A Remote Sensing Damage Analysis of the Chiquibul Forest Impacted by the 2020 Forest Fires

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Abstract:

The 2020 dry season forest fires caused extreme damage to the Caracol Archaeological Reserve and the Chiquibul National Park ecosystem, both of which form part of the Maya Forest, known as the largest remaining contiguous block of neo-tropical forest north of the Amazon. These forest fires burnt vast regions of standing tropical forests as a consequence of uncontrolled and unsustainable slash and burn milpa farming by Guatemalans, leaving behind severe burn scars. Given such severity and extent of the fires this study was conducted with the aim of assessing and quantifying the total acreage of forest and vegetation that was burnt due to human-caused forest fires for the 2020 dry season, in the Chiquibul Forest, using the NBR methodology. Landsat-8 images, dated May 4, 2019 were used to calculate the pre-fire 2019_NBR and Landsat-8 images dated May 22, 2020 were used to calculate the post-fire 2020_NBR, using the Raster Calculator Geoprocessing Tool. The change in pre-fire and post-fire NBR (2019_NBR – 2020_NBR) was then calculated. The fire scars were then digitized. A total of 8,216.46 acres were impacted in the Chiquibul Forest, which represents 3,284.42 acres in the Caracol Archaeological Reserve and another 4,932.04 acres in the Chiquibul National Park. The results of this study revealed that the 2020 forest fires were devastating and urges for an increased intervention to reduce agricultural incursions and cattle ranching that prevents further degradation of the forest.

Background

The Chiquibul National Park (CNP), established in 1995, is Belize's largest protected area, with 289,937 acres (117,333 hectares) of protected land. It comprises 29% of protected land in the country and nearly 5% of Belize's total land area (Groff & Axelrod 2013). Defined as an IUCN (International Union for Conservation of Nature) Category II Protected Area (Meerman 2005; Salas and Meerman 2008). The Caracol Archaeological Reserve (CAR) is a 10,340 ha restricted area designated in 1995 under the Ancient Monuments and Antiquities Act authorized by the Government of Belize to protect the Maya site of Caracol, the largest archaeological monument in Belize (Weishampel et al. 2012). Considered together with the Chiquibul Forest Reserve (CFR), the CAR and the CNP form the Chiquibul Forest, contiguous with the forests of Bladen Nature Reserve, Cockscomb Basin Wildlife Sanctuary, Columbia River Forest Reserve in Belize, and the Reserva de Biósfera Chiquibul-Montanas Mayas of Guatemala (Bridgewater et al. 2006).

The Chiquibul Forest shares a 45 km border with Guatemala, which is not well-defined, therefore causing a constant transboundary resource exploitation and extraction, mainly by Guatemalan farmers (Bridgewater et al. 2006). On the Belizean side, being surrounded by other

protected areas, the CNP has no Belizean communities lying adjacent to its border and has extremely limited access (Groff & Axelrod 2013). Conversely, on the Guatemalan side of CNP, there are approximately eleven communities that lie in close proximity to the Guatemala-CNP boundary line. There is a complex system of trails that lead into the CNP, which was created by Guatemalans located along the border (Salas and Meerman 2008). In Guatemala, land scarcity has led to an expansion of communities within the Reserva de Biosfera Chiquibul-Montanas Mayas (Grandia 2012), which was then followed by transboundary growth into protected areas in Belize. Resource extraction is primarily driven by Guatemalans (Groff and Axelrod 2013).

One of the main forms of natural resource exploitation, in the CNP and CAR, is the clearing and subsequent use of protected land for slash and burn milpa farming and cattle ranching by Guatemalan farmers. This then results in increased deforestation of protected forest in the CNP and CAR. A recent study carried out by Friends for Conservation and Development indicated that in 2019 approximately 2,575 hectares (ha) had been removed over the years in the Chiquibul Forest (including the CAR) for agricultural use. Slash-and-burn, a common practice amongst Guatemalan communities encroaching inside the Chiquibul, is used to convert lush rainforests into agricultural lands, through burning of slashed biomass. However, beyond these intentional fires, emerges the burning of vast regions of standing rainforests as an unintended consequence of uncontrolled human-caused fires due to the current land-use practices (Cochrane 2003). In the Chiquibul Forest, the use of fire in Guatemalan rural land-use systems is the major cause of wildfires. Quantitative estimates of areas burned are sporadic and incomplete in Belize.

Wildfires are, in fact, rare in the tropical rainforest due to the high humidity. Even in the dry season, the forest is usually too damped for lightning to spark a blaze or for accidental fires to take hold. In the Chiquibul Forest, wildfires are a direct result of mismanaged, unsupervised and uncontrolled small-scale fires used to clear land for agriculture. During the dry season, usually before the rainiest part of the year, Guatemalans will clear the forest and let it dry over a period of weeks. They will then burn the biomass and use the cleared land for agriculture. However, because Guatemalans have little to no incentive in controlling the fires, the fire is left unattended and it spirals out of control and burns down standing forest, leaving behind severe burn scars. Burn scar severity is a function of physical and ecological changes caused by fires to the forest cover. Fires burn heterogeneously across landscapes, with unburned and lightly burned patches interspersed among severely burned patches, due to variability in weather and landscape patterns (Hall et al. 1980). Fire spread and burn scar severity have been associated with abiotic factors including weather, moisture and slope (Romme and Knight 1981). The mapping of burn scars provides quantitative information on the acreage of forest burnt down and information on the target recovery activities needed. However, there is no common standard method to map out burn scar severity (Key and Benson 2005). Recently, the Joint NPS-USGS National Burn Severity Mapping Project implemented a method called the Normalized Burn Ratio (NBR) of the near-infrared and short wavelength infrared bands to map fire scars (Key and Benson 2005).

The difference between pre-fire and post-fire NBR, is now the primary method for mapping large remote fires. The short wavelength infrared band is employed due to the "near-infrared and short wavelength infrared" difference showing the largest change between pre- and post-fire images, especially in forested landscapes (Key & Benson, 2005). The near-infrared band encompasses 0.845 to 0.885 µm wavelengths primarily sensitive to the chlorophyll content of live vegetation. The short wavelength infrared band records middle infrared 2.10 to 2.30 µm wavelengths and is sensitive to water content in both soils and vegetation, the lignose content of non-photosynthetic vegetation, and hydrous minerals such as clay, mica, and some oxides and sulfates (Avery & Berlin, 1992). Furthermore, the short wavelength infrared band has been shown to be sensitive in separating non-photosynthetically active (dead) wood from soil, ash, and charred wood in a post-fire environment (Jia et al., 2006). As a result of using these two bands, NBR is particularly sensitive to the changes in the amount of live green vegetation, moisture content, and some soil conditions which may occur post-fire (Miller & Thode 2007).

NASA's Fire Information for Resource Management System (FIRMS) distributes Near Real-Time (NRT) active fire data within 3 hours of satellite observation from both the Moderate Resolution Imaging Spectroradiometer (MODIS) and the Visible Infrared Imaging Radiometer Suite (VIIRS). The goal of FIRMS is to meet the needs of natural resource and protected area managers that face considerable challenges in obtaining timely satellite-derived information on fires burning within and around their management area. VIIRS is a set of sensors on board the Suomi-NPP polar orbiting satellite, a joint initiative of NASA and NOAA (National Oceanic and Atmospheric Administration). There is global data coverage every 12 hours. VIIRS product used for near real-time fire monitoring and has a spatial resolution of approximately 375m. MODIS - refers to a set of sensors on board two satellites (Terra and Aqua) launched in 1999 and 2002. The operation of both sensors allows global coverage of the land every 1-2 days. The MODIS product used for near real-time fire monitoring has a spatial resolution of approximately 1000m. VIIRS, therefore, has the capacity to capture fires that are too small to be captured by MODIS. However, both systems complement each other for fire/detection (Davies et al. 2019).

From March 1, 2020 to May 3, 2020 a total of 267 fires were detected inside the CNP and 129 in the CAR using NASA's FIRMS Alert System. It is evident that the 2020 dry season saw a drastic increase in fire activity and the impact is noticeable through satellite imagery and remote sensing. This study attempts to assess and quantify the total acreage impacted due to human-caused forest fires of the 2020 dry season, inside the Chiquibul Forest, using the NBR methodology.

Methodology

Using Landsat 8 imagery from prior and after the 2020 fires, the damage caused to the Chiquibul Forest was calculated using a Normalized Burn Index (NBI). Landsat-8 images, dated May 4, 2019 and May 22, 2020, were acquired from United States Geologic Survey (USGS-EarthExplorer). Bands 7 (Short Wavelength-Infrared 2) and Band 5 (Near-Infrared), from each imagery were imported into ArcGIS Pro. The May 4, 2019 bands were used to calculate the pre-

fire Normalized Burn Ratio (NBR) and the May 22, 2020 bands were used to calculate the post-fire NBR. Using the geoprocessing tool "Raster Calculator" a new pre-fire raster dataset (2019_NBR) was created using the following equation: *("2019.tif_NearInfrared"-"2019.tif_ShortwaveInfrared_2") / ("2019.tif_NearInfrared" + "2019.tif_Shortwaveinfrared_2")* to determine its pixel values. The same equation was used with the May 22, 2020 imagery to create a new post-fire raster dataset (2020_NBR).

Using the Raster Calculator tool, the change in NBR (Change_NBR) was calculated, using the following equation (*2019_NBR - 2020_NBR*) and a new raster dataset was created. In doing so, values for areas that were not burnt were removed from the new raster dataset which showed only areas that were burnt. The "Condition Number" (green to red) color scheme was used to represent the new Change_NBR raster dataset. The burnt areas were then digitized and their acreage was subsequently calculated.

Fire Hotspots for the period of March 1 to May 3, were obtained from NASA's FIRMS website and were then imported into ArcGIS Desktop. This Near-Real Time (NTR) fire information was used to observe the patterns of the fire hotspots and their geographic distribution of the fires within the Chiquibul Forest.

Results

The Normalized Burn Ratio (NBR) of the Landsat-8 images revealed that primary hotspot areas where the forest fires were most severe included the Sapote and Caballo areas of the CNP and the Caracol Archeological Reserve (*see figure 1*). The area around the Cebada and Rio Blanco Conservation Posts (CPs) have less pronounced fire severity. Most of the high fire severity, seen as fire scars, in the Chiquibul, are conspicuous around land that had illegally been exploited for agriculture by Guatemalans. These agricultural lands, like the fire scars, are geographically spread along the Belize-Guatemalan border, more severe on the Guatemalan side. Outside the Chiquibul Forest, the Vaca Forest Reserve (VFR) and Reserva de Biosfera Chiquibul-Montanas Mayas were affected the most by the 2020 forest fires.

The digitization of the fire scars in the Chiquibul Forest revealed that approximately 3,284.42 acres of forest was impacted in the Caracol Archaeological Reserve and another 4,932.04 acres in the Chiquibul National Park as a result of the 2020 cross border fires (*see figure 1*). The fires reached in close proximity to some of the CPs; 20 meters in Rio Blanco, 100 meters in Valentin, 400 m in Caballo CP, and 1.2 km in Cebada. Furthermore, the fires extended 5 km into Belize in the Sapote area, 4.8 km in some areas of the CAR, 1.5 km in the Caballo area, 1.2 km in the Rio Blanco area and 600 meters in the Cebada area.

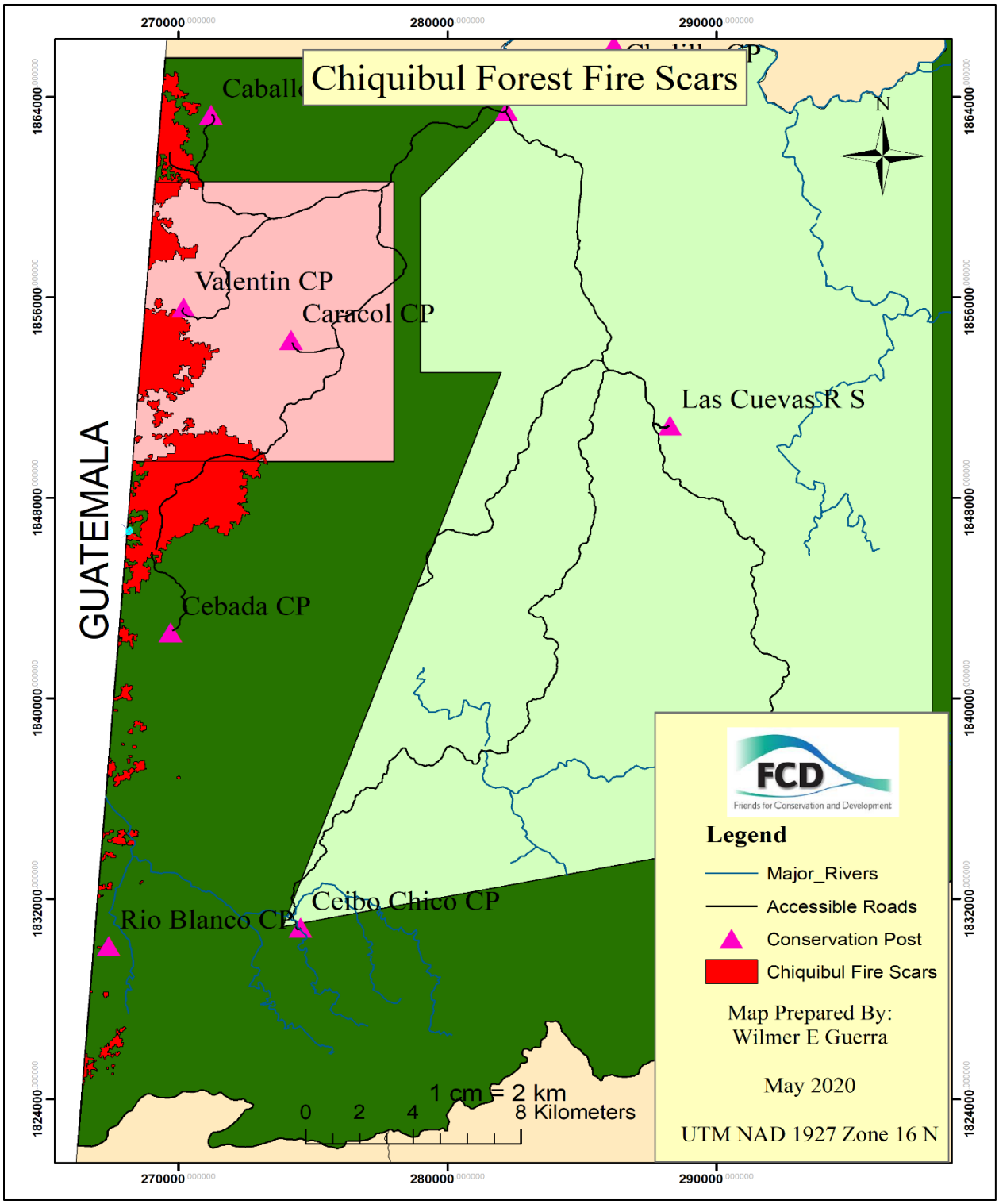

Figure 1: The digitization of the 2020 Chiquibul Forest Fires, (Digitized as Red). Fire scars spread all along the Belize-Guatemala border inside the Chiquibul National Park and the Caracol Archeological Reserve.

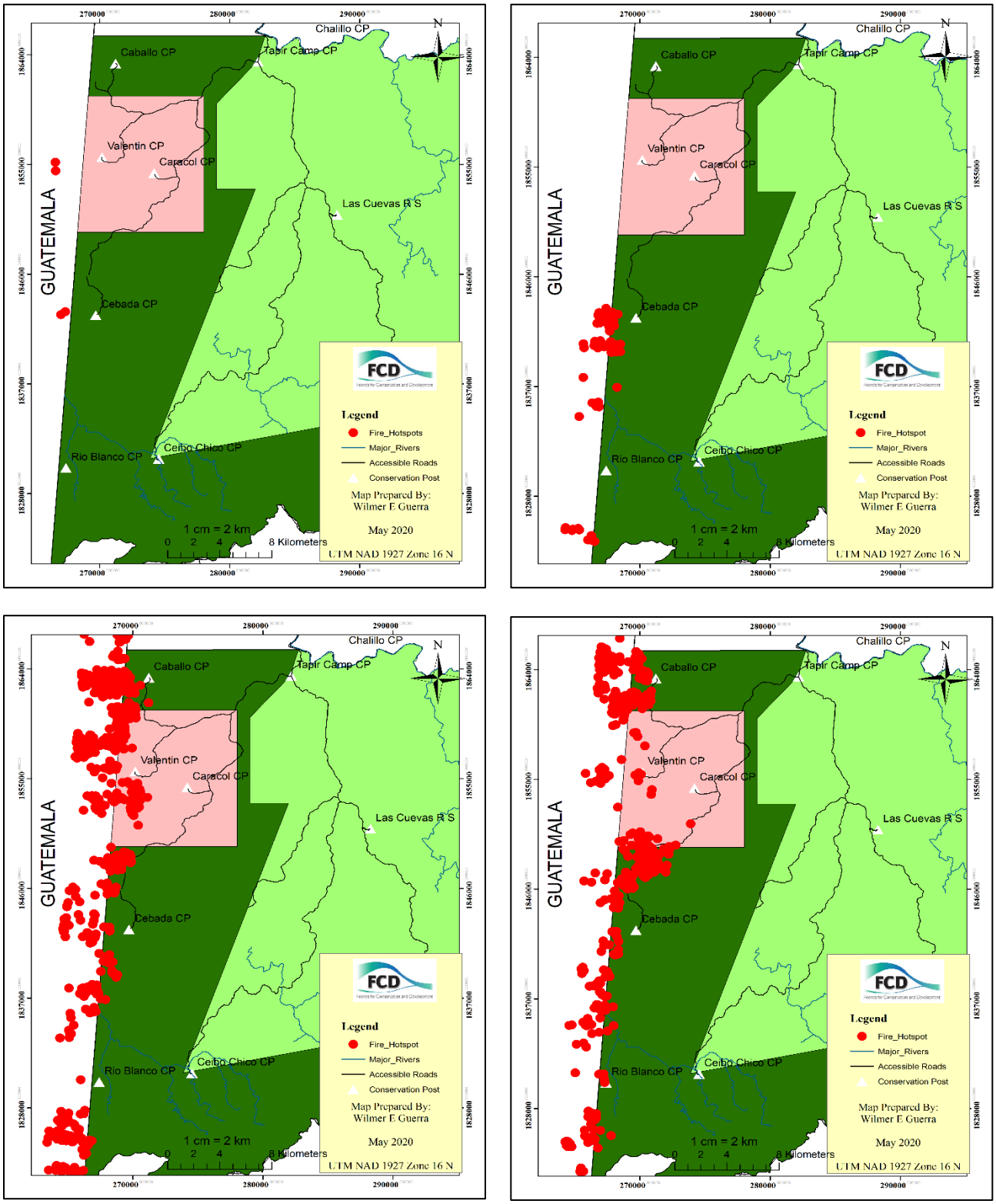

***Figure 2**: Showing Fire Hotspots detected by Nasa's FIRMS VIIRS and MODIS Satellites in the Chiquibul Forest for the periods of a.) (Top left) March 1-15, 2020. b.) (Top Right) March 16-31. c.) (Bottom Left) April 1-15 2020. d.) (Bottom Right) April 16-30 2020.*

Fires were also monitored through NASA's FIRMS Fire Alerts. There are two sources of NASA's Fire Alerts. The first source is MODIS (Moderate Resolution Imaging Spectroradiometer) and the second to VIIRS (Visible Infrared Imaging Radiometer Suite). From March 1 to May 3, 2020, a total of 398 fires were detected inside the Chiquibul Forest (129 fires in the CAR and 268 fires in the CNP). Furthermore, there were approximately 842 fires detected, within a 5 km buffer from the Chiquibul Forest, on the Guatemalan side from March 1 to May 3, 2020. Fire detection initiated, on the Guatemalan side around mid-March but by its peak, towards mid-April, fires had moved well into Belizean territory. On April 13, 2020, a total of 66 fires were detected by NASA's FIRMS satellites, the biggest detection of fires in the Chiquibul Forest in one day (24 hrs).

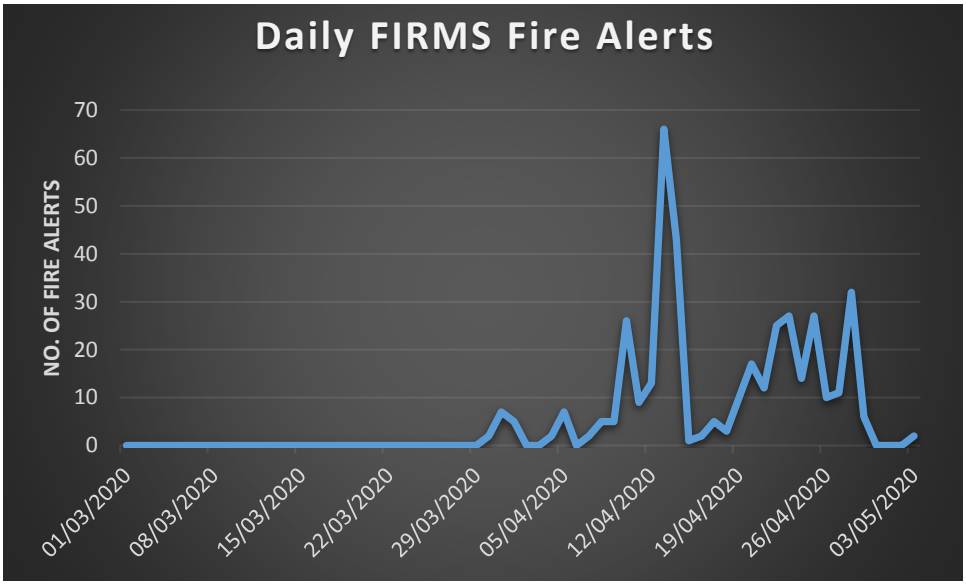

***Figure 3**: Showing Daily Fire Hotspots Alerts for the months of March and April, 2020. Fire Detection peaked on Mid-April with a total of 66 fires detected in one single day.*

Discussion

Belize has a tropical climate with pronounced wet (rainy) and dry seasons. Average temperatures can be influenced by a series of factors including elevation, proximity to the coast, and the moderating effects of the northeast trade winds of the Caribbean. Temperatures are slightly higher inland, except for the southern highland plateaus, such as the Mountain Pine Ridge, where it is noticeably cooler year-round. Overall, the seasons are marked more by differences in humidity and rainfall than in temperature. The dry season, in Belize, is from December to May and the rainy season if from June to November. Average temperature can reach up to 91 degrees Celsius in the dry season and average rainfall is 1,500 mm per year (Dillon & Kelly 2007).

Subsistence agriculture is highly vulnerable to this year-to-year climate variability (Jones et al. 2000). Slash-and-burn *milpa* farming is the common form of subsistence farming by

Guatemalans along the Belize-Guatemala border and those encroaching inside the Chiquibul Forest. This form of farming is characterized by the clearing of forest and subsequent burning of the biomass, which is achieved towards the end of the dry season (April or May), immediately before the rainiest part of the year (Styger et al. 2007). This increases the chances for optimum growth of crops because of the right amount of rain fall. Since large plots of forests are cleared and subsequently burnt, fires were monitored using NASA's FIRMS Alerts. Fire detection inside the Chiquibul Forest and along the border line, initiated around late-March and peaked around mid-April, right before the start of the rainy season. Fires started on the Guatemalan side and right along the borderline but by the end of April fires had moved about 5 km into Belize. A total of 398 fires were detected inside the Chiquibul Forest (129 fires in the CAR and 268 in CNP) from March 1, 2020 through May 3, 2020. On April 13, 2020, a total of 66 fires were detected by NASA's FIRMS satellites, the biggest detection of fires in the Chiquibul Forest in one day (24 hrs). Fire activity was much more pronounced on the Guatemalan Reserva de Biosfera Chiquibul-Montanas Mayas, which abuts Belize's Chiquibul Forest with a total of 842 fires detected within a 5 km buffer from the CNP borderline from March 1, 2020 through May 3, 2020.

Forest clearing and subsequent burning can be linked to Guatemalan agricultural settlements along the border. This transnational border security problem has caused severe forest and resource degradation in the Maya Mountain Massif (MMM), including the Chiquibul Forest. These Guatemalan communities along the border are highly dependent on forest resources and their food sources and economic sustenance is dependent on expanding agriculture or clearing new land on already marginal forests, and extracting/exploiting resources from these forested areas. Rapid population growth and extreme poverty in Guatemala along with a limited law enforcement and border security presence in Guatemala and Belize can be attributed to the persistent illegal forest clearing that has taken place along the border region over the past 3 decades (Chicas et al. 2016).

In the Chiquibul Forest, along the Belize-Guatemalan border, deforestation continues despite efforts to control incursions and illegal extraction by Friends for Conservation and Development, who co-manage the CNP, and other security forces. FCD's efforts are limited due to man-power constraints. Success in curbing deforestation is additionally limited by a lack, if not complete absence, of enforcement on the Guatemalan side. As a result, approximately 3,284.42 acres was impacted in the Caracol Archaeological Reserve and another 4,932.04 acres in the Chiquibul National Park. Primary hotspot areas where the forest fires were most severe included the CAR and in CNP the Sapote and Caballo areas. In some areas of the CAR fires extended to about 4.8 km from the Guatemalan border into Belize and reached to about 100 m in proximity to the Valentin Conservation Post. The 3,284.42 acres (1,329.16 ha) burnt in the CAR represents 12.85% of the total protected area (10,340 ha) of the archaeological reserve. The CAR remains one of the areas most affected by deforestation for agriculture (*see figure 4*). A study by Weishampel et. al (2012) documented that in the CAR, deforestation extended to about 2.5 km from the Guatemalan border and that most of the deforested areas were being used,

continuously, for agriculture or pastureland, and hence forests were not permitted to regenerate.

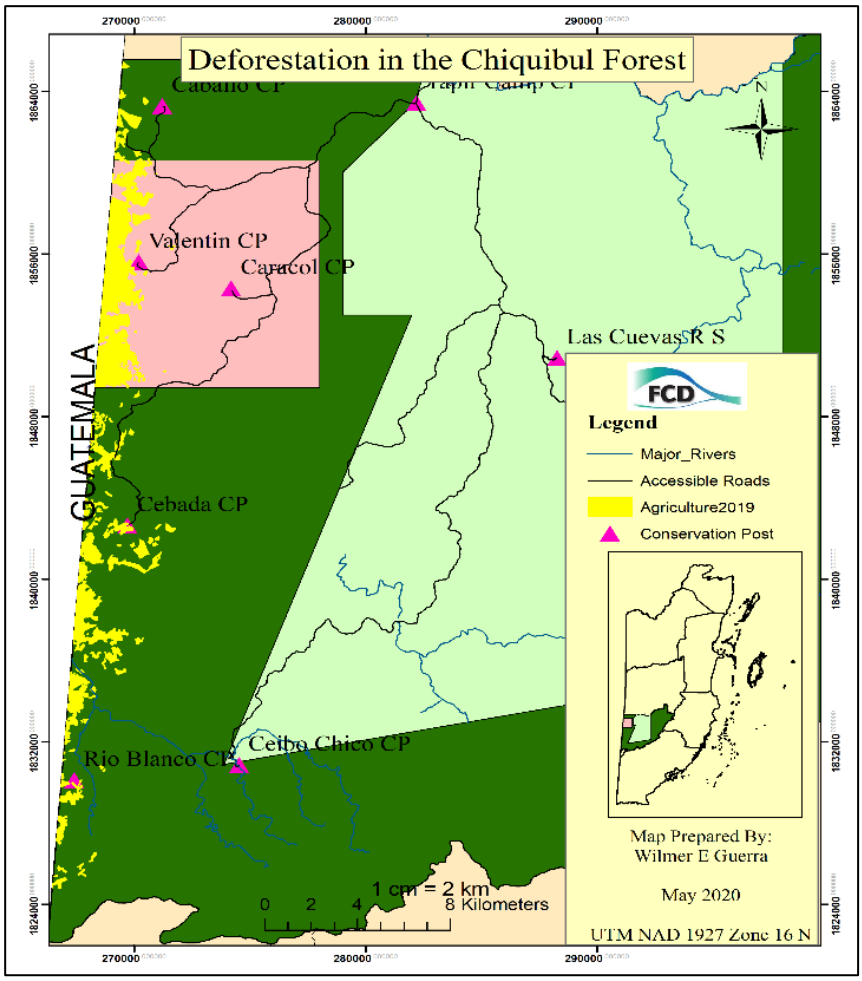

***Figure 4**: Showing Deforestation in the Chiquibul Forest, July 2019.*

The 4,932.04 acres that was burnt in the CNP represents approximately 1.70% of the total land surface of the protected area. Within the park, fires were most severe in Caballo and Sapote, extending 1.5 km and 5 km from the Guatemalan border into Belize respectively. Fires in the Sapote area were the most devastating, 3,348.08 acres were impacted (representing 67.88% of the total burnt area in CNP) in that region. Both Sapote and Caballo border the CAR. Furthermore, adjacent to Sapote and Caballo, on the Guatemalan side, lies the Guatemalan villages of San Jose Las Flores, Nueva Esperanza and La Cebada respectively. These communities, as well as others, along the border, engage in unsustainable slash and burn farming, which many times get out of control, burning down hundreds of acres of forest. By 2014, because of land use for agriculture, only fragmented patches of forest remained in Guatemala (Chicas et al. 2016). With the forest that once served as a buffer for Belize now depleted, and given the limited monitoring capabilities

by regulatory organizations in Guatemala, deforestation and incursions inside Belize's Chiquibul Forest has remained constant.

In the western part of the Chiquibul, along the Belize-Guatemalan border, four Conservation Posts (CP) have been established with the goal of regaining deforested forest patches of the Chiquibul Forest. These include Caballo, Valentin, Cebada and Rio Blanco. Each CP has a mandate to patrol and enforce Belize's environmental laws, through a joint effort which includes the BDF, Police Department (SPU), Forest Department (FD) and FCD. Despite this multi-stakeholder support there was very limited success in preventing fires this year. The fires reached in close proximity to some of the CPs; 20 meters in Rio Blanco, 500 meters in Valentin, 1.2 km in Cebada and 1.3 km in Caballo CP. Currently, there is no Fire Mitigation Plan for either the CNP or the CAR. The Government of Belize has had little success in fire control, even in the pine plantations and the Fire Protection Act has never been implemented successfully (Sabido & Meerman 2001).

The impacts of forest degradation due to agriculture and forest fires along the Belize-Guatemalan border represents ecological and environmental threats for Belize's Chiquibul Forest (Chicas et al. 2016). The increase of forest degradation due to the recent forest fires will further aggravate the current ecological and environmental situation. These tropical broadleaf forest fires are usually low, and slowly creep through the leaf litter but the damage can be profound. In Central America's tropical broadleaf forest most species of trees have evolved in the absence of fire and thus developed little tolerance for it (Budowski 1966). Tree mortality as the result of such slow fires may continue for several years after the actual fire. The mortality either being the result of direct damage or indirect damage such as increased pathogen access through the fire damaged bark. Fire also kills native, regenerating tree species and allows invasive shrubby and herbaceous species to colonize the open surfaces (Styger et al. 2007). Furthermore, each fire, which leaves more dead or dying trees behind makes the forest even more prone to fire damage (Sabido & Meerman 2001). Although this study quantified the acreage burnt due to the 2020 forest fires there is a need for further analysis on the ecological and environmental impacts of these fires.

Conclusion

Using the ArcGIS Pro software and the NBR methodology it was determined that approximately 3,284.42 acres was impacted in the CAR and another 4,932.04 acres in the CNP as a result of the 2020 cross border fires. Areas that were affected the most included the Caballo and Sapote area of the Chiquibul National Park, and the Caracol Archaeological Reserve. In the area of Sapote the fires extended to about 5 km from the Belize/Guatemalan border and the damage was extensive. In some areas of the CAR the fires extended to approximately 4.8 km and in Caballo about 1.5 km. Therefore, failure to develop a Fire Mitigation Plan might result in continued ecological and environmental degradation, and damage public health, welfare and finances as the areas burnt are now fire prone areas.

Recommendations

In order to address this critical transnational, political, and ecological situation that threatens Belize's cultural and natural heritage there must be good collaborative networks between the border area stakeholders, on both sides of the border. In Belize, there must be increased support and a more determined patrol system to reduce incursions along the border.

More specific recommendations include:

1. The Government of Belize to do an exchange of note to the Guatemalan Government about the serious environmental impacts created by Guatemalan farmers and ranchers on Belizean territory and for them to dissuade their populations from further incursions and encroachments in compliance with the Confidence Building Measures and Belizean environmental regulations.
2. Develop a full mapping of the extent and effects caused by the fires through a Commission comprised of Belize and Guatemalan authorities and promote an open dialogue with targeted communities on the adjacency zone through the leadership of the Organization of American States.
3. Institute a Binational Forest Fire Prevention Taskforce as recommended on the MoU for the Protection of the Environment signed by both Governments in 2014 that prevents future upsurge of this environmental threat in the Chiquibul-Maya Mountain landscape.
4. Create an intense annual binational environmental education and outreach campaign in advance of the dry weather with the aim of sensitizing populations across borders of the regulations and guidelines.
5. Impose heavy fines and imprisonment on anyone one found slash and burning the forest in the protected areas.
6. Build local capabilities to combat forest fires and acquire the proper equipment to address tropical montane wild fires.
7. Maintain a monitoring presence at Conservation Posts and boost up patrols as formidable presence to deter agricultural encroachments and cattle ranching.

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