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Trends and Patterns in Luangwa River Valley Fires 2003 ~ 2007

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Abstract. *Efforts at improving resource management, sustainability, and wildlife habitat in the Luangwa River Valley of Zambia includes community education to change the common practices of setting fires throughout the long dry season. Fires are set for many reasons -- to clear fields of last year's crop residue, to clear new land, to remove undergrowth for safety along roads and paths, accidentally, and sometimes apparently with little reason.*

The MODIS satellite data has been used to derive likely fire locations as a means of mapping fires from space. The algorithms use a combination of heat signature and smoke plumes to define the likelihood of a fire. Fire data from 2003-2007 for a regional area surrounding and including the Luangwa Valley were analyzed looking for spatial and temporal patterns in fire occurrence.

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A 5km cell was used as a basic spatial element for aggregating and analyzing fire occurrence. Variation from year to year can be seen regionally that may reflect differences in rainfall and climate between years. Ratios between years were used as a basis for examining different rates of change spatially. Fire occurrence in community areas with a conservation program and those without were compared. The ratio analysis of the fire data were not able to detect a difference between regions with community education to control the practice of setting fires due to limited change in the practice or limitation of the resolution and classification accuracy of the data.

Keywords. Fire, MODIS, Zambia, Luangwa river valley, conservation.

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Introduction

A savanna characterized by grasslands with scattered trees (Miombo) is a common landscape in eastern Zambia (Figure 1). Fire has been an important tool to manage the savanna ecosystem. Anthropogenic activity is one of the main causes of fires in African savanna today (Eriksen, 2007). Fires are set for many reasons: to clear fields of last year's crop residue, to clear new land, to remove undergrowth for safety along roads and paths, accidentally, and sometimes apparently with little reason.

The Community Markets for Conservation (COMACO) program of the Wildlife Conservation Society (WCS) promotes conservation farming and improved land use management for wildlife habitat. One aspect of this program is community education and a requirement of partners to commit to not burning crop residue and to cease from wild land burning. The impact of this educational program has not been assessed on a large scale, and the potential use of satellite imagery for this purpose was examined in this study.

New growth in a burned forest area

Field with brush piles

Figure 1. Landscape of the Luangwa river valley

The purpose of this study is to examine spatial patterns and temporal trends in fire occurrence of the Luangwa River Valley and relationship with climate and land cover. A 5km cell was used as a basic spatial element for aggregating and analyzing fire occurrence. Variation from year to year can be seen regionally that may reflect differences in rainfall and climate between years. Ratios between years were used as a basis for examining different rates of change spatially. Fire occurrence in community areas with a conservation program and those without were compared.

Data

The MODIS satellite data has been used to derive likely fire locations as a means of mapping fires from space. The algorithms use a combination of heat signature and smoke plumes to define the likelihood of a fire. The data provided by FIRMS (Fire Information for Resource Management System) of the University of Maryland includes a confidence estimate, which ranges between 0% and 100%, to assign one of three fire classes (low, nominal, or high-

confidence fire) to all fire pixels within the fire mask (Giglio, 2007). The data was sampled with a time period greater than 8 days to average out sampling bias, and it can routinely detect both flaming and smoldering fires 1,000 m^2 in size. The MODIS data were validated with coincident observations of ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) (Giglio, 2007). In this study, only high-confidence fires (confidence estimate between 80% and 100%) are considered. Fire location point data from 2003-2007 for a regional area surrounding and including the Luangwa Valley were analyzed (Figure 2).

For land cover data we used MODIS/Terra Land Cover Type Yearly L3 Global 1km SIN Grid V004 (Figure 3). Monthly rainfall and lightning data were obtained from AMSR-E (Advanced Microwave Scanning Radiometer – Earth Observing System) Aqua Monthly L3 5×5 deg Rainfall Accumulation and LIS (Lightning Imaging Sensor) / OTD (Optical Transient Detector) Gridded Products LRMTS (Low Resolution Monthly Time Series) respectively. Because the rainfall and lighting data have low resolutions, they could not represent spatial variation of the rainfall and lightning in the study area.

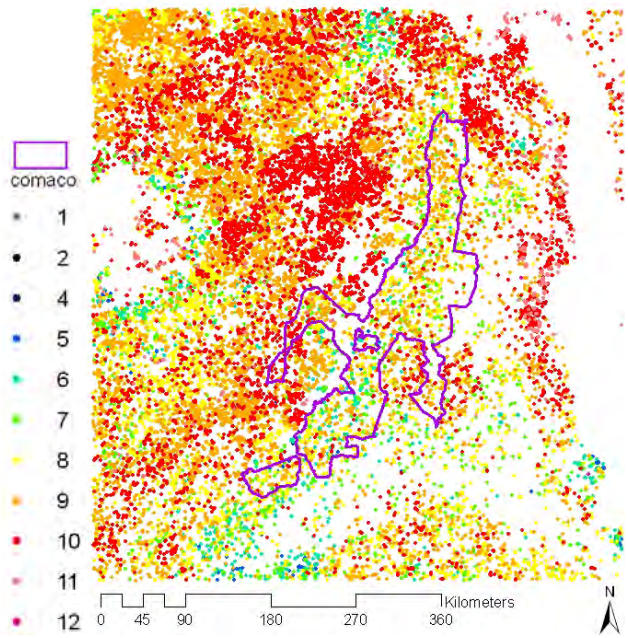

Figure 2. MODIS high-confidence monthly fire points

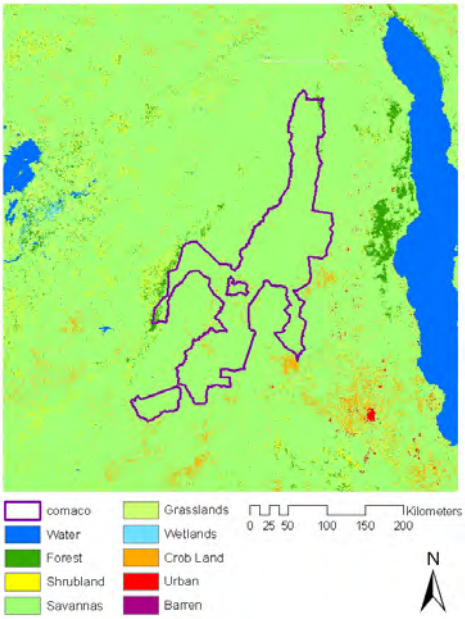

Figure 3. MODIS Land Cover

Method

Spatial Patterns

Quadrat analysis overlays a mesh of equal size on the study area and counts the number of features in each. It also calculates the counts expected for a hypothetical random spatial distribution of the feature. Then, the observed and hypothetical histograms are compared to check if the features are distributed randomly or clustered using Chi-square and K-S tests. The quadrat size was set to 5km, which is approximately twice the size of the mean area per fire (Mitchell, 2005).

Average nearest neighbor distance measures how similar the mean distance is to the expected mean distance for a hypothetical random distribution by calculating a nearest neighbor index. The expected mean distance for randomly distributed features and the nearest neighbor index are calculated. If the nearest neighbor index is less than 0, we can consider the features as being clustered, if it is greater than 0, dispersed, and if it is equal to 0, randomly distributed.

Temporal Trends

The number of the fires for every year was compared to see if there is a temporal trend. And also, cell by cell comparisons were made in order to see spatial distribution of the temporal variations for the fire occurrence. Ratios of the numbers of fire between years were used as a basis for examining temporal changes at different locations. In calculating ratios, NoData cells on fire frequency grid used as a denominator were filled with a value of one. Thus, the ratio could take into account the portion of the fires that happened in the present year but did not happen in the past year at the same location (cell). The beauty of this approach is that we can put bigger weights on the cell that has lower frequency of the fires in the previous year.

The ratios and differences for the COMACO to other regions were compared to see if there is a statistically significant difference between them. Ten ratio layers for all pair combinations of 5 years, from 2003 to 2007, were made through dividing a current year layer by a previous year layer after the filling procedure. A Wilcox test was used to see if there was a detectable difference between COMACO and non-COMACO areas.

Relationship with Climate and Land Cover

Monthly variations of fire occurrence were examined regionally and regression analysis was implemented to assess possible relationships with rainfall and lightning. Also, the relationship between fire frequency and land cover was explored by several statistical tests such as Kruskal-Wallis and pairwise Wilcox rank sum test.

Results

Spatial Patterns

Both tests, Quadrat analysis and average nearest neighbor distance, gave the same results that there is less than 1% likelihood that the clustered patterns of the fire frequencies and points for each year could be the results of random chance. The nearest neighbor indices were calculated by Spatial Statistics Tool of ArcGIS 9.2, and the results including z-scores are presented in Table 1. The spatial distribution of the fires for each year is displayed in Figure 4.

Table 1. Statistics of the elevations and their differences with the resampled DEM

Year	2003	2004	2005	2006	2007
Obs. Mean Dis	1123.7	1360.5	1399.3	1431.5	1350.6
Exp. Mean Dis.	1397.8	1817.6	1896.7	2045.2	1789.5
Ratio	0.80	0.75	0.74	0.70	0.75
Z Score	-78.13	-77.01	-77.01	-81.7	-76.3

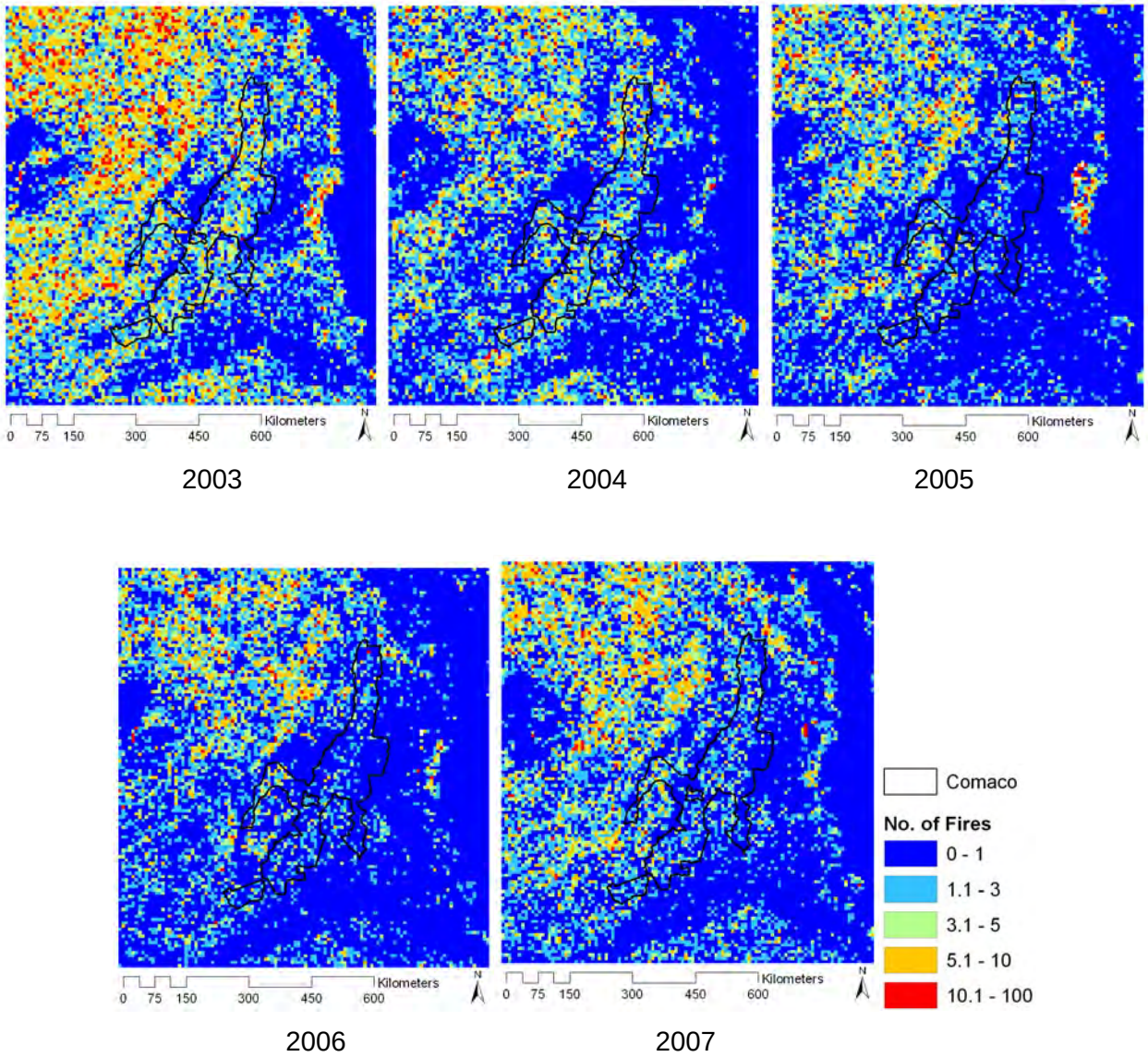

Figure 4. Fire frequencies from 2003 to 2007

Temporal Trends

The fire frequencies in the study area varied over time as seen in Figure 5. The MODIS data shows fires to occur most frequently in 2003. The average fire frequencies for a quadrat in all the regions decreased until 2006, then increased in 2007. The fire frequencies of the COMACO regions are less than those of the other areas in all years except 2004.

However, this analysis cannot show spatial distribution of the temporal variation for the fire occurrences. So the cell by cell comparison such as a ratio of the fire frequency between a pair of years was made to see the spatial distribution. Using Wilcox rank sum test, the ratios and differences for the COMACO region and the surrounding area were compared to see whether there is any evidence that the education to control the fire practice is successful.

The results of the Wilcox rank sum test for the ratios are listed in Table 2, and it shows that the fire frequencies within the COMACO and the other region (without water) increased (mean ratio > 1) between some years (i.e. between 2006 and 2007). The fire frequencies of the COMACO increased in the all consecutive years except from 2004 to 2005. And also, the increasing rates of the fire frequency of the COMACO area exceeded those of the non-COMACO area between 2003 and 2004. The regional distribution of the ratios is presented in Figure 6.

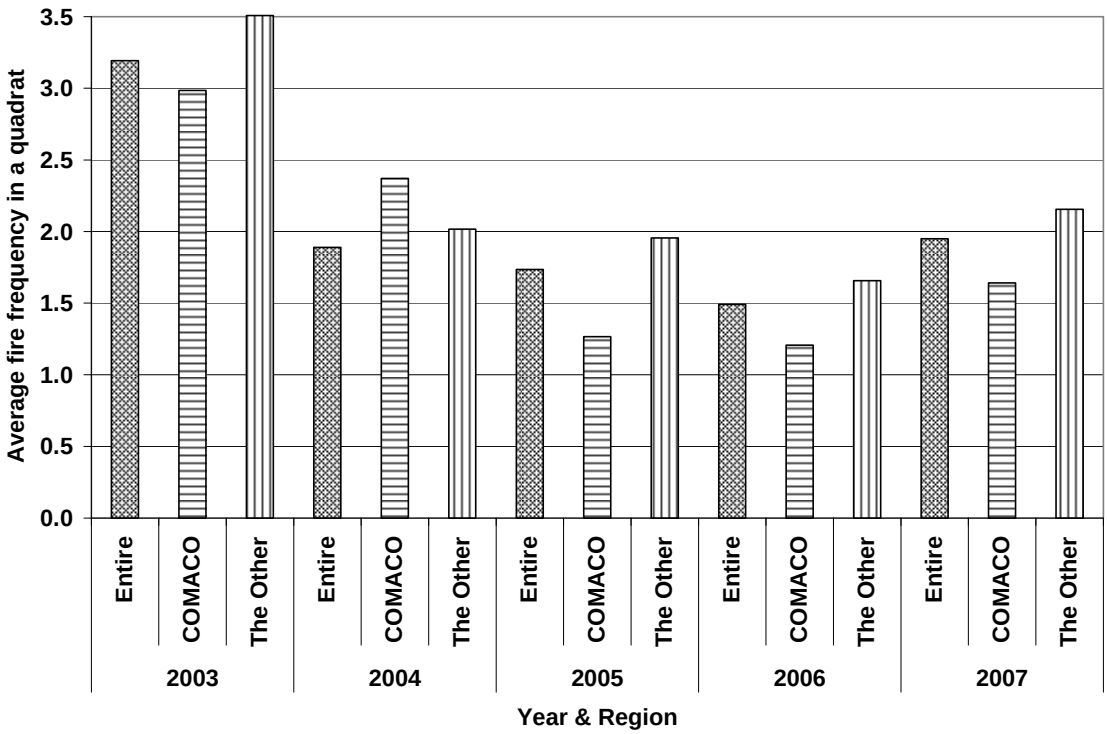

Figure 5. Annual variation of the fire frequency

Table 2. The Wilcox rank sum test results for the fire frequency ratio of the COMACO versus non-COMACO regions for a given pair of years

Year	COMACO (A)			The other (B)			Wilcox Test	
	Max	Mean	STD	Max	Mean	STD	Decision	p-value
04-03	10.00	1.23	1.30	13.00	1.00	1.05	(A) > (B)	1.000
05-03	8.00	0.82	0.82	46.00	0.93	1.12	(A) < (B)	1.000
05-04	8.00	0.97	0.91	63.00	1.40	1.74	(A) < (B)	1.000
06-03	8.00	0.80	0.84	21.00	0.86	0.93	(A) < (B)	0.779
06-04	8.00	0.95	0.93	42.00	1.26	1.40	(A) < (B)	1.000
06-05	11.00	1.26	1.11	17.00	1.26	1.26	(A) > (B)	0.684
07-03	8.00	0.96	0.97	16.00	1.00	1.07	(A) > (B)	0.754
07-04	10.00	1.15	1.17	25.00	1.48	1.57	(A) < (B)	1.000
07-05	10.00	1.48	1.22	16.00	1.47	1.41	(A) > (B)	0.934
07-06	10.00	1.54	1.32	23.00	1.60	1.55	(A) = (B)	0.706

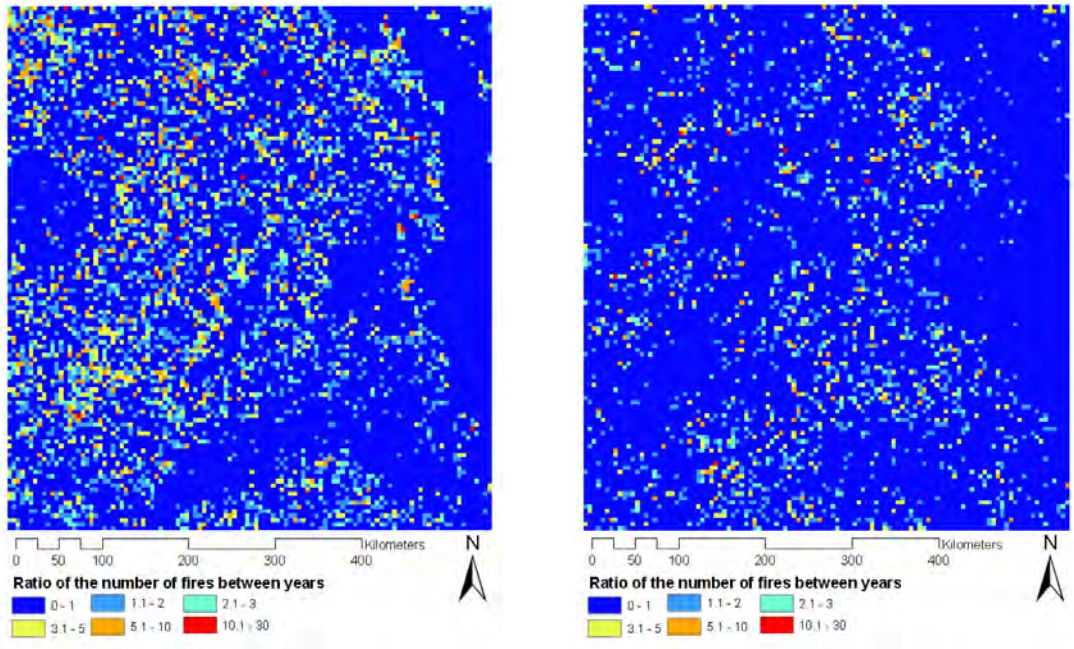

Figure 6. Ratio between 2006 and 2007 (left) & between 2003 and 2004 (right)

Relationship with Climate and Land Cover

Monthly rainfall and lightning data were derived from AMSR-E and LID respectively, and then compared with the total number of the fires in every month to see whether there is a significant relationship among them or not.

As seen in Figure 7, the numbers of fires are inversely proportional to the rainfall amount (R^2=0.58). However, the lightning density is not highly correlated with the fire frequency because the lightning usually is taking place in the rainy season. On the other hand, in the dry season, from May to October, the numbers of fires increases when the lightning densities is higher even though their relationship is not strong (R^2=0.23, Figure 8).

The land cover map was derived from MODIS data set taken in 2004, and then compared with the total number of the fires in every year to see whether there is a significant relationship among them or not under an assumption that the land cover did not change over time. The numbers and average frequencies of the fires for each land cover are listed in Table 3.

From the analysis of the fire frequency and density for each land cover, it can be noticed that the fires were most frequently taken place in the savanna, forest, and shrub. The fire frequencies are also relatively high in the cropland because people clear the fields. Most fires were taken place in the savanna even within the COMACO region, and the proportion, about 97%, is a little bit higher than the 91% of the entire study area. The crop land, forest, and shrub have relatively large numbers of fires as well. The number of the fires in the wetlands may be caused by misclassification of the MODIS data set.

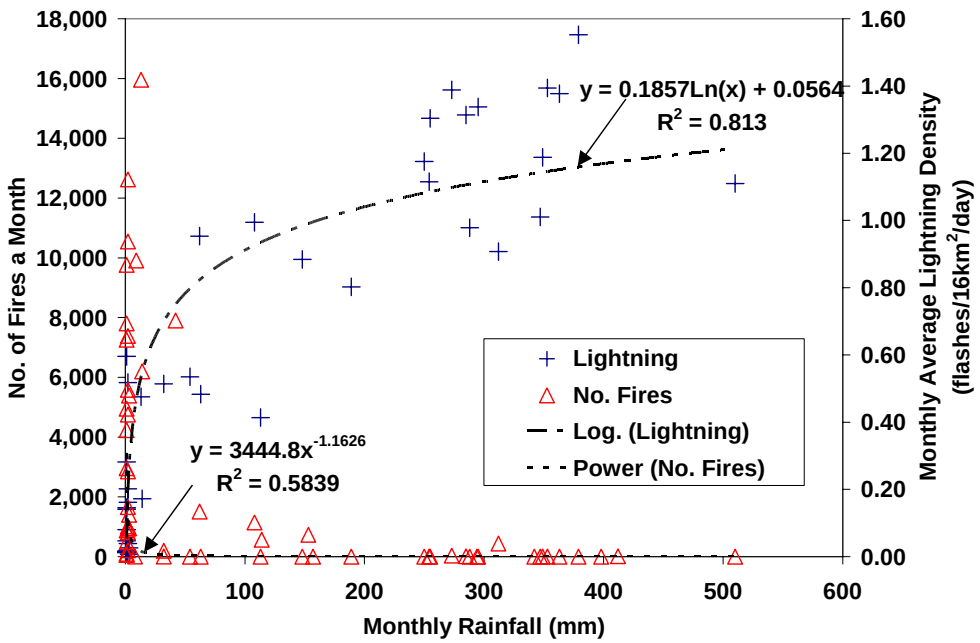

Figure 7. Relationship among the fire, rainfall, and lightning

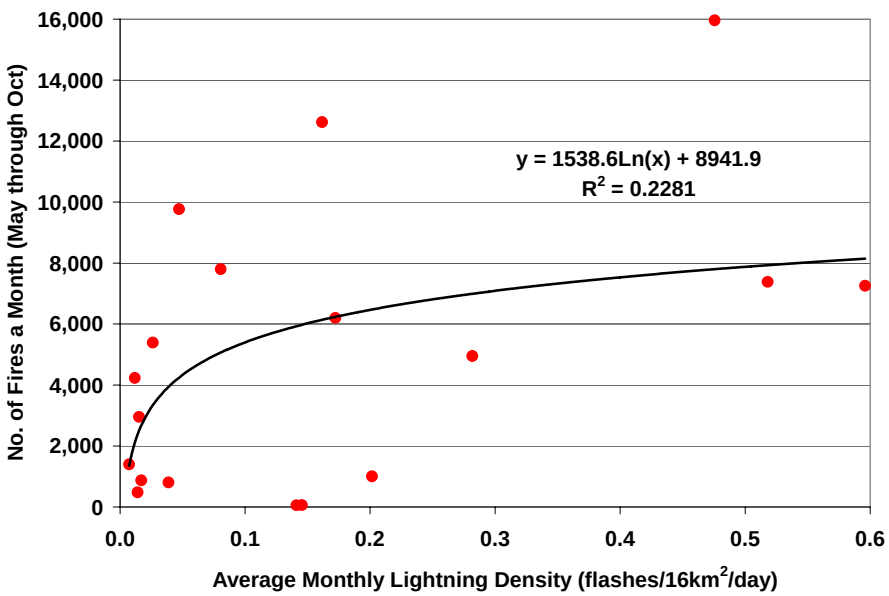

Figure 8. Relationship between the fire and lightning in the dry season

Table 3. The number and average frequency of the fires for each land cover

Land Cover	2003		2004		2005		2006		2007	
Item	Freq.	Dens.	Freq.	Dens.	Freq.	Dens.	Freq.	Dens.	Freq.	Dens.
Water	16	0.018	5	0.008	11	0.01	3	0.007	14	0.011
Forest	857	3.125	357	1.284	767	2.686	337	1.287	433	1.639
Shrubland	822	3.374	478	1.821	475	1.889	354	1.562	494	2.081
Savannas	40,035	3.526	23,740	2.097	21,508	1.885	18,849	1.662	24,695	2.173
Grasslands	399	2.206	269	1.492	286	1.659	212	1.298	220	1.292
Wetlands	37	1.138	26	0.63	37	1.383	33	0.885	12	0.471
Crop Land	1,078	2.594	716	1.794	429	1.245	422	0.957	559	1.337
Urban	12	0.809	10	0.579	1	0.269	4	0.259	1	0.293
Barren	0	0.594	2	0.365	0	0.25	1	0.281	0	0.469

Conclusions

This study shows that the fire frequencies of the study area are highly clustered spatially, inversely proportional to the rainfall amount, and fluctuating over time. However, the resolution of the rainfall data is too coarse (5 degree) to show reasonable spatial relationships between fire frequency and rainfall. And also, if lightning data with high spatial and temporal resolution like 10 km and 1 day can be obtained, it may be possible to see a relationship between dry lighting and fire frequency.

The analysis resolution to derive fire frequencies from the fire points was set to 5km, which is twice the size of the mean area per feature. However, if a different cell size is used, it is possible that the quadrat and other analyses may produce different results. For the quadrat analysis, 3km and 10km cell sizes were tried, and they provided the same results. Further studies should explore having various resolutions.

Only fire points with high confidence over 80% were considered in the study. If the data is extended to the data with medium confidence ranging from 30% to 80%, the quadrat size and the analysis results again may change.

The ratio analysis of the fire data was not able to detect a difference between regions with community education to control the practice of setting fires. This may be due to limited change in fire-setting behavior or may be a limitation of the resolution and classification accuracy of the data.

Acknowledgements

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