largest concentration of permanent forest loss in PAs (39.6%) occurred in a single property, The Mountain Pine Ridge Forest Reserve. Although spanning 30.7% of the total land area in the country, the southern region only accounts for 26.7% of nationwide forest loss between 2000 and 2019. In 2011, 14.1% of the annual forest loss occurred in the southern region, the lowest percentage across the two decades. Additionally, between 2000 and 2019, 62.2% of areas that see forest loss in the southern region experience post-disturbance forestry recovery. Nationwide, 41.8% of the areas experiencing post-disturbance forest recovery are in the southern region. Areas that experienced permanent forest loss in the south are predominantly close to the coastline. In the north, permanent forest loss occurs in larger blocks. This is most prominent in the northern parts of Orange Walk and Cayo districts. Around Belmopan, forest loss is interspersed with post-disturbance forest recovery, particularly as you travel towards more dense forest in the south (Figure 2).

The same overall trend of increasing forest loss exists nationwide, whether looked at in aggregate, or when divided by north and south (Figure 3). In 2011, the highest total amount of forest loss was recorded (200 km^2) and accounted for 10.9% of forest loss since 2000. However, a spike in forest loss in 2011 is indiscernible from other years in the southern region (Figure 3).

5.2 Trends in Fire Occurrence

The peak in forest loss during 2011 is likely due to extensive forest fires. In October 2010, Hurricane Richard swept through central Belize, followed by unusually dry weather. By March 2011, Belize had only received 76% of the precipitation it would have usually received by that time (Meerman

2011). The woody debris windfall caused by the hurricane and the unusually dry fuels provided ideal conditions for large forest fires to occur. Reports suggest that fires ignited in multiple locations, particularly in Cayo District, due to mismanaged agricultural fires (Meerman 2011)

MODIS data reveal that fires occur predominantly outside of PAs, aside from Mountain Pine Ridge Forest Reserve, which sees an abundance of fires across the two decades (Figure 2). Outside of PAs, fires are distributed more randomly, without any discernible pattern, aside from a tendency to track the expansion of more intensive anthropogenic land-uses, for example, a higher concentration around the capital city of Belmopan. Annual fire frequency in the southern region is consistently lower than the north - between 5.7 (2001) to 43.7 (2003) fires per 1000 km^2, versus 41.5 (2002) to 225.4 (2019) fires per 1000 km^2 (Figure 3). Additionally, fire occurrence in the north tracks more strongly with the peak in forest loss in 2011. An OLS regression was performed between annual forest loss and annual active fires, and results show a significant association for the northern region (northern p-value was 0.001 and in the south was 0.32), indicating an association between forest loss and fire in the north but not the south. An (adjusted) coefficient of determination (R^2) of 0.06 for the south and 0.48 for the north further exposes disparities in forest loss drivers between the regions.

6 Discussion - Forest Loss Drivers

In Belize, borders appear to offer distinctive insights in forest loss drivers. These borders are discussed under two categories: PAs, and comparison between northern versus southern districts.

6.1 Forest Loss Drivers for Protected Areas

Comparison between forest loss data and PA boundaries suggest within PAs, forest management is effective in preventing conversion to agriculture, even as some forest loss does occur. The Mountain Pine Ridge Forest Reserve accounts for 39.6% of permanent forest loss in PAs. In this region, Southern Pine Bark Beetle and frequent fires infer chronic disturbance inhibits forest recovery without managed reforestation through tree planting and establishing a managed forest scenario. This is the only example of a high concentration of permanent loss occurring within one PA. The remaining 60% of permanent loss occurring in PAs is dispersed relatively evenly across the remaining PAs and not concentrated in contiguous patches. These finding elucidate claims that an effective web of interdependence between different actors with management responsibilities for PAs enable legislation and enforcement to be enacted with reasonable success (Mitchell et al. 2017). These results align closely with other studies, which suggest Belize's PA network is helping mitigate forest loss (Doyle et al. 2021)

Encroachment along the borders of PAs is taking place nationwide, but particularly in the north (Figure 2). Here, agricultural expansion is a significant driver of encroachment which impacts forest loss in two ways. Primarily, forest loss is driven by the conversion of forest to cropland. Policies such as establishing and enforcing the Protected Areas Act (Young 2015) help curb encroachment into PAs. However, the lack of policies outside PAs means the boundaries of PAs are prone to forest loss as agriculture expands. Secondly, active fire data analysis lead us to believe that mismanaged agricultural burning spreads into abutting PA forest land. Although not directly impacted by agricultural land conversion, agriculture therefore still plays a significant role in forest loss in PAs. Research from Brazil suggests sugarcane production, in particular, is a prominent driver of forest loss (Jusys 2017). Since sugarcane is one of the main economic sectors for Belize (Chi et al. 2017), it is reasonable to wonder whether development of agriculture for sugar cane production could be a driver of forest loss.

Encroachment into four key PAs also occurs along the border between Guatemala and Belize: Vaca Forest Reserve, Chiquibul National Park, Caracol Archaeological Reserve, and Columbia River Forest Reserve. This encroachment can be seen as early as 2001 and remains consistent across the two decades studied. This encroachment corresponds with research demonstrating fragmentation and forest loss are increasing along the border, including illegal logging up to 3.5 km into Belize from Guatemala (Chicas et al. 2017). In addition, results show fires are prevalent along the borders into these reserves (Figure 2), and extensive forest loss in some regions follow distinctive linear patterns of forest loss, consistent with agricultural expansion and its associated impacts. Previous studies indicate the lack of coordination among PA management organizations is the major challenge in this region (Chicas et al. 2017).

6.2 Forest Loss Drivers in the North versus South

As previously discussed, annual fires in the north can explain 48% of the variation in forest loss per year. Spatially, both forest loss and wildfires overwhelmingly track anthropogenic expansion due to the linear nature of their pattern. The correlation analysis also indicates that mismanaged agricultural burns are more of a concern in the north, where agrarian growth is prominent. As seen in 2011, during the most significant forest loss event, many of these fires started through mismanaged agricultural fires (Meerman 2011) used in sugarcane production.

Permanent forest loss in the south is sparse, particularly in Toledo District, aligning with existing literature that suggests forest loss is due to different agricultural practices of Mayan farming populations living in southern regions of the country (Levasseur and Olivier 2000). A coalition of actors and social movements fighting the governments granting of logging concessions were influential in shaping government policy with respect to conservation areas in Southern Belize. Community managed forest concessions in counties such as the Toledo District, as well as longstanding indigenous Maya claims for territorial recognition further protect forest in the south (Grandia 2009). Permanent forest loss that does occur track alongside the main road from Dangriga to Punta Gorda. There, the pattern of forest loss is much more linear and occurs mostly post-2010, suggesting an expansion of forest degradation towards the south over the last decade.

7 Conclusion

Belize has seen limited recent analysis of nationwide forest loss given the ecological significance of its location, as part of the Selva Maya. This study is the first of its kind to disaggregate forest dynamics on an annual basis in Belize. Increasing pressure from agriculture and infrastructural expansion reinforces the urgency of this research. Findings show that although forest loss amounts are high (130.4 km^2 per year), and increasing over time, PAs are helping mitigate permanent forest conversion. Given the significance of PAs in forest loss mitigation, and the unique disaggregated management structure of PAs in the country, there is justification for greater attention to using desegregated models for PA research and policy recommendations in Belize.

Forest loss at the edges of PAs is prevalent along the border with Guatemala and is happening more extensively in the north. More recently, increased amounts of forest loss have expanded towards the south. This appears to encroach towards locations of traditional Mayan farming practices which are more prominent in the south. Illegal logging appears to contribute heavily to PA encroachment along the border with Guatemala, impacting four key PAs south of the main road between Belmopan and Flores.

Results reinforce the analytical distinction between the north and south that should be considered in proceeding projects, for example, future development models, especially considering the relationship between the forest loss and fire occurrence ($R^2 = 0.48$) in the northern region. This correlation elucidates existing literature, which highlighted sugar cane production as a leading agricultural product in the country potentially exacerbating forest loss in the north, both in terms of the direct implications of agricultural expansion and the indirect impacts of mismanaged forest fires spreading to abutting forests.

Government policies have attempted to protect nationwide forests and PAs, yet forest loss continues. There is an urgent need for policies to confront specific forest loss drivers such as uncontrolled agricultural fires and to enhance coordination between PA management organizations given the disaggregated public-private conservation system. Given the global significance of Belizean forests, monitoring active fires, logging, and agricultural expansion is essential - alongside a need for government policies and funding to reflect an enhanced focus on forest protection.

Data Availability Statement

The Global Forest Change data supporting these findings is available on the University of Maryland Global Forest Change website: [https://earthenginepartners.appspot.com/science-2013-global-forest]. The MODIS Active Fire data that support these findings is available in the NASA Fire

Information for Resource Management System (FIRMS): [https://earthdata.nasa.gov/earth- observation-data/near-real-time/firms]. The 2019 30 m global forest canopy height map that supports these findings is available on the Global Land Analysis and Discovery website [https://glad.umd.edu/dataset/gedi/].

References

Anderson, Eric R., Emil A. Cherrington, Laura Tremblay-Boyer, Africa I. Flores, and Emilio Sempris. 2008. 'Identifying Critical Areas for Conservation: Biodiversity and Climate Change in Central America, Mexico, and the Dominican Republic'. *Biodiversity* 9(3–4):89–99. doi: 10.1080/14888386.2008.9712912.

Bridgewater, Samuel. 2012. *A Natural History of Belize: Inside the Maya Forest*. 1st ed. Austin: University of Texas Press.

Carr, Archie. 1999. 'Biological Monitoring in the Selva Maya'. *Wildlife Conservation Society* 51.

Cherrington, Emil A., Edgar Ek, Percival Cho, Burgess F. Howell, Eric R. Anderson, Africa I. Flores, Bessy C. Garcia, Emilio Sempris, and Daniel E. Irwin. 2010. 'Forest Cover and Deforestation in Belize: 1980-2010'. *Water Center for the Humid Tropics of Latin America and the Caribbean*.

Chi, Luciano, Jorge Mendoza-Vega, Esperanza Huerta, and José David Álvarez-Solís. 2017. 'Effect of Long-Term Sugarcane (Saccharum Spp.) Cultivation on Chemical and Physical Properties of Soils in Belize'. *Communications in Soil Science and Plant Analysis* 00103624.2016.1254794. doi: 10.1080/00103624.2016.1254794.

Chicas, S. D., K. Omine, B. Arevalo, J. B. Ford, and K. Sugimura. 2016. 'Deforestation Along the Maya Mountain Massif Belize-Guatemala Border'. *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* XLI-B8:597–602. doi: 10.5194/isprsarchives-XLI-B8-597-2016.

Chicas, S. D., K. Omine, J. B. Ford, K. Sugimura, and K. Yoshida. 2017. 'Using Spatial Metrics and Surveys for the Assessment of Trans-Boundary Deforestation in Protected Areas of the Maya Mountain Massif: Belize-Guatemala Border'. *Journal of Environmental Management* 187:320–29. doi: 10.1016/j.jenvman.2016.11.063.

Devine, Jennifer A., Nathan Currit, Yunuen Reygadas, Louise I. Liller, and Gabrielle Allen. 2020. 'Drug Trafficking, Cattle Ranching and Land Use and Land Cover Change in Guatemala's Maya Biosphere Reserve'. *Land Use Policy* 95:104578. doi: 10.1016/j.landusepol.2020.104578.

Doyle, Colin, Timothy Beach, and Sheryl Luzzadder-Beach. 2021. 'Tropical Forest and Wetland Losses and the Role of Protected Areas in Northwestern Belize, Revealed from Landsat and Machine Learning'. *Remote Sensing* 13(3):379. doi: 10.3390/rs13030379.

Ellis, Edward. 2015. 'Evaluación y mapeo de los determinantes de la deforestación en la Península Yucatán'. *USAID/TNC/MREDD+*. doi: 10.13140/RG.2.1.4132.1682.

Ellis, Edward A., A. Navarro Martínez, M. García Ortega, I. U. Hernández Gómez, and D. Chacón Castillo. 2020. 'Forest Cover Dynamics in the Selva Maya of Central and Southern Quintana Roo, Mexico: Deforestation or Degradation?' *Journal of Land Use Science* 15(1):25–51. doi: 10.1080/1747423X.2020.1732489.

Folkard-Tapp, Hollie. 2020. 'Deforestation in Belize-What, Where and Why' *preprint*. *Ecology*. doi: 10.1101/2020.01.23.915447.

Garcia-Anleu, Rony, Marcella J. Kelly, Jan Meerman, Robert B. Nipko, Brogan Holcombe, Darby McPhail, Gabriela Ponce-Santizo, Roan Balas McNab, Jeremy Radachowsky, Victor H. Ramos, and John Polisar. 2020. 'The Need for Transboundary Collaboration Across the Maya Forest'. *CATNews*.

Government of Belize. 2020. 'Legal Declaration of the North-Eastern Biological Corridor through Statutory Instrument'.

Grandia, Liza. 2009. 'Milpa Matters: The Maya Community of Toledo versus The Government of Belize'. P. 153 in *Waging War, Making Peace: Reparations and Human Rights*, edited by B. R. Johnston and S. Slyomovics. *Left Coast Press*.

Hansen, M. C., P. V. Potapov, R. Moore, M. Hancher, S. A. Turubanova, A. Tyukavina, D. Thau, S. V. Stehman, S. J. Goetz, T. R. Loveland, A. Kommareddy, A. Egorov, L. Chini, C. O. Justice, and J. R. G. Townshend. 2013. 'High-Resolution Global Maps of 21st-Century Forest Cover Change'. *Science* 342(6160):850–53. doi: 10.1126/science.1244693.

Jusys, Tomas. 2017. 'A Confirmation of the Indirect Impact of Sugarcane on Deforestation in the Amazon'. *Journal of Land Use Science* 12(2–3):125–37. doi: 10.1080/1747423X.2017.1291766.
Kunen, Julie L. 2001. 'Ancient Maya Agricultural Installations and the Development of Intensive Agriculture in NW Belize'. *Journal of Field Archaeology* 28(3/4):325–46.
Levasseur, V., and A. Olivier. 2000. 'The Farming System and Traditional Agroforestry Systems in the Maya Community of San Jose, Belize'. *Agroforestry Systems* 49(3):275–88. doi: 10.1023/A:1006327403980.
Meerman, Jan. 2011. 'Provisional Report on the Belize 2011 Wildfires Aftermath of Hurricane Richard'. biological-diversity.info/Downloads/2011_Wildfire_Report.pdf
Meerman, Jan, and Emil A. Cherrington. 2005. 'Preliminary Survey of Land Degradation in Belize'. *United Nations Convention to Combat Desertification*, doi: 10.13140/RG.2.1.3880.6480.
Mitchell, Brent, A., Wildtracks, Sarteneja, Belize, Paul Walker, and Wildtracks, Sarteneja, Belize. 2017. 'A Governance Spectrum: Protected Areas in Belize'. *Parks Journal.* 23(1):45–60. doi: 10.2305/IUCN.CH.2017.PARKS-23-1BAM.en.
Ovando, Dalia Amor Conde. 2008. 'Road Impact on Deforestation and Jaguar Habitat Loss in the Mayan Forest'. *Duke University Libraries.* 116.
Pagan, Andrew, John Rogan, Birgit Schmook, Zachary Christman, and Florencia Sangermano. (2021). Understanding agricultural fire dynamics in the southern Yucatán Peninsular Region using the MODIS (C6) active fire product. *Remote Sensing Letters.* 12. 715-726. 10.1080/2150704X.2021.1931530.
Potapov, Peter, Xinyuan Li, Andres Hernandez-Serna, Alexandra Tyukavina, Matthew C. Hansen, Anil Kommareddy, Amy Pickens, Svetlana Turubanova, Hao Tang, Carlos Edibaldo Silva, John Armston, Ralph Dubayah, J. Bryan Blair, and Michelle Hofton. 2021. 'Mapping Global Forest Canopy Height through Integration of GEDI and Landsat Data'. *Remote Sensing of Environment* 253:112165. doi: 10.1016/j.rse.2020.112165.
Ramírez-Delgado, Juan Pablo, Zachary Christman, and Birgit Schmook. 2014. 'Deforestation and Fragmentation of Seasonal Tropical Forests in the Southern Yucatán, Mexico (1990–2006)'. *Geocarto International* 29(8):822–41. doi: 10.1080/10106049.2013.868039.
World Bank. 2017. 'Country Partnership Framework for Belize for the Period FY18-22'. *World Bank.*
Young, Coleville. 2015. National Protected Areas System Act. *Government of Belize.*

Figures

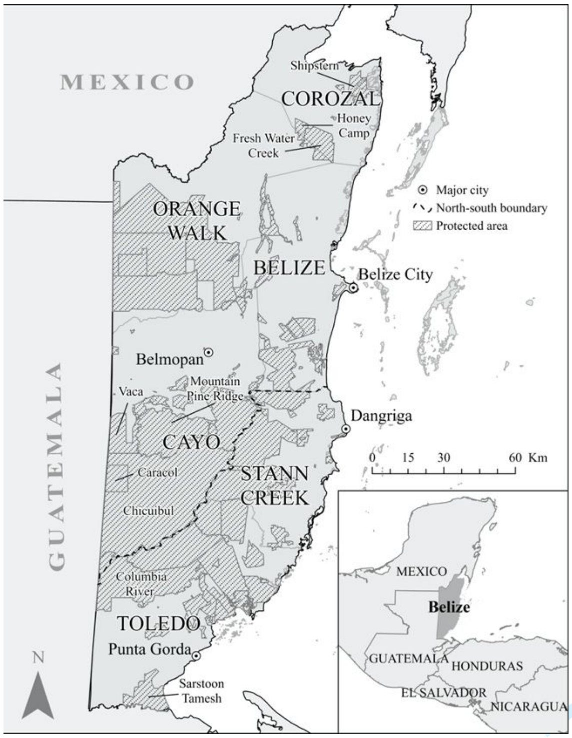


Figure 1: Location of the study area in Belize, including North-south boundary, defined in this project. Projected in NAD 1927 UTM Zone 16N.

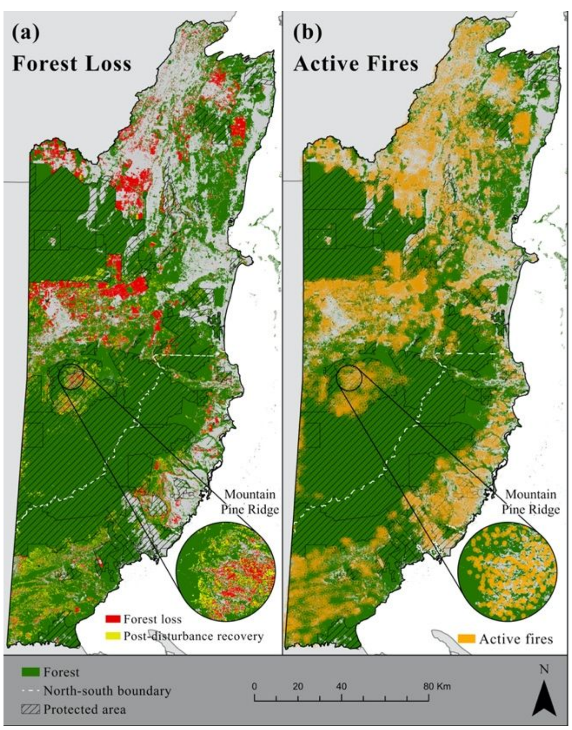


Figure 2: Forest loss and recovery in Belize (a) alongside MODIS collection-6 active fires (b) between 2000 and 2019.

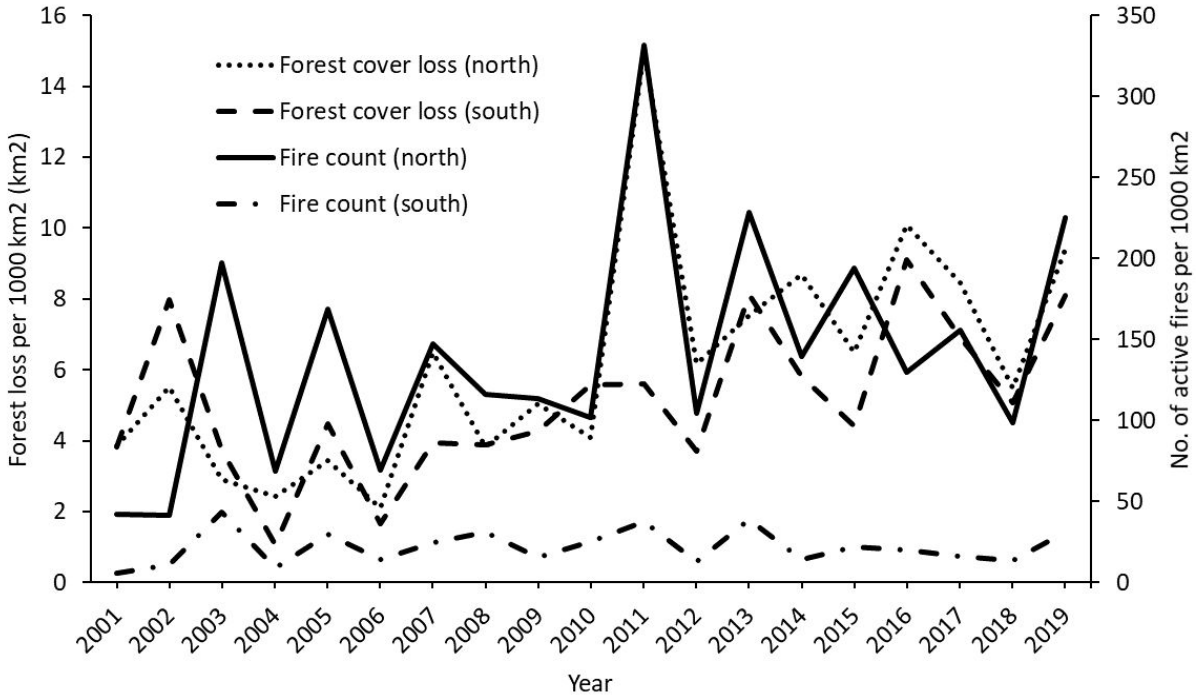
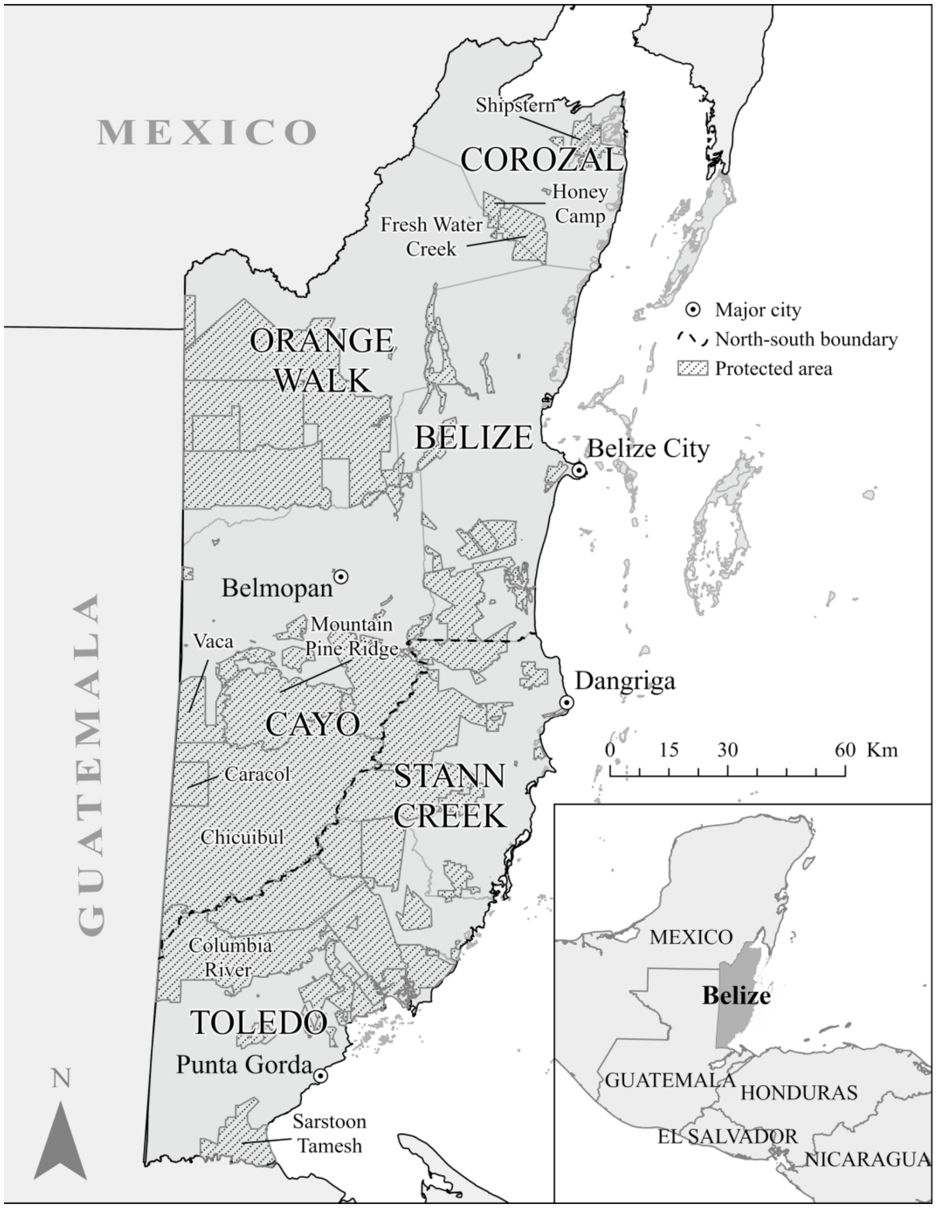


Figure 3: Distribution of MODIS collection-6 active fires per year and annual nationwide forest cover loss alongside loss per 1000 km^2 separated into north and south regions (2000-2019).



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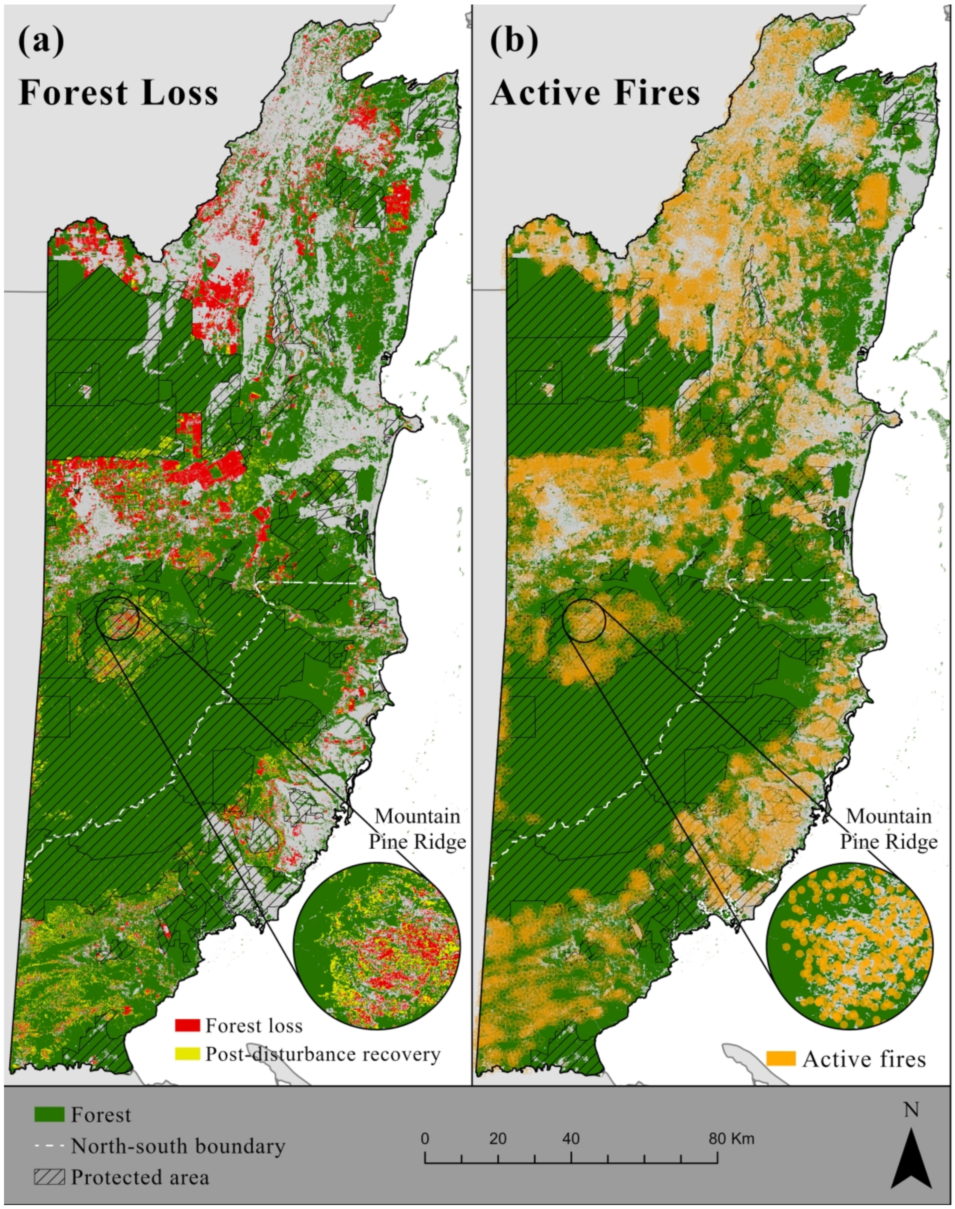

Figure 2: Forest loss and recovery in Belize (a) alongside MODIS collection-6 active fires (b) between 2000 and 2019.

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