Mapping and Assessment of Slash-and-Burn Farming in Palawan, Philippines Using Various Fire and Burnt Area Products

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ABSTRACT

Slash-and-burn agriculture or *kaingin* is a method of clearing and burning of forest for the planting of agricultural and agro-forestry crops. Observed effects of kaingin are destruction of forests, grassland fires due to uncontrolled or accidental fires, degraded soil, cultivation leaching, massive erosion and landslide. This study utilizes Fire Information for Resource Management System (FIRMS), Moderate Resolution Imaging Spectroradiometer (MODIS) Active Fire and Thermal Anomalies, Fire CCI (European Space Agency Fire Climate Change Initiative), and MODIS Burned Area for a study period of 2015 to 2022. Results show that both fire and burn products capture the burning season in Palawan, occurring in April and March with high fire pixel counts, concurrent to its climate's dry season. La Niña affected the trend across datasets wherein declines in fire pixel count during the years 2021 and 2022 were observed. The use of fire and burnt product depicted fire schemes across vegetation types. Clusters are assesed per vegetation type revealing fire incidents occured predominately over shrublands with low intensity and temperature fire, and long duration of burns; and open forests with intense and high temperature fires with varying duration of burning. Moreover, density of fire occurrences are highest in the municipalities of Sofronio Espanola, Bataraza, Rizal, Quezon, Culion, Roxas, Aborlan, Taytay and Narra. Synergestic use of fire and burned area products is instrumental in understanding the quality and characteristics of fire; fire descriptors and schemes are crucial for fire management strategies.

Keywords: Fire detection, Burnt area mapping, Fire intensity, Brightness Temperature, Fire occurrence, Hot spot analysis

1. INTRODUCTION

Palawan is the country's largest province with known primary forests of great biodiversity of flora and fauna. It is recognized as the Philippine's Last Frontier[1]. Over the years, forest cover has been decreasing reported by the Global Forest Watch from 2001 to 2020; and is critical in southern portion of the province. Forest cover loss are attributed to anthropogenic activities such as mining operations, slash-and-burn, oil palm expansion and timber poaching. The effects of such activities has casued destruction of forests, grassland fire due to uncontrolled or accidental firess, degraded soil, cultivation leaching, massive erosion, and landslide[2].

Kaingin is a method of clearing and burning of forest for the planting of agricultural and agro-forestry crops. Practice of slash-and-burn agriculture or swidden agriculture in the Philippines is mainly for subsistence, labour, and livelihood of Indigenous People (IPs) in their ancestral domains. Section of forest area are cleared for rice paddy, root crops cultivation. The land-clearing system of the swidden agriculture of Tagbanua farmers of Palawan drawed on knowledge and practices are aligned with well-honed techniques and environmental care, patience and resourcefulness[3]. IP aim to control kaingin fire limiting areas to cultivate, and size for a more responsible burn. Swidden agriculture has burdened the blame of being a primary cause of tropical deforestation. The slash-and-burn method for agricultural practice and subsistence have very minimal impact on the forest ecosystem; and the land cover change and deforestation in Palawan are largely contributed by logging activities for timber product, mining, and oil palm production and wide-scale kaingin[3]; majority of these are situated in Sofronio Espanola, Brooke's Point, Quezon and Bataraza. Additionally, clearing of new kaingins are done by new migrants in higher elevations or at the forested margins[2]. This created a competition of forest resources between lowland migrants and IPs in their ancestral lands; former traditional livelihoods of IPs are lost due to unsustainable practices of migrants. Consequently ranking slash-and-burn or kaingin in one of the drivers of deforestation and forest degradation in the Philippines.

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With forest management rules and laws, the problem on large scale operations still persists. Existing researches have studied that the protection of forests lack provision for enforement, policies that opened forestlands to various industries and businesses that are contracted for land conversion[5]. Continuous monitoring of fire occurences associated with slash-and-burn and forest fires over the province can be aided with information given by spaceborne sensors; providing synoptic coverage and temporal measurements. Existing studies have shown the use different datasets, and it has challenged the identification and mapping of burnt areas[6]. To date, there are several fire and burnt area products available globally at resolutions ranging from 250m to 1km. Considering that each data product has its own advantages and disadvantages, it is important to examine the synergistic use of available fire and burnt area mapping products to obtain a better picture of kaingin in areas of interest.

This study examines the spatiotemporal distributions of slash and-burn in the Province of Palawan in the Philippines. The use of fire and burned area products is essential in understanding the quality and characteristic of fire; Moderate Resolution Imaging Spectroradiometer (MODIS) Active Fire and Thermal Anomalies provides fire intensity and temperature with Fire Radiative Power measurement and with Fire CCI and MODIS Burned Area, duration of fire activity can be calculated. Hot spot analysis determines fire regime descriptors of high and low intensity, duration and occurence with Getis-Ord (Gi*) spatial autocorrelation statistic. These variables are anaylzed with comprehension on climate and economic drivers undertaken in the region. Information on fire descriptors are crucial for fire management strategies. Best supported and complemented with sound decision making, preventive measures, and rehabilitation efforts, this will help in sustainable foresty in the country.

2. METHODOLOGY

2.1 Study Area

The province of Palawan is situated in the island of Luzon, Philippines. The province is comprised of two climate types: Type I and III; with Type I experiencing two pronounced seasons, dry conditions during November to April, and wet conditions for the rest of the year, while Type III has evenly distributed rainfall with short periods of dry season either December to February or March to May. Nonetheless, dry season is during November to May.

Land cover in the province comprised of annual crop, perennial crop, shrubs, built-up, closed forest, open forest, grassland, inland water, fishpond, mangrove forest, marshland, and bare mapped by the National Mapping and Resource Information Authority (NAMRIA) in 2020 as shown in Figure 1.With 36% of its total area is open forest, 27% is shrubland, 10% are perennial crop, 8% -- closed forest, 7% annual crop and 5% is grassland; that is 97% of the province are covered by vegetation.

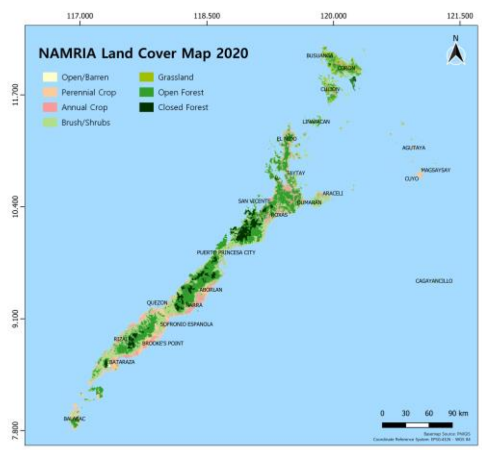

Figure 1. NAMRIA Land Cover Map (2020) of Palawan, Philippines.

2.2 Data Products

Fire global products from Fire Information for Resource Management System (FIRMS), MOD14A1.061/MYD14A1.061 Moderate Resolution Imaging Spectroradiometer (MODIS) Active Fire and Thermal Anomalies and burn products from Fire CCI (European Space Agency Fire Climate Change Initiative), and MCD64A1.061 MODIS Burned Area were utilized for a study period of 2015 to 2022. Algorithm for datasets is shown in Table 1. Monitoring fire and burnt areas with the use of near real time dataset from FIRMS has its advantage for an active monitoring system at 1km spatial resolution. This is derived from MODIS Active Fire and Thermal Anomalies which is also used for comparison. Both products detect fire pixels only during satellite overpass.

Table 1. Fire detection and burn mapping products.

Dataset and Availability	Fire detection/burn mapping algorithm
FIRMS, 1km (until 2022) MOD14A1.061/MYD14A1. 061 MODIS Active Fire and Thermal Anomalies, 1km (until 2021)	Brightness temperatures derived from the MODIS 4 µm and 11 µm channels, denoted by T4 (Channel 21/22) and T11 Channel 31)[7], respectively. MOD14A1/MYD14A1 is a level 3 fire product where eight days of data are composited[7].
Fire CCI, 250 m (until 2020)	Two-phase hybrid approach: Seeds: pixels with high probability of being burned are detected based on the active fires[8] (MOD14/MYD14 Fire and Thermal Anomalies product) Growing Phase: adaptive thresholding of area surrounds each seed using NIR pre and post fire images[8].
MCD64A1.061 MODIS Burned Area, 500 m (until 2022)	Dynamic thresholds from multi temporal composite imagery generated from a burn-sensitive vegetation index and a measure of temporal texture[9]. Cumulative active fire maps are used to guide the selection of burned and unburned training sample[9].

Additionally, land cover layer from NAMRIA for the year 2020, and digital elevation model (DEM) from NASA SRTM were utilized to correlate fire clusters with the land cover and topographic variables associated with slash-and-burn.

2.3 Analyses

Retrieval of fire and burn global data products was processed in Google Earth Engine, utilizing the available image collections which are processed for quality assessment, pixel count, and aggregation. Each dataset highlights different fire and burn feature: brightness temperature from FIRMS, maximum fire radiative power of MODIS Active Fire, length of burning days from MODIS Burned Area and Fire CCI. These characterizes intensity, duration, and frequency of fire activity in the province. Fire and burn pixel count for each dataset were computed monthly and yearly; and subjected to a time series analysis to understand its frequency, occurrence and observed patterns. Quality assessment bands for each dataset, confidence level and uncertainty are applied, accordingly. Generally, images are masked to 80% confidence, and less than 50 level of uncertainty in burn day.

Along with temporal variabilities, spatial clustering is analysed using Moran’s spatial autocorrelation statistics, indicating clustering or dispersion. Hot spot and cold spots of fire temperatures, intensity, and duration were also computed through Getis-Ord (Gi*). These outputs spatial patterns of high-temperature, intensity, and long duration as hot spots while cumulation of low concentrations of features as cold spots. Spatial clusters output of the fire and burn were examined and assessed with respect to the topographic variables: elevation, slope, and vegetation cover for characterization of kaingin.

3. RESULTS AND DISCUSSION

3.1 Fire & Burn Pixel Count

The fire detection products, FIRMS and MODIS Active Fire and Thermal Anomalies, showed similar patterns in fire pixel count; with an average of ± 80 in fire pixel count difference. Difference between the dataset is mainly manifested during the months March and April and suggests algorithm differences as they are derived from the same product, MODIS MOD14/MYD14 Fire and Thermal Anomalies. FIRMS provide ultra near-real time data, with a latency of less than ~60 seconds from observation in continental United States using direct broadcast while available globally within 3 hours[10]. This information on active fire locations is apt for environmental monitoring, response to hazard/disaster events, etc. On the other hand, MODIS Fire standard product is made available within 8-40 hours of satellite observation[11]; providing standard and science quality product using best available ancillary, calibration, and extensive pixel-level quality assurance[7]. Both fire detection dataset is grounded to contextual algorithms that exploits brightness temperature from MODIS 4um and 11um channels identifying only fire and non-fire pixels. Fire pixels are identified through the neighbouring pixels characterization of background or signature of an active fire. For each fire pixel detected, fire radiative power is estimated using the 4um brightness temperature, expressed in megawatts, mW. Misclassifications of the detection can be from sun glint, desert boundaries and errors in water mask[7].

Fire CCI maps burnt area at 250 m, and MODIS Burned Area Product at 500 m provides burn products measured retrospectively through multi-temporal detection, accompanied with active fire as training samples. Fire CCI and MODIS Burned Area Monthly Global show temporal similarities in burned area detections, a comparatively ± 187 in burn pixel count. Despite the similar approach, Fire CCI provides higher spatial resolution of 250 meters and good agreement with fire products.

3.2 Temporal and Spatial Distributions

3.2.1 Monthly and Yearly Time Series

Monthly and yearly aggregates from the fire and burn products were plotted to time series shown in Figure 2 and 3. Seasonal pattern of fire activity was observed with highest count during the dry months of March and April and minimal during the rest of the remaining months. Both datasets captured the burning season in the province, concurrent to the dry climate conditions. Accordingly, Tagbanua farmers timing of burn is typically in March which was considered as the hottest month; conditions are sustained until April and May[3].

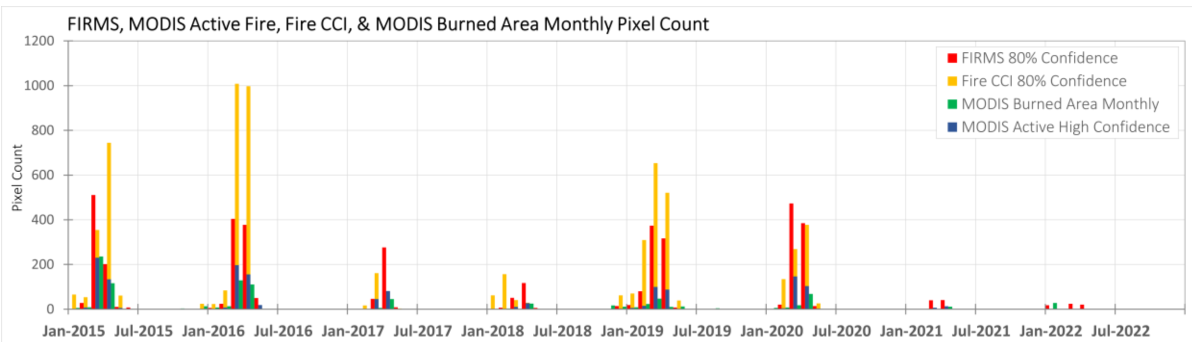

Figure 2. Monthly Time Series of Pixel Count Average of Fire and Burn dataset from 2015 to 2022.

Highest recorded fire pixel is from the year 2015, 2016 and 2020, from MODIS Active Fire and FIRMS; while burn pixels are highest during 2015 and 2016 from MODIS Burned Area Product, and Fire CCI, respectively. This high fire and burn pixel count may account for the El Nino drought event in the Philippines, where dry conditions due to lack of precipitation can easily instigate dry-fuel combustion, and prevalently set alight fire incidents. This resulted to widespread fires throughout the Philippines archipelago[12]. Notably, a decreasing trend in the yearly time series plot can be observed in the years 2021 onwards with an anomaly calculated for 2021: -1.8, -1.0, and -1.5 from FIRMS, MODIS Burned Area, and MODIS Active Fire product, respectively. The decline in recent years may suggest La Niña effect, as PAGASA advised with above-normal rainfall levels.

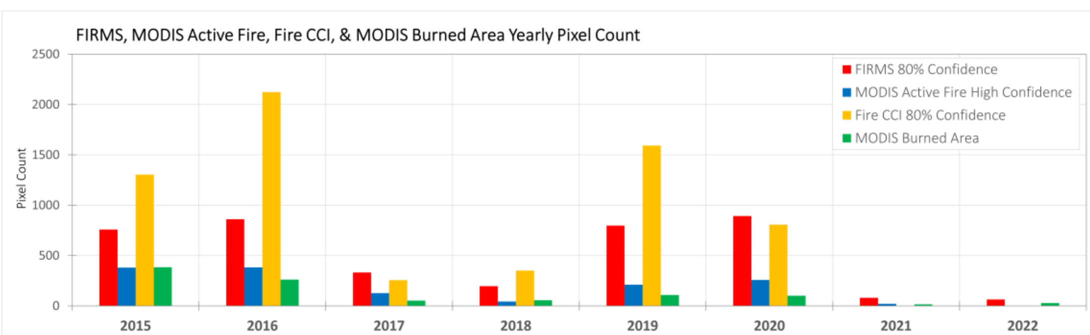

Figure 3. Yearly Time Series of Pixel Count Average of Fire and Burn dataset from 2015 to 2022.

3.2.2 Hot Spot Analysis

Spatial distribution of fire and burn pixels in the province are mapped in the figures below. Fire activity per municipal is most prevalent in Sofronio Espanola, Bataraza, Rizal, Quezon, Culion, Roxas, Aborlan, Taytay and Narra; while no incidents detected in the municipalities of Magsaysay, Cagayan, Agutaya, Linapacan, and Cuyo, which are islets situated in the east of the province; and minimal detection in Araceli, El Nido, Dumaran, and Brooke's Point.

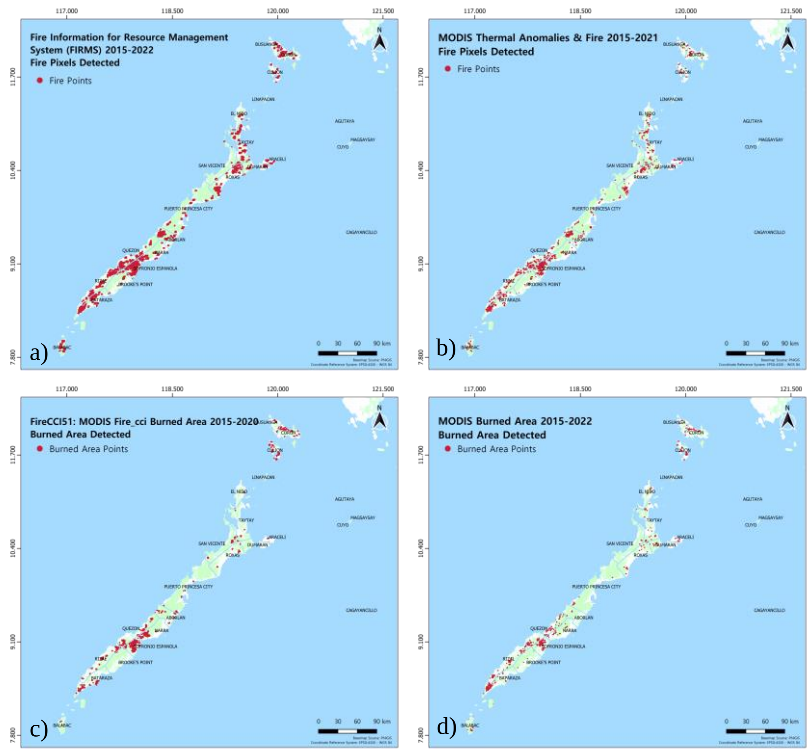

Figure 4. Yearly Pixel from 2015 to 2022 of a) FIRMS, b) MODIS Active Fire, c) Fire CCI, and d) MODIS Burned Area.

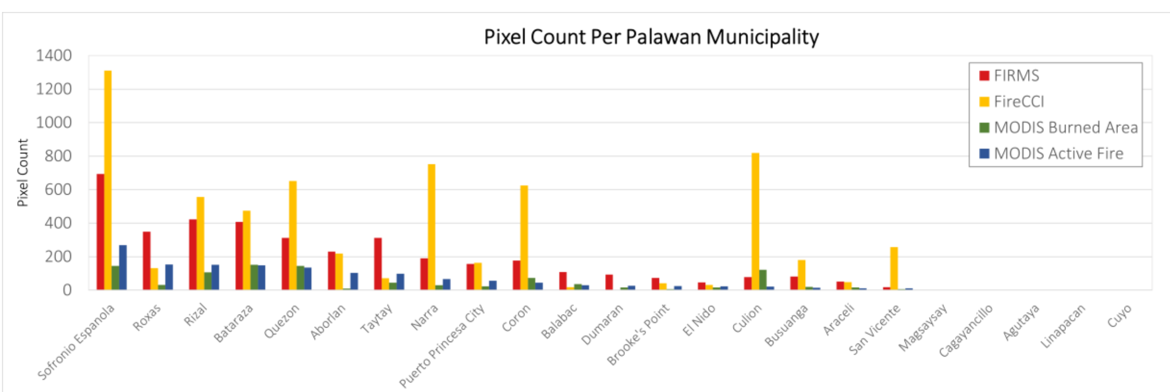

Figure 5. Pixel Count per Palawan Municipality and Dataset.

The mapped fire and burn pixels are widespread within the province. Test for clustering and identification of hot spots and colds spots using Moran's I statistics and Getis-Ord Gi* were carried out. The local Moran's Index results range from 0.298 to 0.663, indicating clustering of similar values with significant spatial autocorrelation of pseudo p-value <0.05. This substantiates with the resulting z-value of positive results from 18 to 105 that clustering is spatial in footprint. To this degree, fire activity in the province is clustered i.e., locations of fire are generally in the same proximity of fires and distinct in areas; and from different dataset, clusters of fire activity carry out different fire schemes; where in FIRMS clusters indicate high and low temperatures, MODIS Fire describes high and low intensity, Fire CCI reveals short and prolonged duration of fire, and MODIS Burned Area highlights if fire is localized or widespread. Among the products utilized, Fire CCI resulted a high index and z-value generally indicate a strong and statistically significant spatial pattern in the using its dataset.

Table 2. Moran's I statistics of fire and burn datasets.

	Moran's Index		**Pseudo p-value**	**z-value**
FIRMS	0.394	Clustered	0.001	50.53
MODIS Fire	0.331	Clustered	0.001	23.52
Fire CCI	0.663	Clustered	0.001	105.54
MODIS Burned Area	0.298	Clustered	0.001	18.16

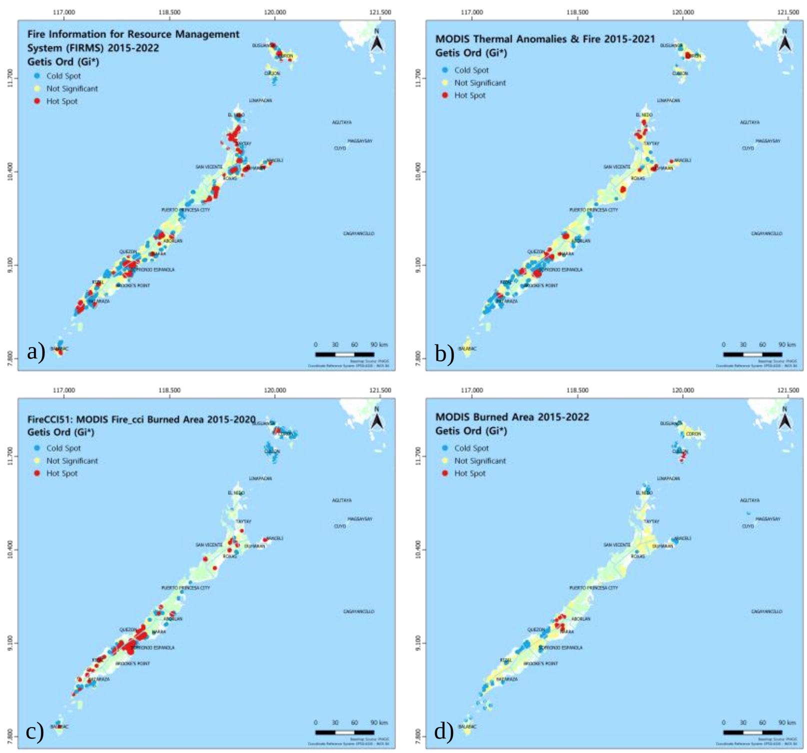

Figure 6. Hot spot (red dots) and cold spot (blue dots) clusters from 2015 to 2022 of a) FIRMS, b) MODIS Active Fire, c) Fire CCI, and d) MODIS Burned Area.

Hot spots and cold spots of fire and burn products determines brightness temperature of FIRMS, intensity of MODIS Active Fire, duration, and occurrence from Fire CCI and MODIS Burned Area. Illustrated in the figure above: FIRMS low temperature clusters are at 57% of the detected pixels and 43% are high temperature cluster. Fire pixels detected from MODIS Active Fire shows 55% are low intensity while 45% are high intensity fire. Municipalities with high fire pixel count are found in hot spot clusters, Sofronio Espanola, Bataraza, Rizal, Quezon, Puerto Princesa, Aborlan, Roxas, Balabac, Taytay and Narra experience intense and high temperature fire incidents. While cold spots are present in the municipals of minimal fire pixel detection with less intense and low temperature fires.

On the other hand, burned area products has a large extent of cold spots by 56% and 68%, and 44% and 32% hot spots from Fire CCI and MODIS Burned Area, respectively. Hot spot clusters are in the municipalities of Coron, Culion, Araceli, Taytay, San Vicente, Roxas, Aborlan, Narra, Quezon, Sofronio Espanola, Rizal, Bataraza, and Balabac. While cold spots for rest of the municipalities. These areas can be characterized by the length of burning days and the widespread of fire per burn date; hot spots figure long duration of burning and occurring across the province whereas cold spots are the contrary.

3.2.3 Analyses on Topography and Land Cover

Characterizing these clusters can be examined and assessed by the topographical variables and its land cover class, as to where are the hot spots are located and its affected land cover. Digital elevation model and its variables slope, and aspect were sampled per pixel detection. The variables influence the amount solar radiation reaching any location, affecting moisture content of fuel, preheating of fuels, and changes in temperature. Land cover classes are detailed to different vegetation types: closed forests, open forests, shrubs, grassland, annual and perennial crop. Association of the features to fire and burn pixels may suggest characteristics of fire activity, specifically, kaingin farming.

Resulting correlation between the topographic variables showed no direct correlation with the fire and burn pixels detected. Fire activities in the Philippines are more influenced by the interplay of shape, size, slope, wind direction and debris in the field revealed by one key-informant IP farmer in Tagbanua from an anecdotal interview[3]. Average and maximum elevation per cluster for each dataset is summarised in the table below. This shows vegetation types in the province are mostly elevated, with a minimum 30 meters height of an annual crop to a of 976-meter peak of an open forest. Cold spot and hot spots are found in all vegetation type, annual crop, shrubs, closed forests, grassland, open forest, and perennial crop. The two clusters differ in the elevation where the vegetation is situated; as shown below, minimum elevation for a cold spot in an open forest is at 630 meters; while minimum elevation for a hot spot is at 484 meters; for grasslands, cold spots can be found at 196 meters minimum elevation while hotspots start at 263 meters elevation. Generally, cold spots in the vegetation types holds a broad range of elevation specifically in annual crop, shrubs, close forests, and grassland; compared to hot spots that are found extensively in open forests and perennial crops.

Table 3. Minimum and Maximum Peak Elevation (meters) Per Vegetation Type.

	Cold Spot		Hot Spot	
	Min. Peak (m)	Max. Peak (m)	Min. Peak (m)	Max. Peak (m)
Annual Crop	42	191	30	145
Shrubs	282	648	345	542
Closed Forests	156	922	503	759
Grassland	196	563	263	368
Open Forest	630	734	484	976
Perennial Crop	97	358	77	210

Hot spot and cold spot cluster per vegetation type shows variability in distribution observed throughout the study period, as shown in the time series plots below. Instances of hot spots has occurred in shrubs, grassland, closed and open forests. Indicative of fire schemes that utilize intense heat and temperature. The vegetation types of shrubs, open forests, and grassland are characterized as cold spot clusters which are exposed to low intensity and low temperature fire. Overall, the most affected area is the shrubs, occupying a maximum elevation of 542 m and 648 m for hot and cold spots, respectively. Following this, open forests are almost equally affected by fire activities in the province. Situated in the elevations 663 m to 798 m for both clusters.

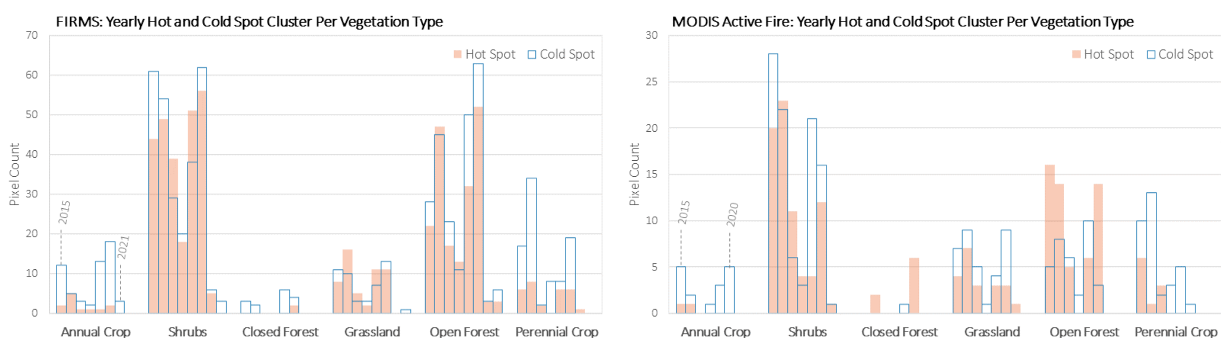

Figure 7. FIRMS (left) and MODIS Active Fire (right) Yearly Pixel Count of Hot Spot and Cold Spot Cluster Per Vegetation Type.

Burned area products from Fire CCI and MODIS shows of fire activities in the vegetation types, annual crop, shrubs, grassland, and open forests. Over the study period, hot spot and cold spots varied for each land cover class, annual crop and grassland were mostly cold spots, suggesting short burning days and in constricted areas within the province. On the other hand, shrubs and forests has prolonged burn duration and occurring throughout the province clustered in hot spots.

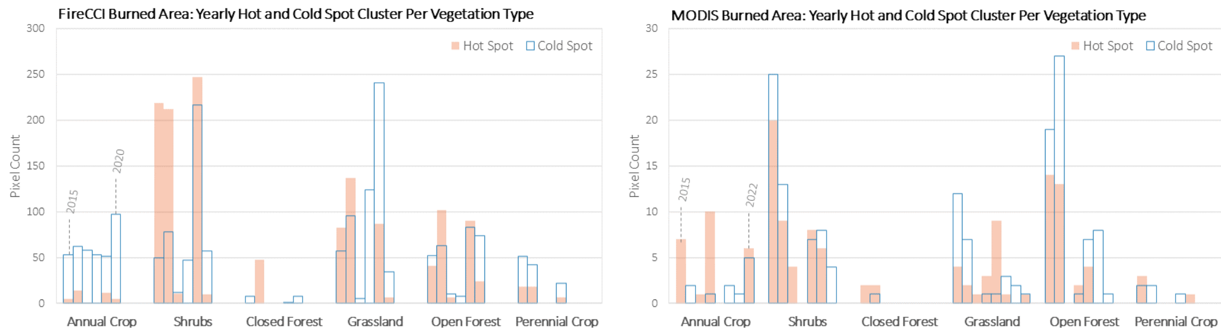

Figure 8. Fire CCI (left) and MODIS Burned Area (right) Yearly Pixel Count of Hot Spot and Cold Spot Cluster Per Vegetation Type.

Forested areas undergone logging and other extraction operations, mainly by big companies, forms post-extraction secondary forests. These areas that are totally denuded or converted, leaving brush/shrub or upland farm or grassland after successive clearings in an area[3,13]. As things go, there is an atmosphere of consent in cultivation in secondary forests, as long as fire breaks are utilized, and responsible burning is practiced[3]. The younger forests are more combustible, dries out quickly and burn efficiently reported by a key-informant[3]. Comparing this to burning old growth forests which comprised of larger trees and massive roots requiring multiple and intense burns that last several days. These suggests fire and burn pixels over the shrubs and grassland vegetation type can be characterized as kaingin while fire incidents in open forest are logging or land conversion.

4. CONCLUSION

Monitoring of fire occurrences with FIRMS, MODIS Active Fire and Thermal Anomalies, Fire CCI, and MODIS Burned Area Product described the spatiotemporal distributions of slash-and-burn practices in the Province of Palawan in the Philippines. The datasets utilized show good agreement of fire detection products with ± 80 in fire pixel count difference while burned area products with ± 187. Time series of across dataset captured the burning season of Palawan, occurring in April and March with high fire pixel counts. While in the yearly time series, trend showed decline in fire count suggesting effects of a climate event, La Niña.

Moreover, fire regime descriptors: intensity, temperature, duration and occurence characterize fire activity within the province. Spatial clustering per vegetation type assessed incidents describing fire schemes. Clustering for each dataset has a greater proportion of cold spots by a difference of ~10%. Temporally, distribution clusters vary per year influenced by climate events. Shrublands in high altitudes generally sustained low intensity and temperature fire during, and prolonged burning during the years 2015 to 2019. Grassland is clustered both in cold spot for fire and burn datasests, experiencing low intensity, temperature fire and short-lived burns. Fire activities related to this are wide-scale kaingin implementing land clearing system using fire. On the other hand, open forests are hot spots during the years 2015, 2016, and 2020, experiencing high intensity and temperature fires and varying duration of burning. Forest fire activities are associated with land conversion or expansion, wood extraction, etc.

Lastly, fire and burn pixel counts from 2015 to 2022 revealed the fire hotspot municipalities: Sofronio Espanola, Bataraza, Rizal, Quezon, Culion, Roxas, Aborlan, Taytay and Narra. The synergistic use of available fire and burnt area mapping products is essential in obtaining a better picture of schemes of fire activities in areas of interest.

5. RECOMMENDATION AND FUTURE WORK

The study is limited to the existing and available data. Updated and reliable land cover map for the individual years may recalibrate and account for land conversion transpired over time. Climate data such as temperature and precipitation, and new fire and burn products are to be integrated in the future works.

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