A Fire Regime Model of Panama

Un Modelo del Régimen de Fuego de Panamá

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Problem Statement

How can we reliably explain and understand where and when forest fires are occurring in Panama since 2003?

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1. RATIONALE

1.1 Rationale: Global and Local Effects of Burning

Biomass burning is a global phenomenon that is currently receiving global attention. Over twenty million hectares of tropical forests fell to the 1997 El Nino event, causing over forty percent of global carbon emissions for that year (Cochrane 2003). Worldwide**,** tropical forests sequester roughly 15% of carbon emissions— storing in total nearly 550 gigatonnes[1] of carbon annually (Trumper 2009). However, the concentration of atmospheric CO2 today is more than 1.3 times that at the dawn of the industrial revolution (IPCC 2001; Trumper 2009) and biodiversity losses have also grown 1000-fold on the same time frame (Houghton, 2005; CBD 2006). Land cover changes account for about a quarter of anthropogenic carbon (C) emissions and are the leading cause of species extinctions (IPCC 2001). The aerosols released from burning reduces solar radiation, in some places doubling the heating capacity of the lower 3km of the troposphere, ultimately reducing rainfall and relative humidity over vast areas (Lewis 2006, Ramanathan 200). The particles also reduce natural filtration processes, increasing residence time of particles in the atmosphere (Ackerman 2000).

But while public awareness has grown about the global effects of fires on the carbon cycle and biodiversity, the scientific community has also begun to examine the ways that fires urge the local environment away from its state of equilibrium. These feedback pathways include precipitation regimes and cloud formation, local ecosystem composition, runoff soil erosion and biogeochemical quality, and are most heavily influenced in early stages by the degree of intensity and frequency of the fires (Betts 2004).

Tropical forests are less adapted to burning and have thinner layers of protective bark than in temperate locations (Uhl and Kauffman 1990). The thinnest barks are of course indicative of younger trees. Typical initial burns kill selectively, removing 40% of trees with less than 10cm DBH, destroying less than 10% of biomass (Uhl and Kauffman 1990). But that initial fire also sparks a feedback process: reductions in

[1] 1 GT=109 tonnes; 1 unit of carbon = 3.67 units carbon dioxide

seed availability (Van Nieuwstadt 2001) and a reduction in flowering and fruiting – even for nearby forests (Kinnaird 1998) facilitates grass, vine and woody liana invasions (Woods 1989). These contribute to the existing layer of dry, woody debris to fuel the succeeding fire, which typically destroys 40% of all biomass without selection for DBH (Uhl and Kauffman 1990). These feedback pathways thus depend on the frequency of fires in the immediate area.

There are other processes sensitive to the intensity (heat) of fires: oil denuding and hydrophobicity (Muckel 2005). Hydrophobicity involves an accumulation of post-fire substances and soil fungi into a water-repellant layer in the soil; this reduces the amount of water infiltration, increasing runoff (Muckel 2005). Tropical forests also sometimes contain a layer of mycorrhizal fungi to which high post-fire soil temperatures are lethal (Betts 2004).

Another process depends on the density of fires within a regional area: forest edging. Fires typically open and dry the canopy, compromising the tropical rainforests natural resistences to drought:high levels of leaf area index which would trap and recycle moisture, vast, dense swatches of low albido which encourage clouds to move further inland, and the production of mykists which facilitate raindrop formation (Betts 2004). On a large scale, (i.e. if fires occur in high density) the fragmentation of the forest landscape means exposing trees to dessicating sunlight and stronger winds, favouring the selection of wind-distributed, light-demanding pioneer species (Cochrane 2003).

1.2 Rationale: Using Fire Regimes to Localize Effects

The most recent study to use active satellite observation data to group fires based on their characteristics was published in 2008 by Chuvieco, E, entitled “Global Characterization of Fire Activity: Toward Defining Fire Regimes from Earth Observation Data”. This study similarly identifies fire regimes based on characteristics sorted from active satellite observation records, but is scaled at a local level, limited to a single country. Panama is divided into grid cells one kilometer squared in size, and sorted into either no fire, or one of eight regimes based on a division of three metrics: brightness, which uses temperature at time of observation as a proxy to measure intensity; regional density, which identifies whether or not the fire is immediately neighboured by another fire; and frequency, which counts whether or not another fire has occurred in the seven-year period of study.

Conventionally, climatological groupings are granted the name regimes only after they have demonstrated their characteristics consistently through the decades. There is much reason to believe, however, that in the past decades fire regimes have changed—and that they will even more in the upcoming ones. It is therefore all the more critical that a foundation by which to build long term comparative analysis of fire regimes changes is recognized. Current research recognizes that while such changes in boreal climates can be attributed largely do global warming, those in temperate developing countries owe more to evolving government management policy, and those in tropical developing countries (such as Panama) are better explained by the the expansion of agricultural areas (Cochrane et al., 1999). All three factors are directly or indirectly anthropogenic in origin.

1.3 Rationale: Socioeconomic significance

In fact, vast majority of forest fires in Panama can be attributed to direct or indirect local anthropogenic causes (MIVI 2005). While topical regions do tend to attract a high density of lightning strikes, these are most often correlated with heavy rainfall, and thus are responsible for relatively few fires (Vayda 1999). Most volcanoes in Panama are dormant, and eruptions are a rare and insignificant contributor to forest fires. Rather, human activity is found to be a major contributing factor to the frequency of fire occurrence (Goldammer 2000). Rich tropical forests neighbor growing cities, whose roads, water transport systems, railways and electrical girds not only directly increase wildfire risk by fragmenting the forest landscape, but also provide access to anthropogenic factors such as cattle/ranching, open pit mining (Uhl 1985), selective logging (Siegert 2001) and slash and burn agriculture in industrial-size scales (Condit et al 2001). The consequences manifest as thousands die yearly from forest-fire smoke related respiratory and cardiovascular illnesses (Arbex 1998). If accounting for healthcare costs, timber losses, airport closures (due to smoke) and soil erosion, wildfires routinely cause billions of dollars in damages in the tropics (Contreras 2000, Barber 2000).

Yet, at least in Panama, there is another side to the story. For local Panamanian stakeholders, biomass burning is as important an aspect of land management as it is an agent of destruction. Fire is used for pest control, incinerating trash, cooking, and perhaps most importantly as part of the slash and burn technique used in traditional subsistence agriculture. Burning efficiently reduces biomass of cut forests to a fertilizing ash for crops, and promotes forage growth for grazing animals that are often central to the campesino lifestyle (Cochrane 2003). Over a third of the country is already designated as a protected zone by ANAM. Each time such a zone is selected, it supplants existing local stakeholders and displaces their use of fires to border zones of the park, where they are pressured not to burn in case the fires enters the park. Pressures will only increase as human populations in Panama grow another 2.6% by 2020 (Heckadon/Moreno et al 1999). One park interview conducted for this study in Soberania National Park cites bordering villages as the primary cause of fires within the park, whether for agricultural use, hunting or as a form of revenge (Grandi 2010). Another study's interview records the local people of Cuernavaca, pointing out the unfairness between ANAM criticizing their crop burning while allowing mining companies to deforest and exploit the territory without consequence (Whysner 2010). There is no clear answer to be found in the conflict until a more localized system of understanding of fire behaviour and its causes is established.

1.4 Rationale: The Purpose of this Model

Localization is extremely important when considering fire policy and land use planning. Previous studies attempt to either construct fire regimes without identifying statistical correlations of causal factors, or have limited their study to short-term analysis of localities based on climatic zone or socioeconomic variables (Dwyer et al. 1999, Clerici et al. 2004).

To that end, this study has summarized typical relevant causal factors into four anthropogenic measures and 3 ecological ones, scaled to the same level as the fire regimes of square kilometer grid cells. It offers a foundational layout with which to analyze any given square kilometer of the country according to these seven measures and according to the eight groupings of fire regimes identified over seven years, with specific attention to conservation zones and their immediate one-kilometer buffer area. Additionally, the basic temporal structure of individual fires throughout the seven year period is analyzed.

2. METHODOLOGY

2.1 Methodology: Resources of this Study

As discussed, this study uses long-term data sets, accumulated over seven years of active observation. Active observation through aerial photographs, or burnt area analysis through tree-ring analysis are both too resource-intensive and inconsistent to obtain over large regions and long time-frames. Satellite data, on the other hand, facilitates a detailed comparison of data through time and space. Satellites also enable consistent active observation, which is more useful than burnt area data, since burn scars do not last very long in tropical areas, and harder to distinguish on radiometric photos than the sharp contrast of active fires.

The Non-governmental organization Water Center for the Humid Tropics of Latin America and The Caribbean (CATHALAC) has provided me with the tools and knowledge to obtain and understand this information. Established in 1992, CATHALAC’s mission to promote sustainable development through applied research and development is accomplished today through education and technology transfer on water resources and the environment. Working with NASA, CATHALAC supports a Mesoamerican version of SERVIR, The Regional Visualization and Monitoring System which includes the active observation satellite system known as the Moderate Resolution Imaging Spectroradiometer (MODIS).

Table 1: Organization Chart		
Organization Name	**Acronym**	**Purpose**
The Water Center for the Humid Tropics of Latin America & the Caribbean	CATHALAC	Promoting sustainable development in Latin America and the Caribbean through applied research, development, education and technology transfer
U.S. Agency for International Development	US AID	Partner and financier of CATHALAC
National Aeronautics & Space Administration	NASA	Partner to CATHALAC and financier of SERVIR
Regional Visualization & Monitoring System	SERVIR	A platform for the observation, forecasting and modeling of environmental processes currently used in Mesoamerica and South Africa.
Fire Information for Management System	FIRMS	Developed by University of Maryland to integrates satellite data into ESRI shape files accessible and manageable on GIS operations.
Rapid Response System for *Moderate Resolution Imaging Spectroradiometer*	MODIS	Active fire observation satellite system. Uses high saturation levels and long-wave infrared bands for better surface distinction.

2.1.1 Methodology: MODIS and Data Preparation

MODIS satellite sensors use high saturation levels and long-wave infrared bands in order to more accurately distinguish low-intensity surface fires from high-intensity crown fires. MODIS searches for the signature blackbody radiation emitted during bio-combustion within 1-km pixels, using tests to reject false positives. Each square kilometer pixel is assigned a class: fire, nonfire, missing data, cloud, water, or unknown. This multispectral approach offers superior monitoring services for active fires as well as smoke and aerosol investigation.

No system boasts a more consistent, database of active fire detection than MODIS to date. To facilitate the organization and accessibility of this database, the Unveristy of Maryland developed the program known as the Fire Information for Management System (FIRMS) to integrate teleobservation and SIG technologies to enter MODIS data as point data, accessible and freely downloaded online. The resulting data was more useful in vector format, since small size and querying abilities were more valuable to this study than the relatively bulky and unwieldy rastor format (the ability to discern smoke, clouds and individual fire sizes is more valuable for daily use by park managers).

However sophisticated the MODIS data delivery service is, several adjustments to the database were still required before it could be analyzed in this study.

First, while MODIS records have been effectively compiled in the dual platform Aqua – Terra daily in Panama since 2001 (see fig 1), the program only began using a high-confidence processing algorithm by 2005. Until then, it was subject to false positives and other errors. Therefore the data for this study has been sorted by detection confidence, a heuristic rating of the radiometric contrast between fire and non-fire pixel. Only the top 70 percent of the data is selected for this study. Moreover, there was a two-year gap between the two satellites' launch, which cased a four hour difference in their overpass times. This problem was corrected by 2003, which is from when this study begins to select the data. Both selection thresholds are based on the previous work of Emil Cherrington, research scientist of CATHALAC (Cherrington 2007). Future work based this study may find it useful to develop an overpass correction algorithm in order to extend the study further into the past, and also to filter for data losses due to MODIS' occasional inoperable days and inadequate transmission due to equipment malfunction (18 days in 2003, for instance).

Several more difficult and fundamental data-collection caveats must also be addressed. These disadvantages fall into three main categories: cloud opaqueness, limited observation times and bulkiness of fire pixels (NASA 2008).

1. Persistent cloud cover is a problem endemic to Central and South America, rather than the MODIS system (Giglio 2005). While some studies in these areas have found that the conditions under which persistent clouds occur tend to be less likely to burning because of rain, other studies have developed sorting algorithms, similar to the

overpass correction algorithm, using the average fraction of each grid cell obscured by clouds during a given month.

2. While two satellites Orbit daily, only two snapshots of active fires are be taken per 12 hours. While it is unlikely that large fires could burn completely between those times, it is possible that fires are not caught at their average burning intensity. However, over the long term, since snapshots are taken at regular intervals without bias for time of day, no bias of fire brightness needs to be considered.

3. The individual “hot spots” signified by 1km cells on the MODIS map, it must be noted, do not necessarily signify one single fire. While MODIS can detect fires <100 m^2, or 0.1% of the pixel area, it may be that 5 or 6 such small fires are causing a positive pixel reading, or a portion of another fire from a different grid cell. Moreover, smaller fires underneath canopy layers are unlikely to be detected. But this second point is generally less of a problem: several studies have found that increasing canopy greenness tends to reduce the effective burnt area per unit fire pixel anyways, since tree cover slows the fire spread rate (Scholes 1996, http://maps.geog.umd.edu/firms/faq.htm#confidence). A wholly different problem endemic to tropical areas undergoing deforestation does result, however. Since burning is often preceded by an accumulation of deforested slash, MODIS may fail to account for all of the area that has been cleared and burnt, reading a higher fire intensity where greater severity would be more appropriate (Giglio 2005). In sum of these problems, it is unwise to use fire pixels as the most accurate reading of area burnt. However, MODIS still provides the most useful product for nation-wide and global data aggregation in the interim until better long-term burnt area estimates become available.

Because all data is overlaid with the MODIS 1km by 1km fire detection, all data has been scaled to fit this grid cell size. One square kilometer is, however, a resolution difficult to both the resources of national coverage and to data processing. Census data is therefore limited to 1143 of 8500 positive fire grid cells, out of a total national coverage of 78,123 cells.

Three fire metrics— brightness, density and frequency – were selected to distinguish the fire cells into eight categories, which I have labeled regimes.

2.2 REGIME METRICS:

2.2.1 Methodology: Frequency

Since all fires are related on a seven year scale, frequency was simplified into a sum of fires in a given square kilometer grid cell. A count of 8500 cells revealed with a minimum of 1 and maximum of 54 revealed a standard deviation of 0.91 and a mean of 1.3. At such a small grid cell resolution, it is not surprising that the numbers are so small. Exactly 6452 of 8500 cells had a count higher than one. All cells with a count higher than one are labeled *high frequency*, or F; all those with only one are labeled *low frequency*, or f. Obviously the binary threshold could not be divided evenly; here it lies at the 75th percentile. This problem could not be corrected, but will be addressed later in the results.

2.2.2 Methodology: Brightness

Brightness refers to the photon behavior at a particular wavelength presented in Kelvin units of temperature. However, brightness is not equivalent to the fire radiative power (FRP) according to the Stefan-Boltzmann law, and so cannot calculate the mass of fuel consumed. In other words, while brightness can be used as a proxy for fire *intensity*, FRP would be used as a proxy for fire *severity*. Severity is more useful to the study of carbon emissions. In future studies I recommend accounting for FRP as well as brightness, since FRP has been correlated with cropland burning in tropical climates, and in forested areas in boreal climates.

Of the 8500 cells with a minimum of 305.4 and maximum of 461.1, the mean was found at 326.4, and the standard deviation 11.2. Like the frequency metric, I allowed the binary threshold to be uneven with brightness, addressing the problem later when analyzing results. I let the threshold rest just above the mean, at 327 (the 62nd percentile) All cells with brightness higher than 327 are grouped *high brightness*, or B; all those equal to or below 327 are *low brightness*, or b.

2.2.3 Methodology: Regional Density

Regional density measures the presence of neighbouring fires within the seven-year period. A value of 1000 buffering distance was chosen, since it is low enough that at least 40% of the data has a neighbour, but high enough that the regional density metric has meaning beyond the frequency metric. However, because so many of the cells are still valued at 0 (with no nearby neighbours), the threshold is actually divided at the **40th percentile**. Those with nearby neighbours are *high regional density*, or D; those without are considered *low regional density;* or d.

2.3 ANTHROPOGENIC VARIABLES

Almost all information for the anthropogenic variables is derived from the government census map, from the Contraloría de Panamá. The census contains a great deal of information about people in a given site from which formulas to measure such variables as living density and economic access are built. Yet these census input points invariably bring two disadvantages.

First, while the points are distributed as to cover roughly the same area as the fire cells, they do not fall precisely into the center of each cell, causing some inaccurate results. However, since it is unlikely that the pattern by which census taking chooses its locations would systematically skew the data one way or another, the map is still appropriate for this study.

Second, only 1143 of 6706 total census points actually intersect with 1143 of 8500 total fire cells. However, so long as the census location choices are not influenced by the fire variable, it is still appropriate to compare points near fires to points not near fires.

Third, most unfortunately but also unavoidably, the census was taken in 2000. However, as discussed before, this study is intended not only as a base from which to localize causal analysis in localized sites, but also as a foundation from which to build comparison in the long term. Thus my recommendation is to overlay the statistics in this study with the next census map in 2010.

2.3.1 Methodology: Living Density

The field was created using two columns of information from the census: population, and number of homes.

Basic = Homes / Population + (Population scaled to percentage)

Field calculator = ([HOGARES] / [PERSONAS]) *100 + [PERSONAS] / 276.57

The equation is built so as to express both the measure of people in an area as a function of the number of homes, and simply the number of people in an area. Measuring only population size or only density would not represent dense and highly populated cities separately from rural zones. In future studies however, I would recommend running separate fields for rural and non-rural geographic zones, and then examining population and living density separately.

Once living density is defined and scaled, it is broken into five categories using a quantile scale, in order to obtain a more even distribution. Category one, below, is all values on the scale between 0 and 18.

1 (0-18)	2 (19-22)	3 (23-25)	4 (26-30)	5 (31-128)

Those five categories are then tabulated with the existing eight fire regimes.

	Regime classifications							
Living density scale	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1 (0-18)								
2 (19-22)		37						
3 (23-25)								
4 (26-30)								
5 (31-128)								

Tables 2.1-2.8: Regime Calculation Sample

Next, a value is counted for each intersection. As an example, 37* is shown above as the number of cells from Regime 2 which are classified as Living Density Category 2. When the sums of these numbers per each Living Density Category are converted into percentages, they show the relative distribution of all fire cells for Living Density. This number by itself is not statistically significant, since the formula used to obtain living density was created in this study and is not a world-recognized standard. However, when this relative distribution is compared to the relative distribution in all of Panama, the results are significant (see table on right). Each of those percentages are obtained by summing all numbers in the row** (shown below), and then converting the sum into a percentage of the sum for that column.

Fire %	**Panama %**
15.75	18.63
23.10	20.18
21.52	19.03
22.22	23.31
17.32	18.82

									Sum
2 (19-22)	12	37	5	12	15	23	6	14	124

*37 is not the actual number.

**not the actual numbers

This process of converting into percentages is repeated across all rows (rather than all columns) until a relative distribution is set across each Living Density Category (see table below).

0.56	2.78	3.89	8.89	16.67	26.67	10.00	30.56
2.65	3.41	7.95	10.61	13.26	22.73	14.77	24.62
2.44	1.22	7.32	8.94	12.20	21.14	14.63	32.11
3.54	3.54	6.69	11.42	17.32	22.05	11.02	24.41
4.04	2.02	9.09	12.12	13.13	21.21	13.13	25.25

Though relative distribution of Living Density across Fire Regimes is itself not useful (since we already have divided the Regimes unevenly), it is important to know which Living Density Categories rank unusually high or low for each fire regime. To make the results more readable, each cell is written as the difference between the average percentages (shown below),

2.71	2.63	7.09	10.42	14.45	22.59	12.87	27.23

and the existing percentage in the cell. For instance, here row 1 would be replaced by this:

-2.16	0.15	-3.20	-1.53	2.22	4.07	-2.87	3.32

Finally, there is still the problem of uneven quantile groups. Though each equation strived to distribute the numbers evenly, with a reasonable maximum, the resulting numbers were often distributed in such a way that would have required more than 15 divisions. And so, to compensate for large inequalities, the difference between "actual" distribution in fire cells and "expected" distribution shown in All Panama cells is obtained, and added to the cells.

In the resulting table, a positive number indicates a higher than average distribution, and a negative number (highlighted in red) is lower. The highest and lowest distribution for each regime is bolded.

LIVING DENISTY	**Regime classifications**								**Fire %**	**Panama %**
Living density scale (quantile breaks)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**		
1 (0-18)	**-5.04**	-2.73	**-6.08**	**-4.41**	-0.66	1.19	**-5.75**	0.44	15.75	18.63
2 (19-22)	**2.86**	**3.70**	**3.78**	**3.11**	1.73	**3.06**	**4.82**	0.31	23.10	20.18
3 (23-25)	2.21	1.08	2.71	1.01	0.24	1.04	4.25	**7.37**	21.52	19.03
4 (26-30)	-0.26	-0.17	-1.49	-0.09	**1.78**	-1.63	-2.94	**-3.91**	22.22	23.31
5 (31-128)	-0.17	-2.11	0.50	0.20	**-2.82**	**-2.88**	-1.24	-3.48	17.32	18.82
Expected %	2.71	2.63	7.09	10.42	14.45	22.59	12.87	27.23	**1141**	**6706**

If the positive values corroborate with the average mean for Living Density in its respective Regime, then this finding is discussed in the "results and discussion" section. For example, regime 8 (*low frequency, low regional density, low brightness*) is most strongly associated with Living Density Category 3, or "average". Regime 8's mean is 24.96— within group 3, as expected, and so this finding will be discussed later. While the average mean is useful for corroboration, it should not be the sole measure, since it is difficult to make a judgment of relative distribution with only one number. Moreover, only working with a mean does not allow us to identify where the weakest statistical grouping occurs.

The number 1141, bolded, refers to the number of fire cells counted for Living Density. While 8500 cells exist, this number is limited by the number of census stations which coincide with fire cells. The number 6706 is simply the total number of census stations available.

This procedure is almost exactly repeated for all four anthropogenic variables. The only difference between them is that because each variable has a different equation, the resulting scales will have different appropriate quantile break locations.

The procedure is also applied to the three ecological variables, except that the mean averages per cell cannot be identified, since the ecological variables are discrete rather than continuous.

2.3.2 Methodology: Economic Access

Poverty indices are extremely difficult to summarize across a country where a large number of indigenous groups and *campesinos* live through subsistence agriculture. However, while it would be unfair to use poverty rates as the sole measure of a community, indices such as unemployment, illiteracy and average annual income should not be ignored in this study. Thus economic access is defined separately from grid access, which is a measure of access to water, electricity, roads, vehicles and other services. The equation used to calculate the Economic Access field is below:

basic: ((1/(unemployment rate +0.1) + 1/(illiteracy rate + 0.1)) / (sqrt (0.1 * average income +1))
Field calculator: ((1/([DESOCUPA] / [OCUPADOS] +0.1)) + (1/ (([PERSONAS] - [SABELEER]) / ([PERSONAS]+0.1)))) + (Sqr (0.1 * [ING_PROM] +0.1))
Fires select by attributes: "PERSONAS" > "SABELEER" AND "PERSONAS" >0 AND "ING_PROM" >0 AND "OCUPADOS" >0

Because the equation cannot divide by 0, it was necessary to select only those cells where there were in fact people, where at least one of those people was occupied, and the average income was above 0. However, this did not significantly alter the reading, since the procedure was repeated exactly for the all-Panama grid, and since those with no income, and no people occupied, would receive very low scores anyway.

2.3.3 Methodology: Grid Access

Grid access is a reading of how many people in each cell have access to water, electricity and service for those utilities, combustion vehicles, road density, radio and telephones. Since not all of these factors have equal importance, they are each weighted to the degree that they are used on average. Road density is converted into a scale from 1 to 100 and added to the sum. The field equation is as follows:

Basic = ((Sum water/sum total)*water+(Sum service/sum total)*service+(Sum electricity/sum total)*electricity+(Sum combustion vehicle/sum total)*combustion vehicle+(Sum telephone/sum total)*telephone+(Sum radio/sum total)*radio)+road_density/(0.01*max_road_density)

Field calculator = 0.10998378* [V08_AGUA] +0.08170903* [V09_SERVI] +0.19860465* [V10_ELEC] + 0.20541915* [V11_COMBU] + 0.24102758* [V12_TEL] + 0.16325581* [V12_RAD] + ([rdmaster] /258.05265146)

2.3.4 Methodology: Indigenous Ratios

This index conveys the ratio of indigenous persons to other persons within each fire cell. The equation is below:

Basic: Indigenous ratio= ((nonindigenous-population)/population)*100

In addition, the field "indigenous groups" is broken into its six components: Guaymi, Kuna, Teribe, Bokota, Embera and Waunana. For each component a mean average is found, and those means are compared by percentage in a pie chart. The mean is also compared by number on a bar graph, which is a more useful reading for this study. A recommendation for future studies is to compare indigenous ratios geographically as well, by dividing the country among provincias and comarcas.

2.4. ECOLOGICAL VARIABLES

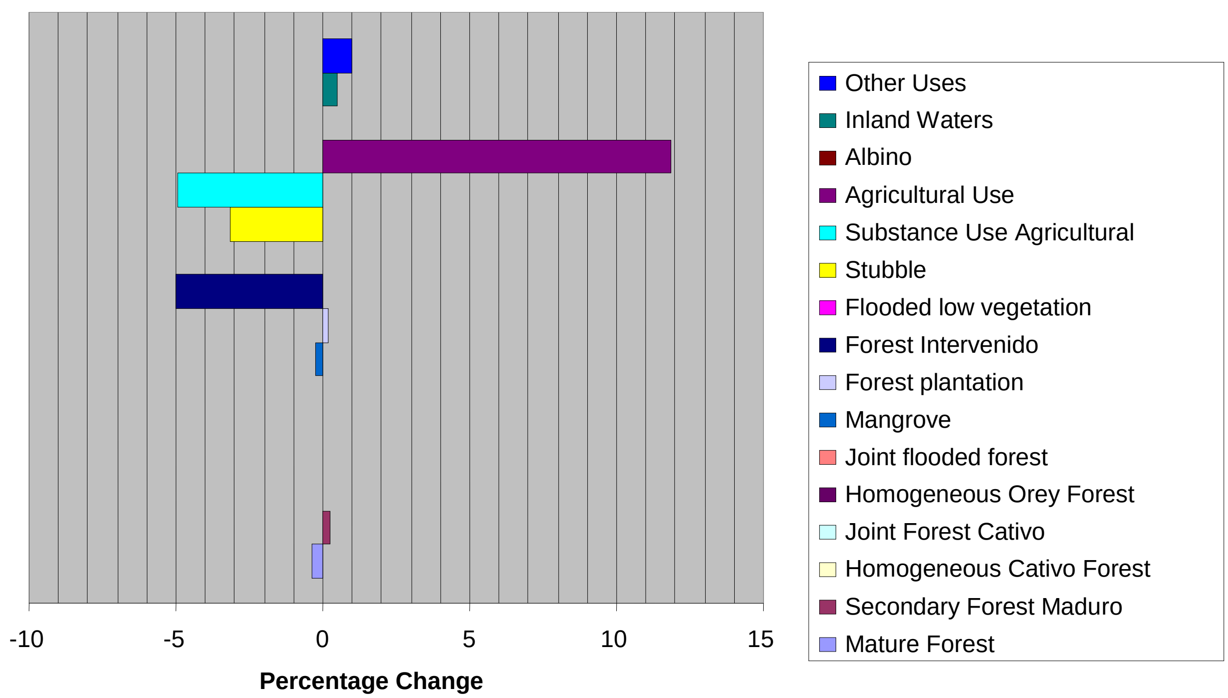
2.4.1 Methodology: Land Cover

The land cover data, retrieved from a 2008 map, lists 16 classes of land cover which I have organized into ten basic classes and summarized within 1km grid cells to match the size of the regime cells (Escobar 2009). It must be noted that although 2009 fires are included in the regime makeup, the land cover map is recent only to 2008.

2.4.2 Methodology: Land Cover Change

A 2008 land cover map has been overlaid with a 2000 map, and the changes have been codified (Escobar 2009). For example: a change from category 15 to category 2 is given its own number, arbitrarily, 4. The primary changes are summarized in the following chart:

Fig 1: Land Use Changes by Percentage 2000-2008



First, it was necessary to sort these changes in to meaningful and relevant categories. With 16 potential covers, over 1000 possible change combinations are available to choose from.

For the category of Change From, it was intuitive that forest should be selected. I summarized forest into two categories: Mature, and All Other (excluding plantation forest, which received its own category).

From there, two separate readings of 12 change types could be obtained; one reading for each forest type. In addition, it was necessary to use the select by attributes function in order to find those instances in which All Other forsts did not change.

Select by attributes where:

("USO_08" = 'Bosque Inundable Mixto' AND "USO_00" ='Bosque Inundable Mixto') OR ("USO_08" = 'Bosque Secundario Maduro' AND "USO_00" = 'Bosque Secundario Maduro') OR ("USO_08" = 'Bosque de Cativo Homogéneo' AND "USO_00" = 'Bosque de Cativo Homogéneo') OR ("USO_08" = 'Bosque de Cativo Mixto' AND "USO_00" = 'Bosque de Cativo Mixto') OR ("USO_08" = 'Bosque de Orey Homogéneo' AND "USO_00" = 'Bosque de Orey Homogéneo') OR ("USO_08" = 'Manglar' AND "USO_00" = 'Manglar')

2.4.3 Methodology: Holdridge Life Zones

The Holdridge Life Zones are a concise analysis of climate and potential vegetation characteristics (Holdridge 1967). As a variable, it is well suited to complement the land use maps. The km by km dataset used in this study was generated by a colleague at CATHALAC and originally downloaded from the WorldClim databases (Silva 2009). The table below summarizes the life zone data for Panama:

Table 3: Holdridge Zones of Panama								
Number	Name (Spanish)	Name (English)	Mean annual temperature **(°C)**	Mean annual precipitation (mm)	Elevation from sea level (m)	Coverage in Panama (km^2)	Coverage in Panama (%)
56*	Bosque muy húmedo montano bajo	Lower montane wet forest	12 - 18	2000 - 4000	1801 – 2800	2153	2.48
65*	Bosque muy húmedo premontano	Montane wet forest	18 - 24	2000 y 4000	801 – 1800	435	0.50
66	Bosque pluvial premontano/ Montane rainforest	Montane rainforest	18 - 24	4000 - 8000	801 – 1800	16961	19.57
75	Bosque seco tropical	Tropical dry forest	>24	700 - 2000	0 - 800	18053	20.83
76	Bosque húmedo tropical	Rainforest	> 24	2000 y 4000	0 - 800	48912	56.45
77*	Bosque muy húmedo tropical	Tropical wet forest	> 24	4000 - 8000	0 - 800	138	0.16
Total						86652	100

*sample size too small to be considered in summary table

2.5 Methodology: Conservation Zone Analysis

Conserved zones are defined as those within mapped conservation areas with a width exceeding 2 km at its narrowest point. The idea is to represent a continuous ecosystem structure in contrast to the fragmented and exposed bordering zone on the perimeter of the national parks. This bordering zone is defined as that area within a 1 km on each side of the park border. The 2009 map was obtained from the Autoridad nacional del ambiente, from the department of biological corridors (Nobleman 2009).

2.6 Methodology: Temporal Analysis

Since the fire regimes already combine the seven years of data, for temporal analysis it is necessary to separate the fires into individual occurrences. The fires were then sorted by acquired date and counted per year and per month. This allows both a basic intra-annual and inter-annual comparison of fires.

3. RESULTS AND DISCUSSION

3.1 Results and Discussion: Fire Regime Layout

As mentioned in the methodology, the binary divisions of frequency, regional density and brightness are not even. Therefore the relative distribution of the fire regimes are not 12.5% each but instead the percentages apparent on the table below.

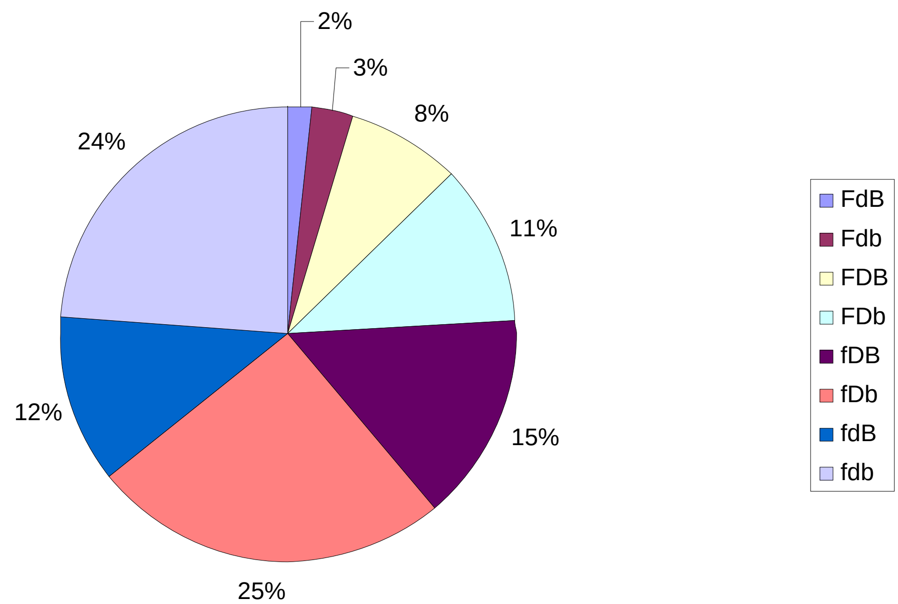
Table 4: Regime Classifications

Fire class	Frequency		Regional density (within 1000 m)		Brightness		Summary	Relative Distribution by %
	High F	Low f	High D	Low D	High B	Low B		
	> **1**	**=1**	**>=1**	**0**	**>327**	**=<327**		
Percent:	24.09%	75.91%	59.38%	40.62%	36.84%	63.16%		
1	F			d	B		FdB	1.72
2	F			d		b	Fdb	2.99
3	F		D		B		FDB	8.15
4	F		D			b	FDb	11.24
5		f	D		B		fDB	14.91
6		f	D			b	fDb	25.08
7		f		d	B		fdB	12.06
8		f		d		b	fdb	23.86

Instead, this distribution can be obtained one of two ways: first, by applying this formula on each group:
Relative distribution = % F * % D * % B *100 or % f * % D * % B *100 or % F * % d * % B *100…etc
Eg. Expected 8 (fdb) = ((0.7591*0.4062*0.6316*8500)/ 8500)* 100

Or, it can simply be obtained by selecting each group by attributes, counting, and finding the relative distribution of that group. This uneven distribution is always something to keep in mind in this study until a solution can be found in future studies that work in such fine resolution.

Fig 2: Relative Fire Regime Distribution



3.2 ECOLOGICAL VARIABLES

For each variable, the final percentage table is displayed, with strong and weak associations highlighted, as well as a bar graph illustrating the relative difference between the variable counted in fire cells, and in all of Panama. Relevant results are discussed.

3.2.1 Results and Discussion: Holdridge Life Zones

Table 5: Holdridge Life Zone Distribution

Holdridge life-zones		**Regime classifications**								**Fire %**	**Panama (%)**
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**		
56	*Lower montane wet forest	45.81	-5.46	-10.62	-13.71	-17.38	-27.55	35.47	-26.33	0.011774	2.48
65	*Montane wet forest	-0.49	1.15	-2.47	-0.76	-3.23	-0.39	-1.76	4.08	0.023549	0.50
66	Montane rainforest	**-12.70**	**-13.19**	**-12.77**	**-13.62**	**-11.42**	**-11.61**	**-10.69**	**-15.52**	6.876251	19.57
75	Tropical dry forest	**8.05**	**8.10**	**8.35**	8.51	**7.83**	**7.65**	7.21	8.76	28.89438	20.83
76	Rainforest	5.88	4.61	-0.55	**13.03**	-7.31	-9.15	**28.87**	**25.41**	64.05275	56.45
77	*Tropical wet forest	45.81	-5.46	-10.62	-13.71	-17.38	-27.55	35.47	-26.33	0.141293	0.16
Expected %		1.72	2.99	8.15	11.24	14.91	25.08	12.06	23.86		

*sample size too small to be considered for summary table

Comparing the relative distribution of fire cells to all of Panama, three major differences are apparent. While the rainforest, and tropical dry forest, are associated with fire cells, montane rainforests (and to a smaller degree, lower montane wet forests) are strongly associated with non-fire cells. This is likely due to the relatively high elevation, and extremely high precipitation levels, despite the higher temperatures. Although Holdridge zones are described with the predicted vegetative cover, the actual cover distribution is explored in the next section.

3.2.2 Results and Discussion: Land Cover

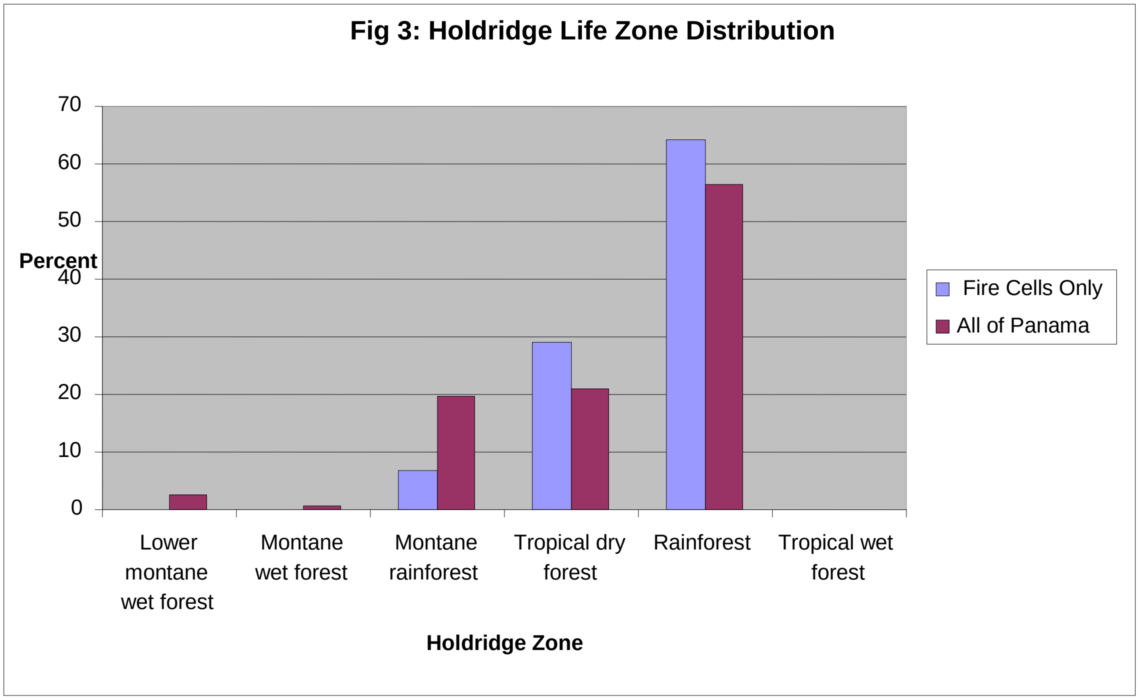
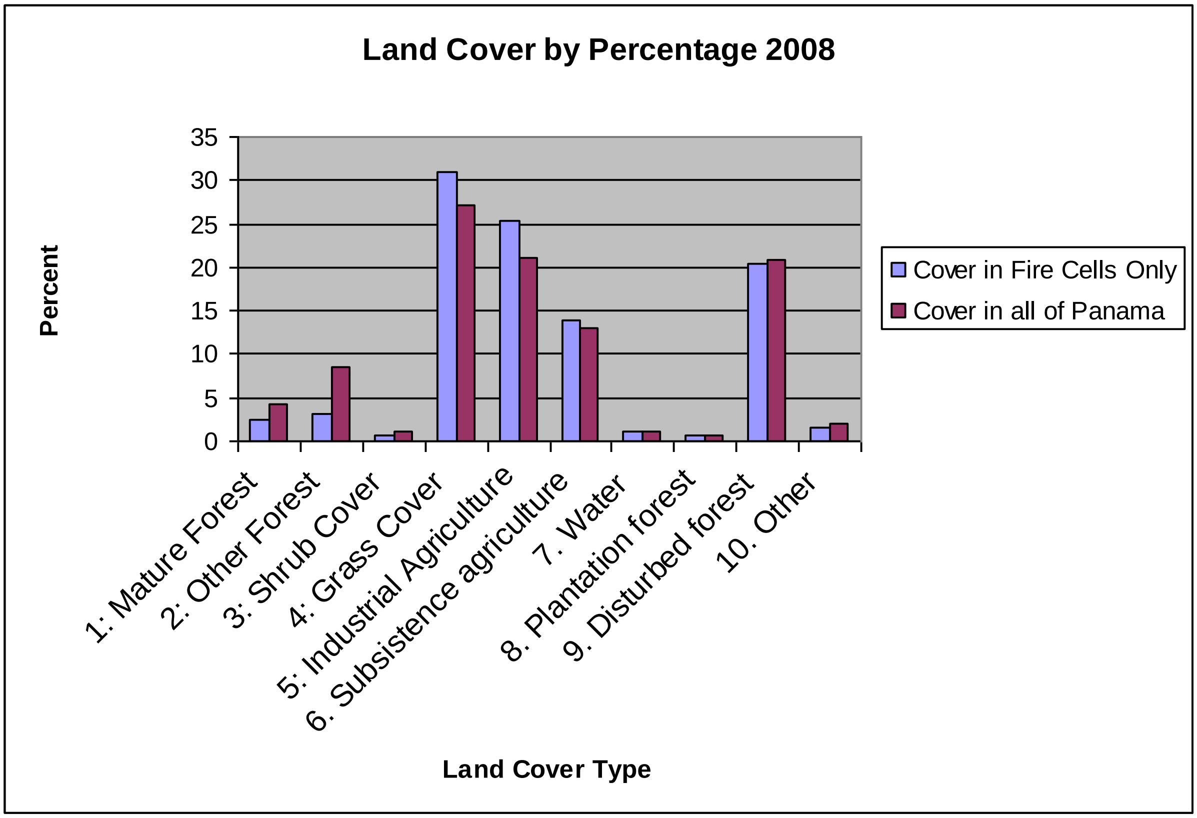


Table 6: Land Cover Distribution

	Regime classifications									All of Panama*
Land cover types	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Fire Cells Only**	
1: Mature Forest	-2.18	-0.28	-4.41	-5.44	-6.05	**-9.50**	0.13	**12.35**	2.40	**4.32**
2: Other Forest	**-5.46**	**-6.26**	**-7.16**	**-6.40**	**-8.04**	-6.20	**-1.73**	-2.20	3.07	**8.50**
3: Shrub Cover	-1.38	-0.05	4.65	-2.80	-0.25	-4.94	4.47	**-3.97**	0.64	**1.17**
4: Grass Cover	4.29	4.15	3.23	3.32	3.87	2.25	4.65	5.12	31.05	**27.19**
5: Industrial Agriculture	**4.49**	**4.62**	**4.76**	3.65	**4.58**	**3.28**	3.89	4.47	25.42	**21.06**
6. Subsistence agriculture	1.08	2.10	-1.17	0.75	-1.85	-0.30	1.20	4.60	13.91	**13.11**
7. Water	0.51	1.17	0.01	-3.16	-0.21	-4.69	**5.41**	-0.24	1.04	**1.188**
8. Plantation forest	0.17	1.96	0.36	**3.76**	-2.36	-4.81	0.00	0.33	0.65	**0.72**
9. Disturbed forest	-0.41	0.19	-1.55	-1.43	-1.10	-1.48	-0.38	2.48	20.31	**20.77**
10. Other	-0.41	3.82	-3.19	0.38	-6.14	-6.63	4.48	4.17	1.51	**1.95**
Expected %	**1.72**	**2.99**	**8.15**	**11.24**	**14.91**	**25.08**	**12.06**	**23.86**		

The most fire-attractive land cover zones are grass and industrial agriculture, and very slightly subsistence agriculture. I hypothesize that grass cover can be explained

Fig 4: Land Cover Distribution



largely by small and medium-scale cattle ranching by campesinos. This could be tested by tracing the campesino movement as it follows the major roadways to the east, though it would be difficult to obtain accurate and consistent data about campesino presence and cattle ownership, particularly since such activities are often illegal squatting or without land titles. Industrial agriculture's coverage is very likely due to large scale sugarcane slash and burn annual activity. This could be tested using another MODIS function to differentiate between types of crops, by tabulating the number of frequently burnt crops with a temporal analysis. In other words, if most fires on industrial agricultural lands match the rhythm of slash and burn patterns, then the hypothesis stands.

On the other hand, mature forests and other forests are relatively aversive to burning. Note, however, that these patterns do not apply to disturbed forests, which do not show significance one way or another. Interestingly, other forests (including mangrove forests, secondary mature forests, joint flooded forests, homogeneous cativo forests and joint cativo forests) have a stronger association with non-fire cells than mature forests. Perhaps, however this is because some of the forests which make up the former category are water-based.

To explore these relationships further, this study identifies both mature forest and other forest degradation distribution, and identifies which type of land change is most associated with fires, below.

3.2.3 Results and Discussion: Land Cover Changes

Table 7: Mature Forest Land Cover Changes										Sum fires	Panama %
Land cover change from mature forest		**Regime Classification**									
Code	**Changed to…**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**		
0	**No change**	**-4.25**	-4.10	**-5.35**	**-6.01**	-4.71	**-10.04**	-2.26	-2.23	21.29	26.16
2	**Disturbed forest**	0.90	0.29	0.22	2.56	0.76	1.53	0.24	1.33	25.68	24.70
3	**Grasses**	0.16	-0.37	0.80	-0.08	0.87	2.51	1.37	-1.49	20.99	20.52
4	**Industrial Agriculture**	**5.75**	**6.23**	**8.80**	8.30	**9.22**	**9.76**	**3.55**	**-5.05**	16.45	10.63
5	**Subsistence Agriculture**	-2.20	-1.10	-3.69	-5.11	-5.93	-2.84	-3.03	7.91	15.24	17.24
6	**Other**	-1.60	-4.70	-1.73	5.63	**-6.62**	2.69	**-7.80**	**10.84**	0.34	0.75
	Expected %	1.19	4.29	6.32	**8.96**	11.21	21.90	12.39	33.75		

From mature forests, two types of change show clear associations with fire cells. First,

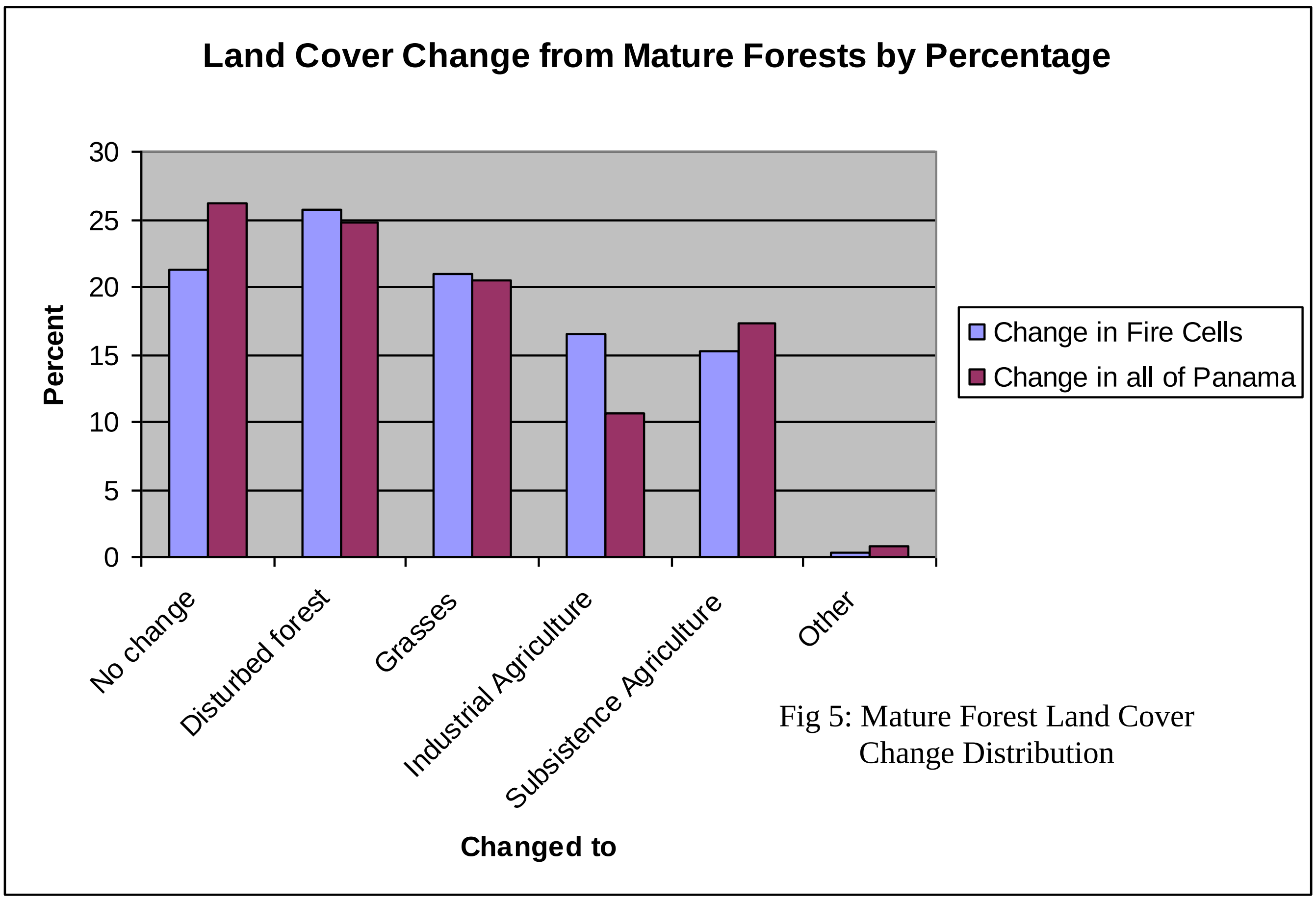


Fig 5: Mature Forest Land Cover Change Distribution

those which remain undisturbed are the least likely to attract fires. Second, those designated for industrial agricultural use are most likely to host fires.

Interestingly, the change from mature forests to grasses show no tendencies either way—even though grasses are one of the most dominant land covers to attract fires.

The change from mature forests to subsistence agriculture is one worthy of further study, since it is actually *less likely* to host a fire. Given that the other local ecological and anthropogenic variables are optimal, policy makers and land planners should consider designating more substistence agriculture in areas of mature forest which have selected for human use, rather than any other land choice. Moreover, ANAM should strongly reconsider displacing subsistence agricultural land to make room for more conservation areas, as long as the inhabitants do not carry other anthropogenic threats.

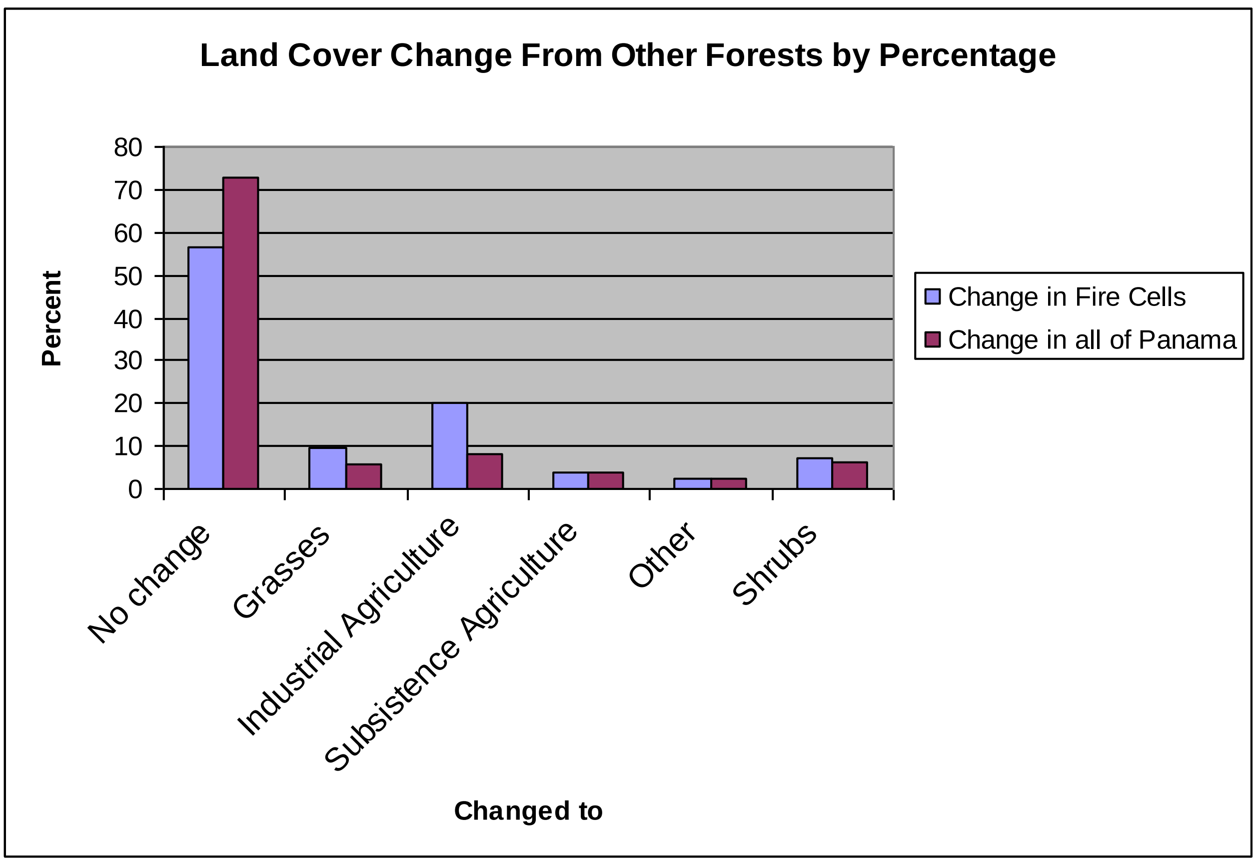
Table 8: Other Forest Land Cover Change Distribution

Land Cover Change from Other Forests		Regime Classification									
Code	Changed to…	1	2	3	4	5	6	7	8	Fires %	Panama %
7	***No change**	-18.11	-18.47	-21.87	-24.58	-27.62	-36.85	-30.07	-38.54	56.36	73.04
8	**Grasses**	4.30	3.94	5.74	8.24	6.42	1.17	3.66	-2.36	9.78	5.89
9	**Industrial Agriculture**	**10.76**	**10.21**	6.98	2.10	0.23	-7.87	-1.26	-6.49	20.25	8.22
10	**Subsistence Agriculture**	-0.21	**0.40**	**-1.18**	**-2.07**	**-0.51**	**-15.43**	**-5.81**	**-10.91**	3.73	4.07
11	**Other**	**-1.84**	9.39	**10.70**	**15.59**	**31.13**	**51.50**	**35.99**	**42.95**	2.50	2.53
12	**Shrubs**	-0.66	2.90	0.37	-0.49	2.58	2.81	2.64	-0.95	7.39	6.24
Expected %		1.81	2.17	6.66	10.47	13.76	23.83	16.15	25.14		

From other forests, those cells which change into industrial agriculture are most strongly associated with fires. The fact that both mature and other forests changing to industrial agriculture are most associated with fires suggests that land changes in particular, rather than simply the existence of industrial agriculture, are partly responsible for fires. One testing idea is to conduct a series of interviews at industrial farms >50 years old, and those recently adapted from forests, to see which attract more fires.

Grasses are associated roughly half as strongly as this. Perhaps the fact that the change from other forests to grasses attracts fires while those from mature forests do not can be explained by the water-based forests which make up the category "other forests". To test this idea, one could measure the degree to which other forest to grassland precipitation changes, and compare this figure with precipitation changes in mature forest to grassland change. If these two figures are significantly different, the hypothesis stands.

Fig 6: Other Forest Land Cover Change Distribution



3.3 ANTHROPOGENIC VARIABLES

3.3.1 Results and Discussion: Living Density

Table 9: Living Density Distribution										
	Regime classifications								**Fire %**	**Panama %**
Living density scale	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**		
1 (0-18)	**-5.04**	-2.73	**-6.08**	**-4.41**	-0.66	1.19	**-5.75**	0.44	15.75	18.63
2 (19-22)	**2.86**	**3.70**	**3.78**	**3.11**	1.73	**3.06**	**4.82**	0.31	23.10	20.18
3 (23-25)	2.21	1.08	2.71	1.01	0.24	1.04	4.25	**7.37**	21.52	19.03
4 (26-30)	-0.26	-0.17	-1.49	-0.09	**1.78**	-1.63	-2.94	**-3.91**	22.22	23.31
5 (31-128)	-0.17	-2.11	0.50	0.20	**-2.82**	**-2.88**	-1.24	-3.48	17.32	18.82
Average %	2.71	2.63	7.09	10.42	14.45	22.59	12.87	27.23	***1143**	**6706**

Those areas of lowest living density are most strongly associated with non-fire cells. However, close behind are also the top two categories of living density. These categories very likely represent cities across the country, while categories two and three are likely the more highly populated rural zones.

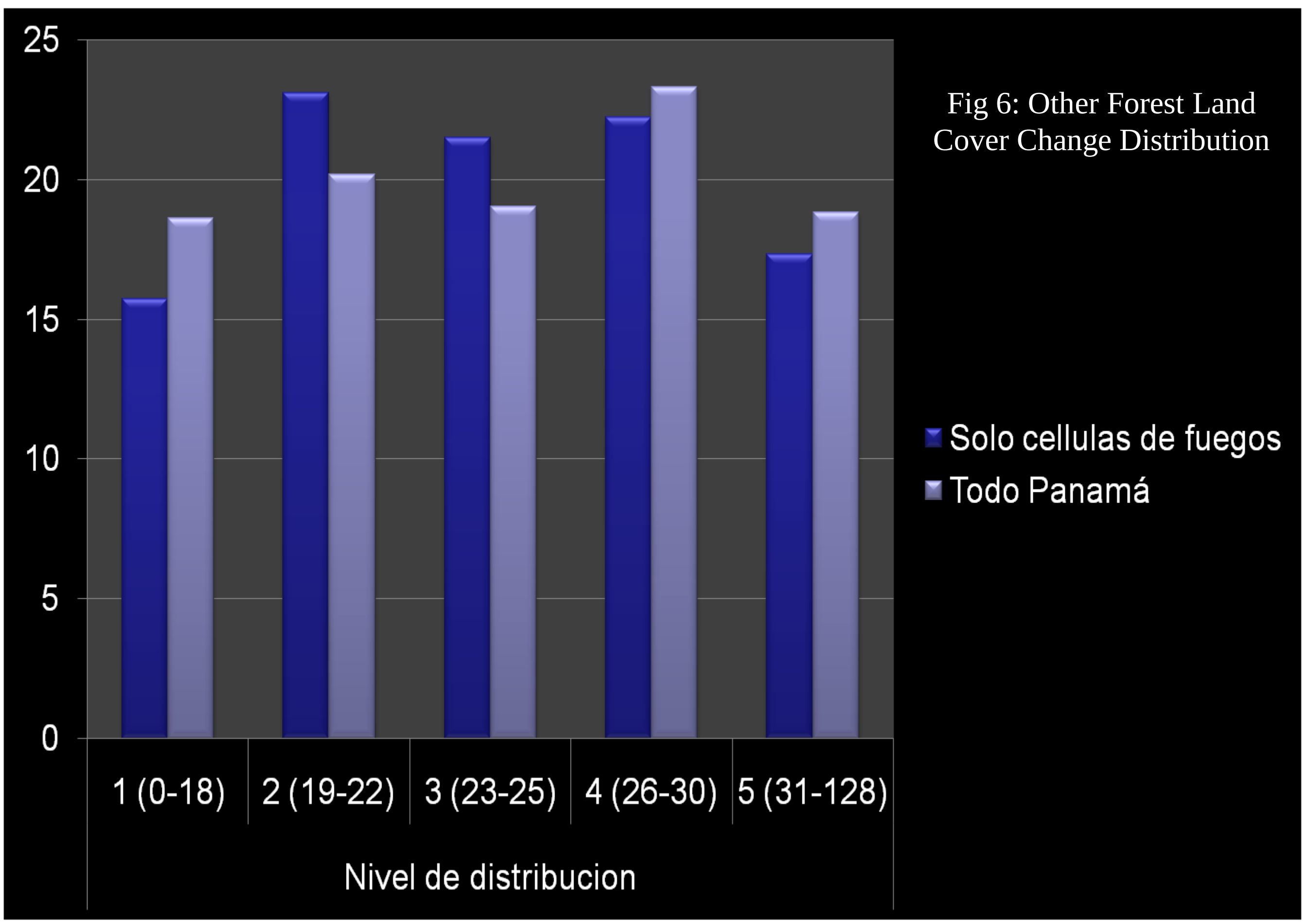


Fig 6: Other Forest Land Cover Change Distribution

3.3.2 Results and Discussion: Indigenous Ratios

Table 10: Indigenous Ratio Distribution									
	Regime classifications								**Total**
Indigenous ratio	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Difference Between Panama and Fire Cells**
1 (0)	96.37	**95.94**	109.23	109.20	96.81	88.14	86.04	88.51	-9.3
2 (1-2)	**1.48**	1.59	**3.84**	2.26	0.61	**1.15**	3.59	**0.57**	1.72
3 (3-17)	0.68	7.45	3.04	**5.54**	1.04	**5.39**	**4.15**	**4.58**	2.52
4 (18-96)	0.57	**-2.66**	0.12	**0.33**	**-0.92**	1.79	4.04	2.22	2.63
5 (97-100)	0.78	-2.45	**-2.49**	3.60	**1.76**	2.39	**1.53**	2.76	2.42
Total	3%	3%	7%	10%	14%	23%	13%	27%	***1140**

*Group 1, (0) indigenous ratio, is not included in the selection for the summary table.

Clearly, those areas with no indigenous population are more associated with fires than those with indigenous people in the population. All categories with indigenous people are associated with more non-fire squares than those without. Next, the category “indigenous groups” is broken into its component parts.

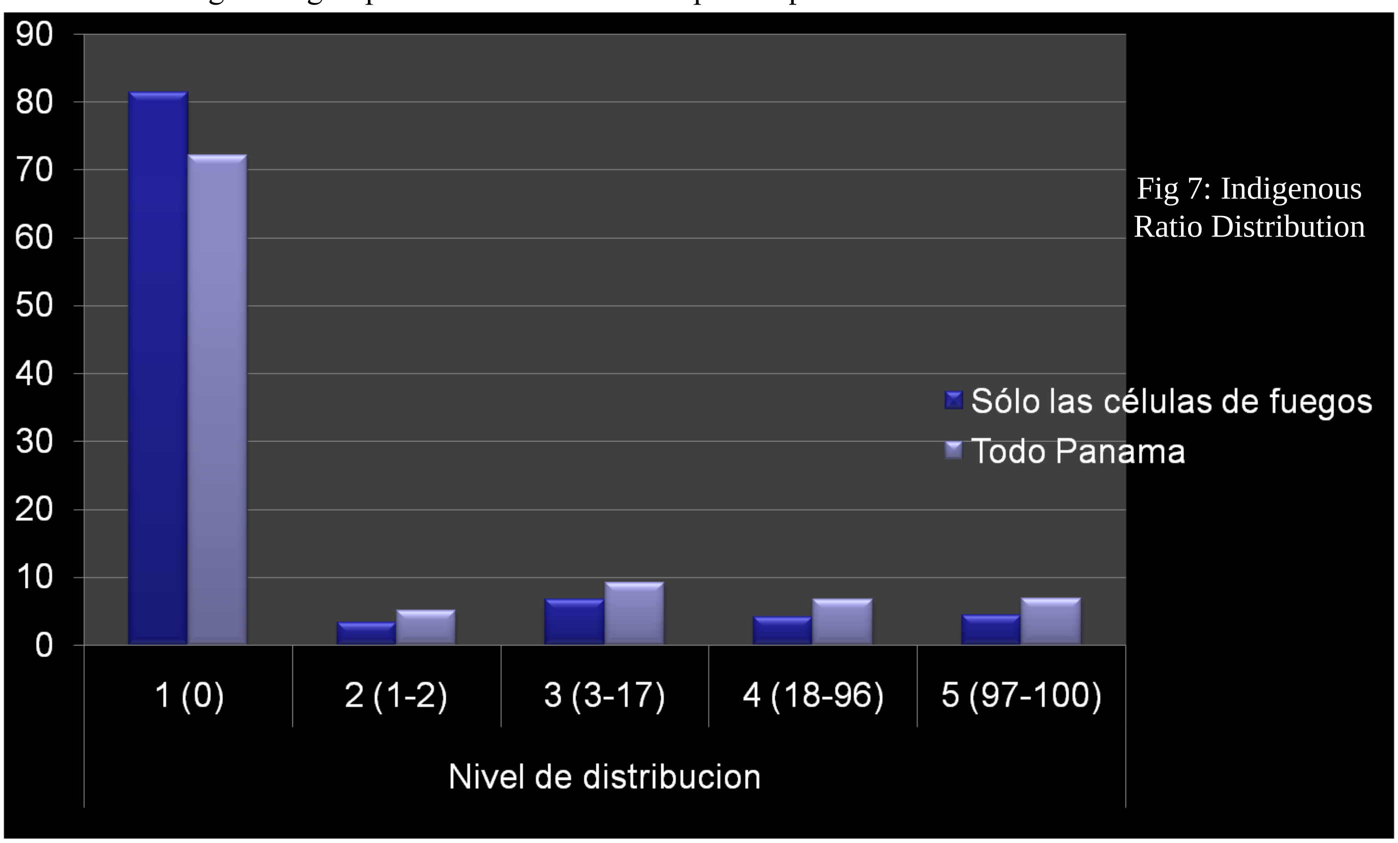


Fig 7: Indigenous Ratio Distribution

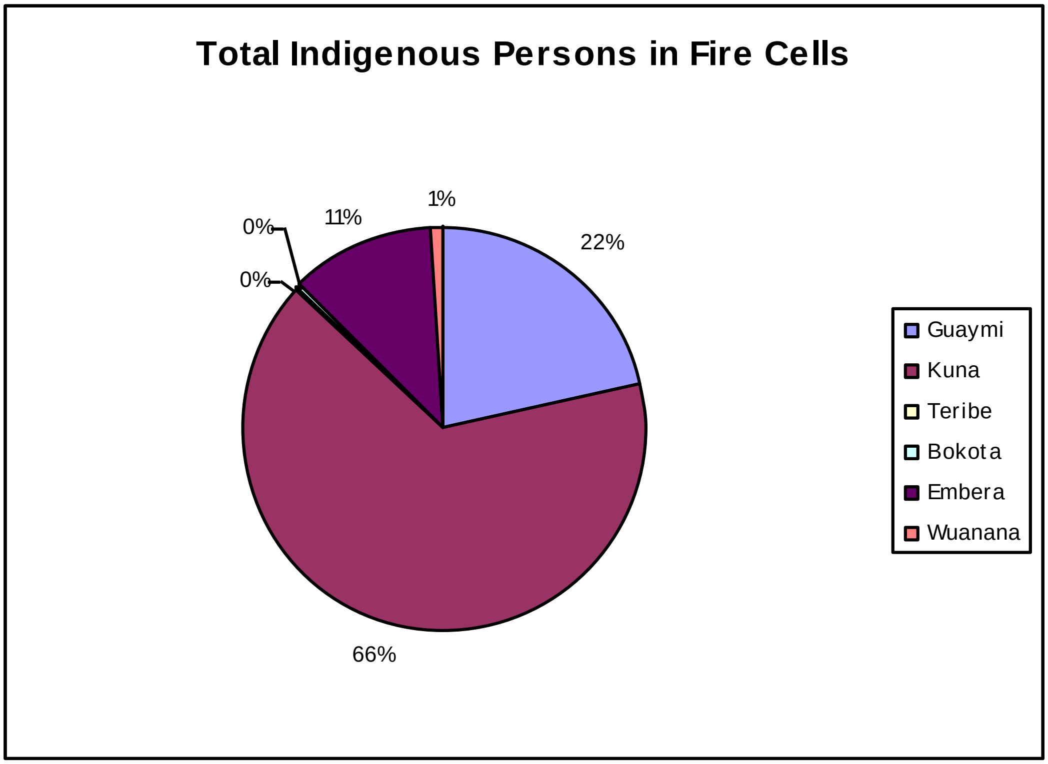


Fig 8: Total Indigenous Persons in Fire Cells

The following two pie charts are displayed here only as an example of why mean averages must be read carefully, though it is a much simpler process to obtain them. According the charts below, Kuna are more responsible for fire cells than any other indigenous group. While this is technically true, the bar graph below those demonstrates that the *relative* difference between fire cells and non-fire cells is actually insignificant. For this reason, in the summary table for the Fire Regime analysis, mean averages are not used to identify dominant and weak fire categories.

Fig 9: Total Indigenous Persons in Panama

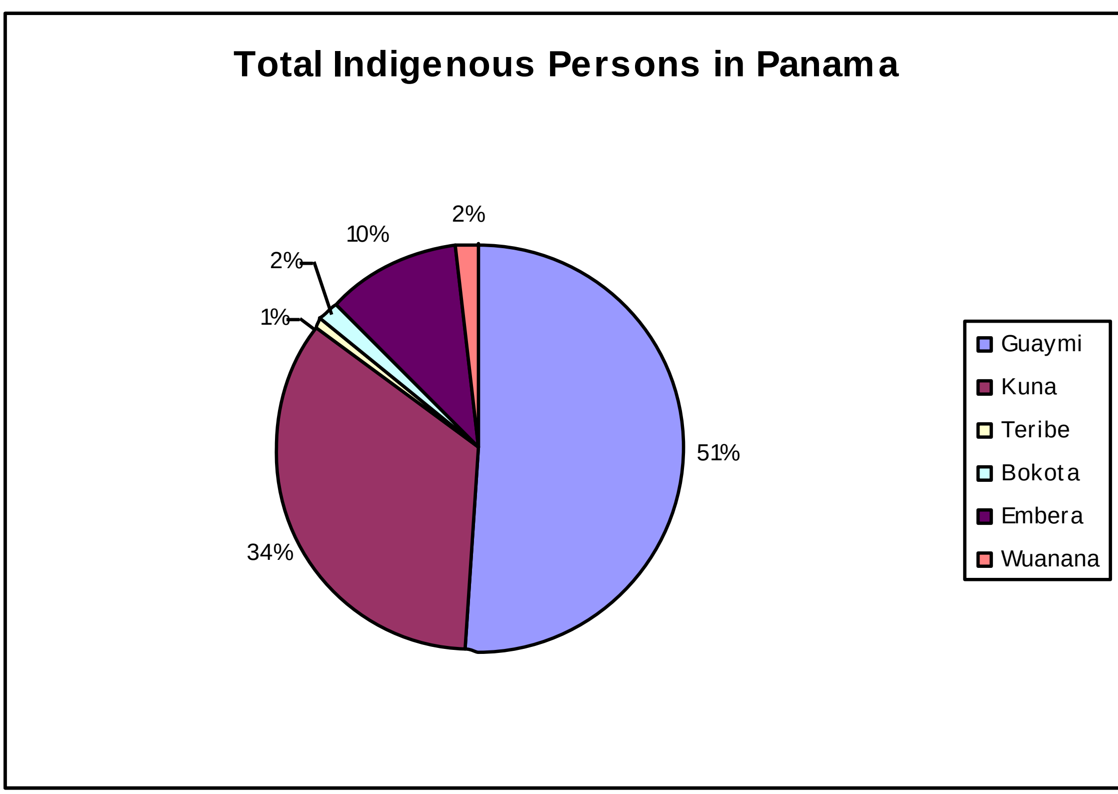
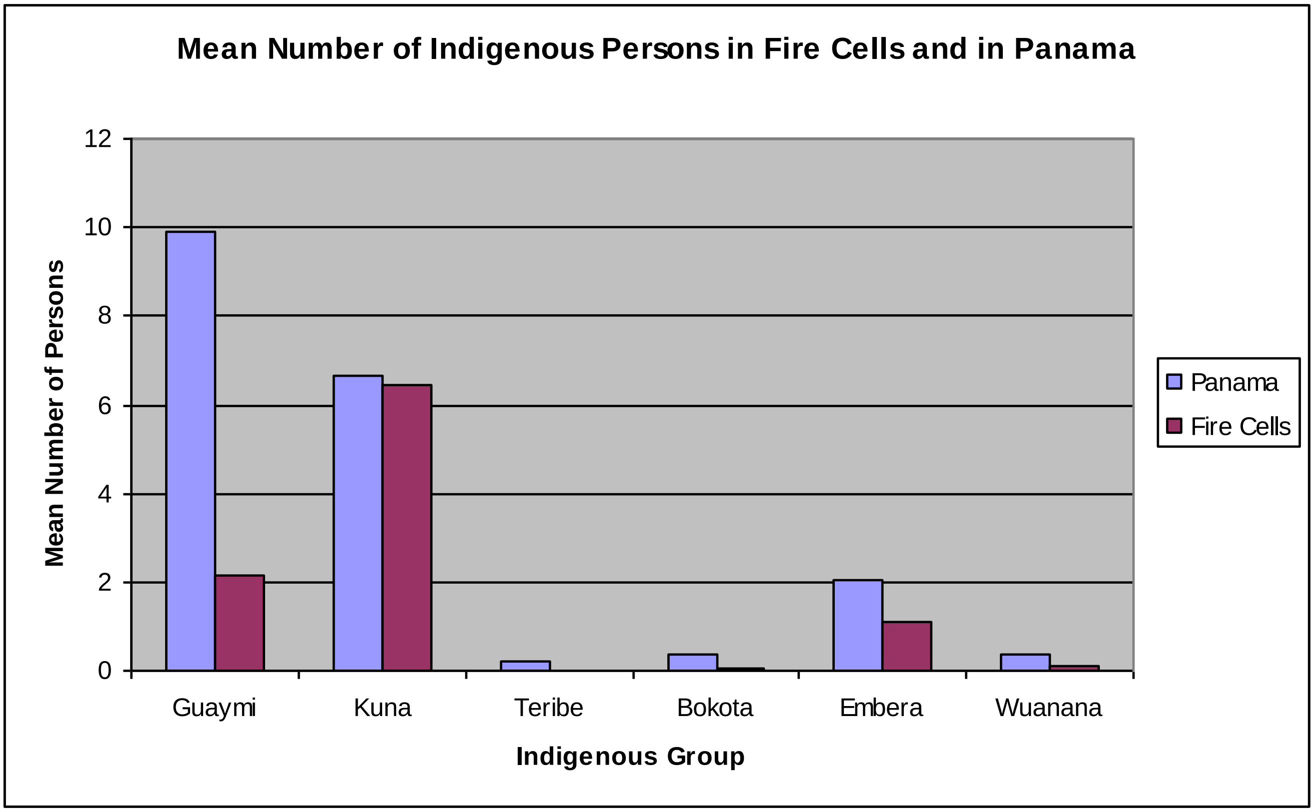


Fig 10: Indigenous Groups Distribution



Here it is apparent that the Guaymi indigenous group is most strongly associated with non-fire cells, followed distantly by the Embera. Kuna, on the other hand, do not show an association. If a follow-up study compared indigenous associations by comparing the comarcas and provincias, they may notice that geographic location (and the climate and other features it entails) has a greater influence than the behavior of the indigenous group. For example, the cloud cover around the San Blas islands is more persistent than most areas of the country, blocking satellite observation. This study is careful not to mistake correlation with causation when considering factors as complex as population groups. For this reason, not one but four detailed anthropogenic variables are used, separating confounding variables whenever possible.

3.3.3 <u>Results and Discussion: Grid Access</u>

Table 11: Grid Access Distribution

	Regime classifications								**Total**	
Grid Access (Quantile Breaks)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Fire cover %:**	**Panama cover %:**
1 0	-68.47	-73.14	-77.61	-76.17	-80.19	-74.04	-78.62	-35.91	1.84	72.36
2 1-4	19.47	19.22	20.80	21.84	21.50	23.10	20.06	15.35	**26.07**	**5.90**
3 5-7	7.77	8.94	7.72	6.56	9.56	7.37	5.19	9.13	**16.19**	**8.40**
4 8-12	10.15	8.73	13.36	9.53	8.53	7.47	9.60	11.33	**17.32**	**7.49**
5 13-489	**32.97**	**33.51**	**31.09**	**32.53**	**32.13**	**32.16**	**34.39**	**33.10**	**38.58**	**5.85**
Total	**2.71**	**2.62**	**7.09**	**10.41**	**14.44**	**22.57**	**12.86**	**27.30**	**1143**	

Unlike the living density factor, grid access is very clearly polarized. The vast majority of non-fire cells are placed in areas of 0 grid access. The highest association with fire cells is also the highest measurement of grid access. The rest of the zones

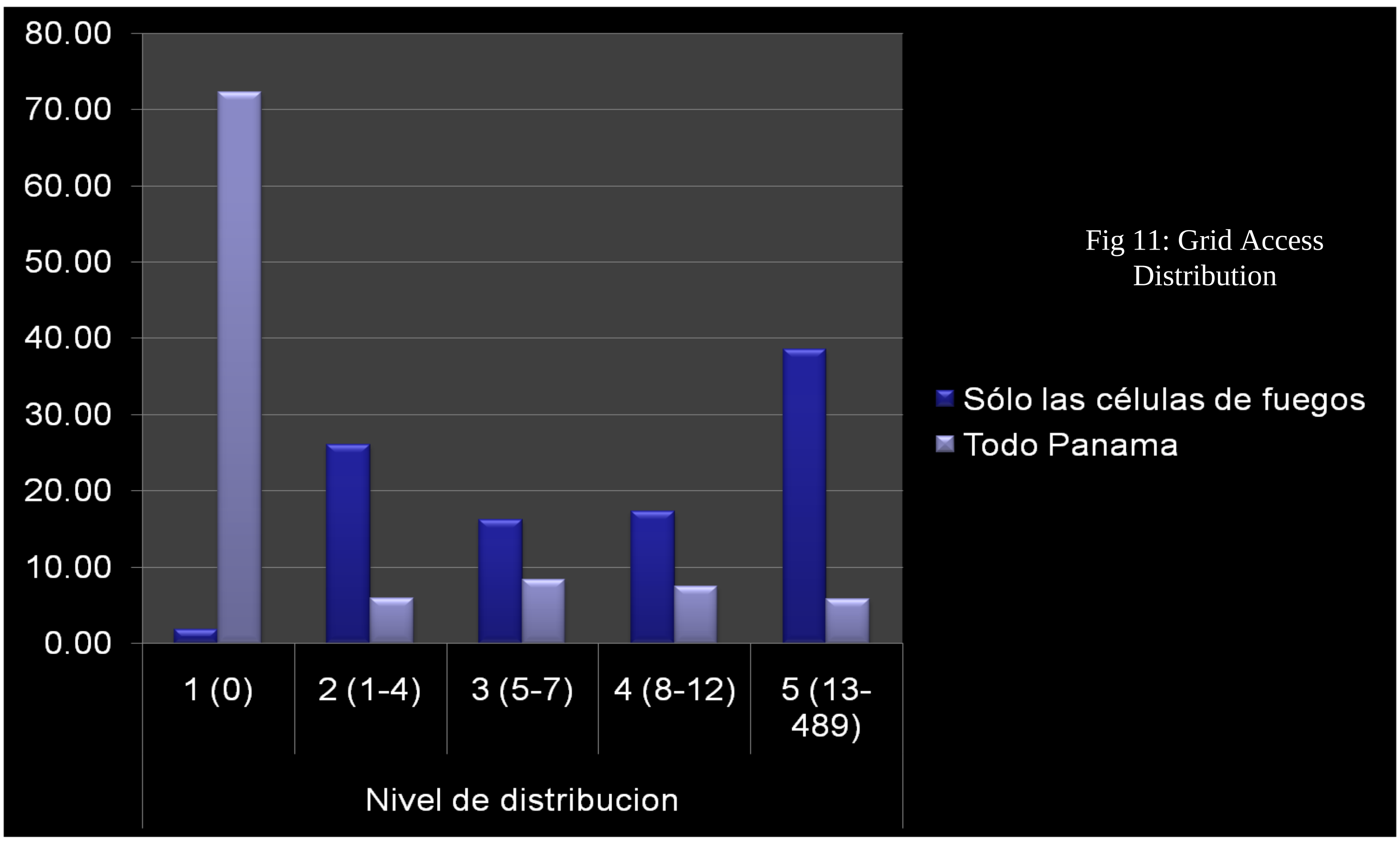


Fig 11: Grid Access Distribution

demonstrate and umbrella curve, conveying that, except for zones of 0 grid access, fires occur at the extremes. Future studies may find it useful to separate road access from other grid access variables, since roads themselves present a fire risk, as well as being a proxy

for accessibility of major anthropogenic factors.
3.3.4 Results and Discussion: Economic Access

Table 12: Economic Access Distribution										
	Regime classifications									
Economic Access (Quantile breaks)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Fire cover %:**	**Panama cover %:**
1 (0-10)	**32.27**	19.88	**34.19**	**26.50**	20.80	**15.67**	**28.97**	**13.61**	29.40	20.22
2 (11-12)	11.88	9.27	-0.74	-6.77	**-7.69**	-14.94	-0.62	-13.79	14.26	19.03
3 (13-14)	27.46	31.85	17.51	20.14	**21.85**	5.70	17.53	-1.48	28.08	26.95
4 (15-17)	20.27	**27.89**	18.49	17.02	0.32	-3.30	2.69	-11.21	21.78	24.60
5 (18-42)	**-5.30**	**-1.88**	**-4.74**	**-8.80**	-7.33	**-15.86**	**-12.73**	**-23.48**	6.47	9.07
Total	2.71	2.62	7.09	10.41	14.44	22.57	12.86	27.30	**1143**	**6706**

The lowest category of economic access receives almost 10 percent more data in fire cells than in Panama as a whole. Though the relationship is null in the middle category, at the highest categories, more non-fire cells are collected.

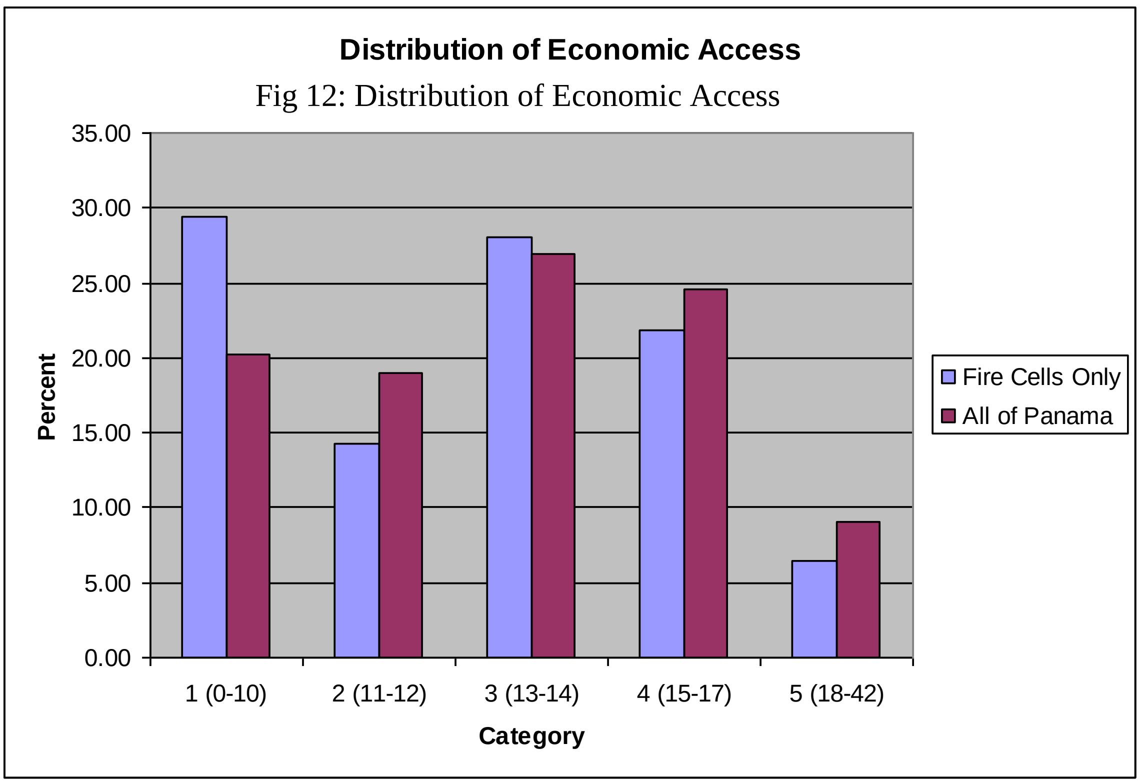


Fig 12: Distribution of Economic Access

3.4 Results and Discussion: Conservation Zone Analysis

Table 13: Conservation Zone Analysis									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Sum**
Cells pure conserved	5	11	70	75	105	164	71	201	702
Average density p.c.	3.75060106								Area:18717 km2
Cells bordering (inside 1km)	10	24	66	95	112	194	89	240	830
Average density b.i.	13.3914166								Area: 6198 km2
Cells bordering (outside 1km)	20	33	105	143	149	270	138	287	1145
Average density b.o.	15.8807212								Area:7210 km2

The results of the fire cell count in conserved areas showed that across all regimes, fires were more frequent and denser in cells bordering the outside of zones than those inside, and both outside and immediately inside significantly more than the interior. It would be worthwhile to follow up this study with a comparison of areas outside of those studied here, in Panama, in order to identify whether or not there is a border effect with conservation zones. That is, when indicating a large segment of land as conserved, it may displace a large population to the borders. Then out of necessity, revenge or simply higher population levels, the fires burnt surrounding the park would be higher than normal areas of the country.

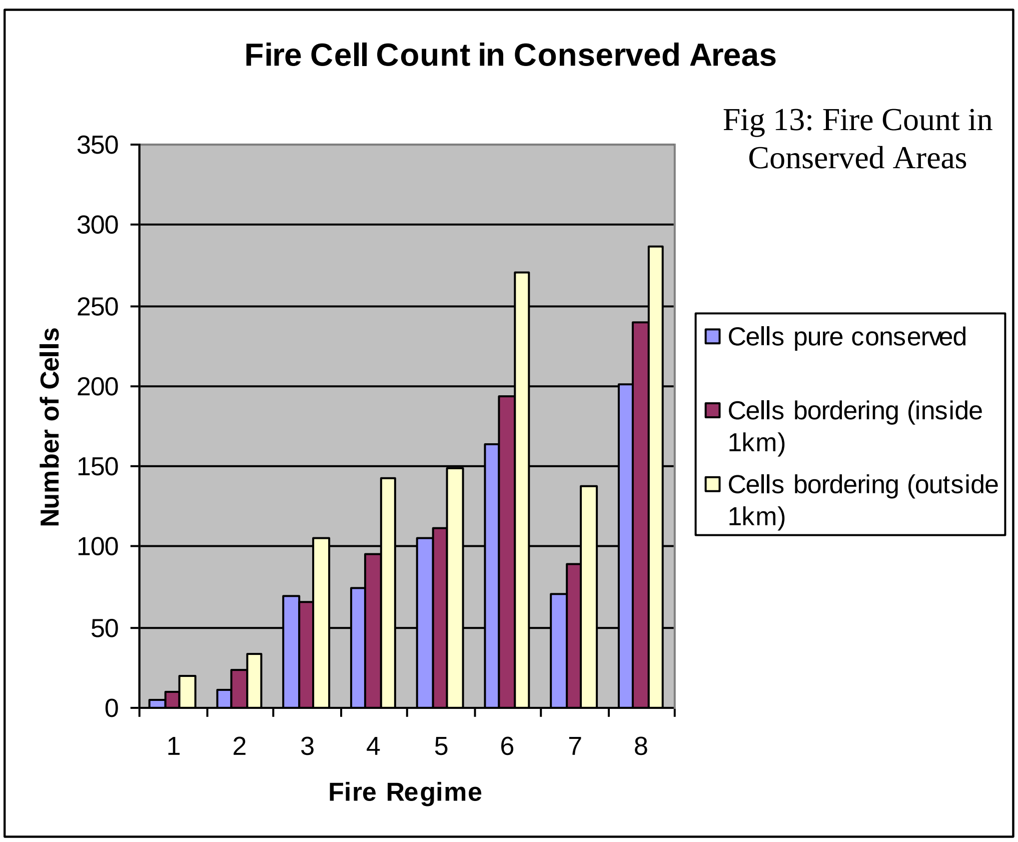
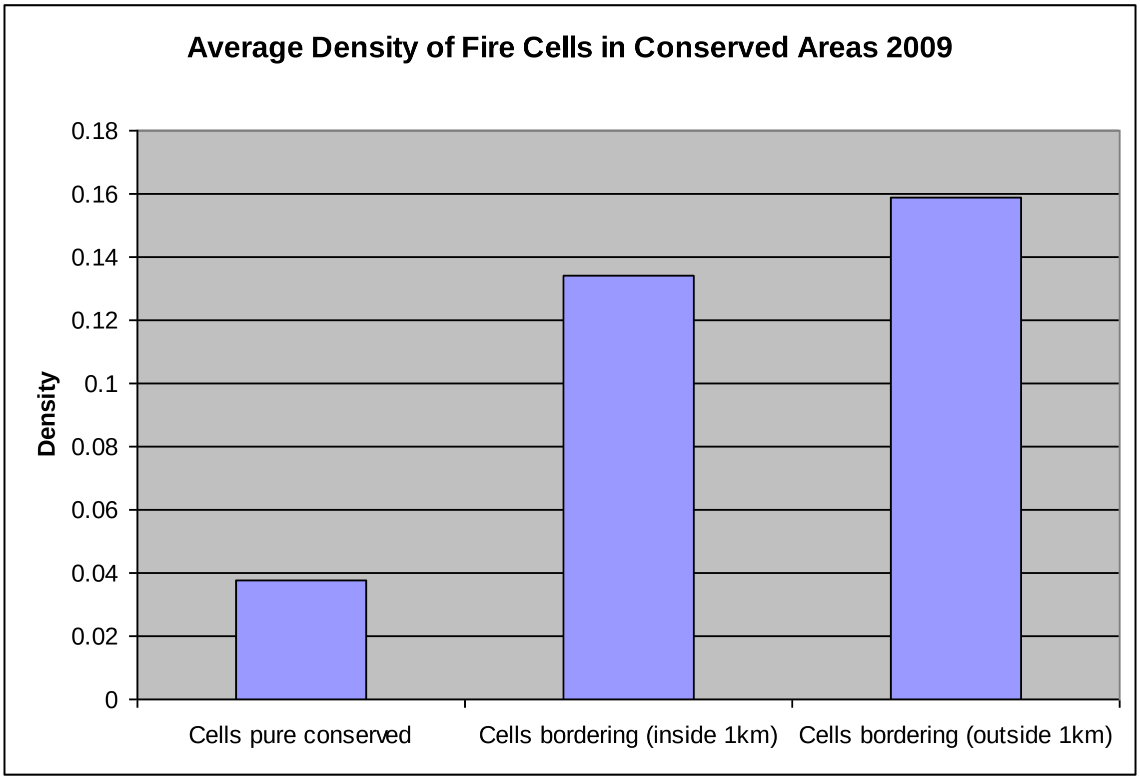


Fig 13: Fire Count in Conserved Areas

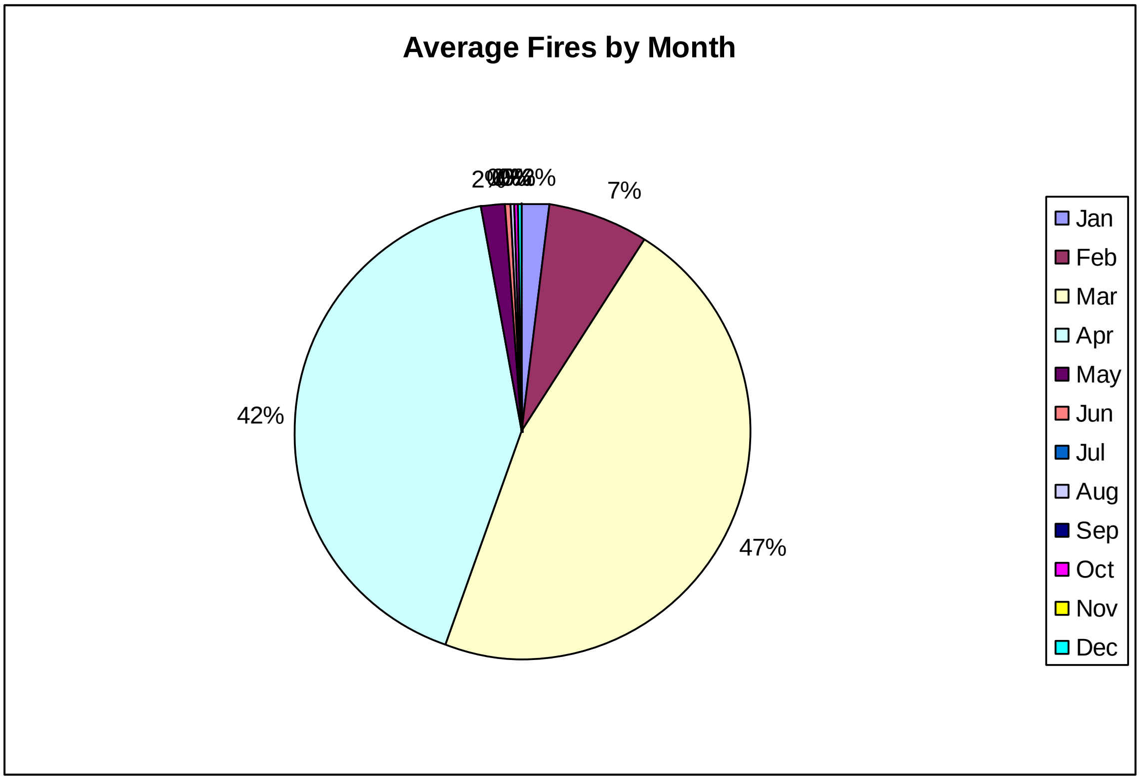
Fig 14: Conservation Area Density



The comparison above is also useful as further evidence of the anthropogenic origin of most fires in Panama. And comparing those cells immediately inside to immediately outside the park also suggests a forest edging effect is occurring.

3.5 Results and Discussion: Temporal Analysis

Fig 15: Average Fires by Month



Average monthly analysis shows that two months can be considered the dominant fire season in Panama, provided that cloud cover is not compromising results during the wet season. The dominant fire season is most likely due to a combination of anthropogenic and ecological causes. Most likely, an optimal burning interval is selected during the agricultural due to ecological characteristics of the crop grown and wet/dry season cycle.

Low interannual variation, once isolated from variation in precipitation rates across the seven years, would support this hypothesis. Below, it is apparent that interannual variation is quite low. Those differences which are apparent can partly be explained by a higher or lower total number of fires for that year.

Fig 16: Interannual Variation

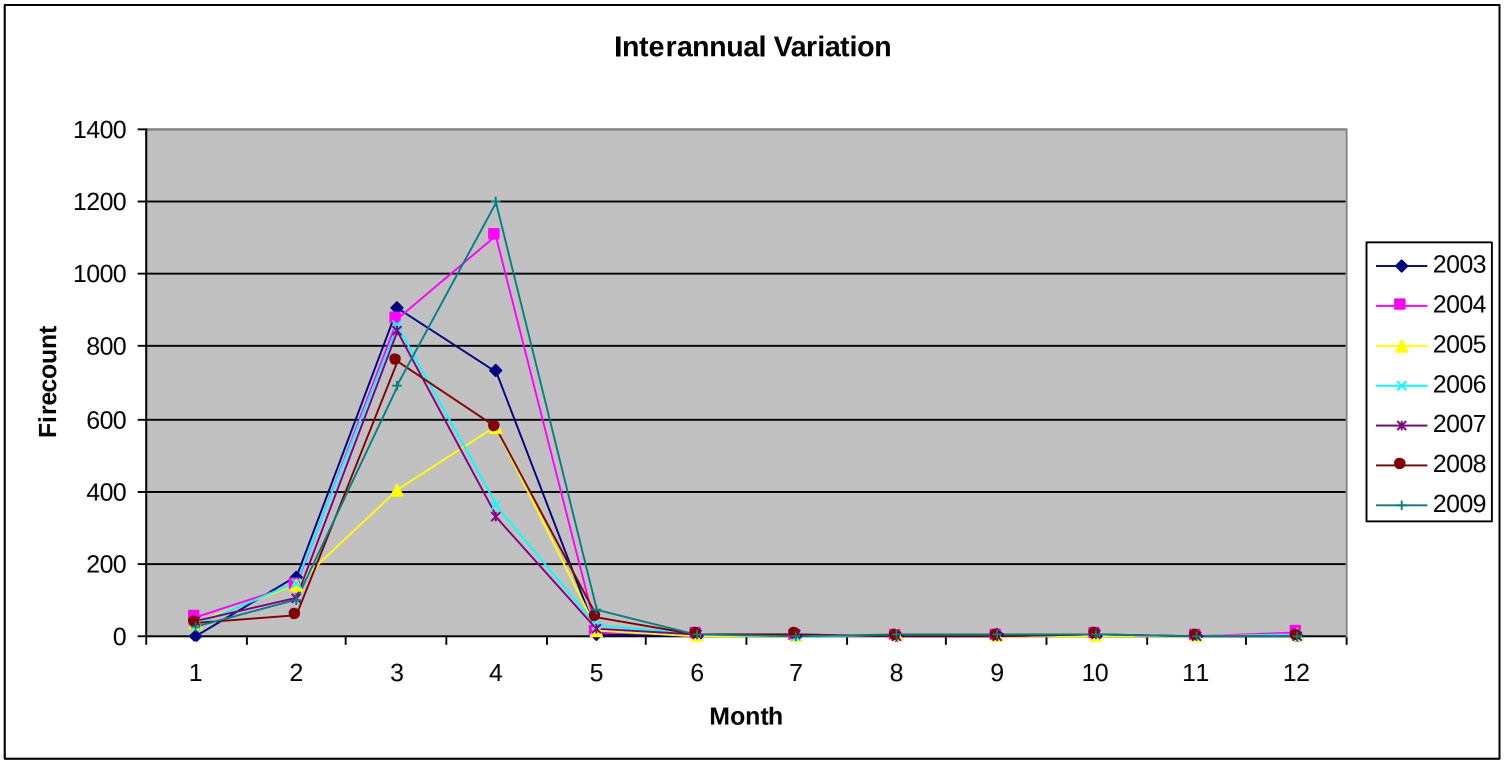
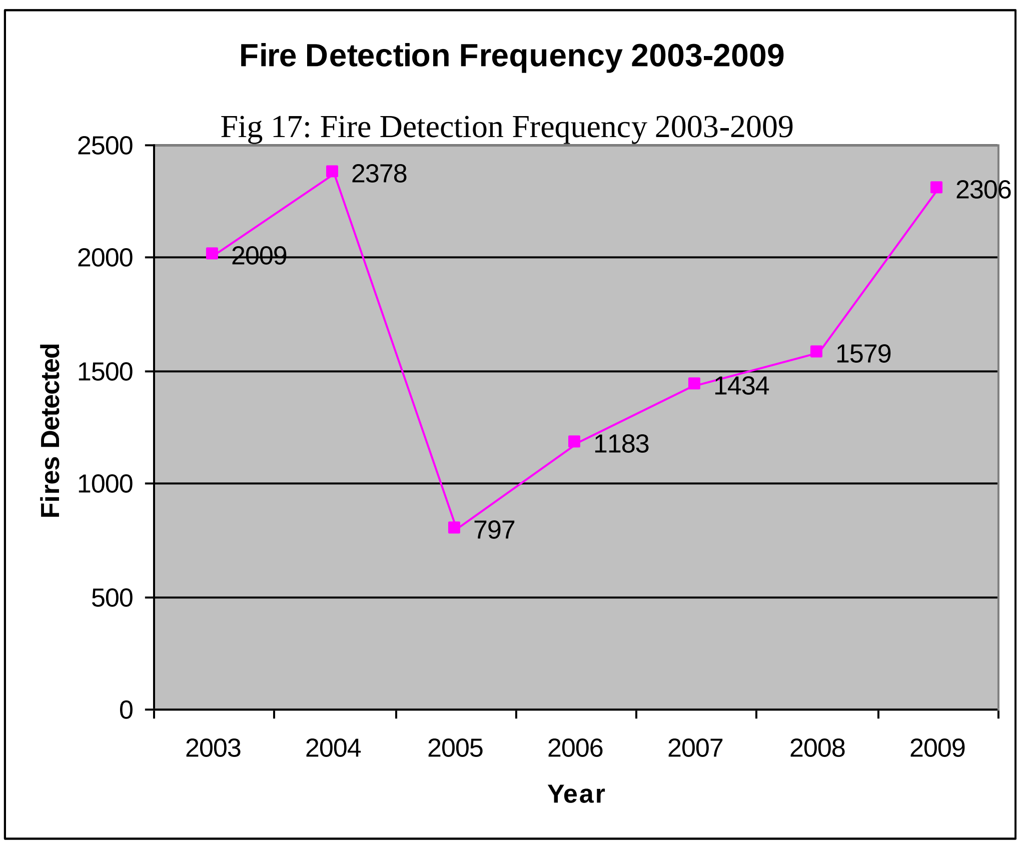


Fig 17: Fire Detection Frequency 2003-2009



4. FINAL SUMMARY

4.1 Final Summary: Ecological Factors

Red highlighting indicates a dominant zone or variable, while green indicates the weakest or most negatively associated. Particularly relevant or anomalous readings are highlighted in orange and bolded.

Table 14: Ecological Factor Distributions

Group	1	2	3	4	5	6	7	8
Relative Abundance (%)	1.72	2.99	8.15	11.24	14.91	25.08	12.06	23.86
Characteristics	FdB	Fdb	FDB	FDb	fDB	fDb	fdB	fdb
Life zone	Tropical dry forest	Tropical dry forest	Tropical dry forest	**Rainforest**	Tropical dry forest	Tropical dry forest	**Rainforest**	**Rainforest**
Life zone	Montane rainforest	Montane rainforest	Montane rainforest	Montane rainforest	Montane rainforest	Montane rainforest	Montane rainforest	Montane rainforest
Land cover	Industrial agriculture	Industrial agriculture	Industrial agriculture	Plantation forest	Industrial agriculture	Water	Mature forest	**Grass cover**
Land cover	Other forests	Other forests	Other forests	Other forests	Other forests	Mature forest	Shrubs cover	Shrub cover
Mature forest change	Industrial agriculture	Industrial agriculture	Industrial agriculture	Industrial agriculture	Industrial agriculture	Industrial agriculture	Industrial agriculture	Other
Mature forest change	No change	Other	No change	No change	Other	No change	Other	**Industrial agriculture**
Secondary forest change	**Industrial agriculture**	**Industrial agriculture**	Other	Other	Other	Other	Other	Other
Secondary forest change	Other	Subsistence ariculture	Subsistence agriculture	Subsistence agriculture	Subsistence agriculture	Subsistence agriculture	Subsistence agriculture	Industrial agriculture

4.2 Final Summary: Anthropogenic Factors

Table 15: Anthropogenic Factor Distributions								
Group	FdB	Fdb	FDB	FDb	fDB	fDb	fdB	fdb
Living density	Low	Low	Low	Low	High	Low	Low	Medium
Living density	Very low	Very low	Very low	Very low	**Very high**	**Very high**	Very low	High
Economic access	Very low	**High**	Very low	Very low	Medium	Very low	Very low	Very low
Economic access	Very high	Very high	Very high	Very high	**Low**	Very high	Very high	Very high
Grid access	**Very high**	Very high	Very high	Very high	Very high	Very high	Very high	**Very high**
Grid access	**Very low**	Very low	Very low	Very low	Very low	Very low	Very low	**Very low**
Indigenous ratio	Low	Medium	Low	Medium	**Very high**	Medium	Medium	Medium
Indigenous ratio	High	High	**Very high**	High	High	Low	**Very high**	Low

4.3 Final Summary: Discussion

Both tables tell us which category of the factors listed in column one each fire regime would be most heavily distributed, if the distribution of those factors across Panama was equal.

The most relevant or surprising associations are highlighted in orange and bolded, in the two tables above.

Interestingly, rainforests are most dominant in three regimes: Fdb, fDB and fdb. Perhaps the association of these different regimes to tropical forests can be explained by a more primary cause, such as characteristic populations choosing to live nearby climates described by this life zone, or because the climate here is ill-suited to industrial agriculture and so is used for other purposes. Recall that the names used to describe Holdridge Zones are only expected vegetation covers, and do not necessarily match the actual land cover. In terms of land cover, Fdb, fDB and fdb are 3 of only 4 regimes which are *not* dominated by industrial agriculture.

For example, the regime fdb is dominated by grassland. This suggests that fires which are characterized as sparse, dim and infrequent are most likely to occur – if land cover distribution were equal – in grasslands. That regime, however, would be least likely to occur in industrial agriculture, which is the dominant zone of every other fire regime. In contrast, at least for changes from secondary forests, subsistence agriculture is the least likely land cover to host all fires regimes but FdB.

While industrial agriculture in boreal climates may be associated with low fire levels, it is in Panama's tropical climate responsible for most of the bright, frequent and dense burning (Cochrane 2003). Faster growth necessitating slash and burn agriculture, and economic pressures to industrialize agriculture are most likely the two contributing factors to this burning. These results should be used to differentiate between subsistence and industrial agriculture when enforcing fire regulation and managing land use.

Regimes FDb and fDB, are both least likely to be dominated by a very high living density, probably because it is associated with urban populations.

The grid access definitively shows that all fires clearly prefer locations highly accessible by people, and vice versa. Yet economic access generally demonstrates a preference for the very low category, except for regimes Fdb and fDB.

Infrequent, but dense and bright fires would be likely to congregate where indigenous ratios are very high, but regimes fdB and FDB would avoid those areas. Much of the rest of the fires would exist where indigenous ratios are at their middle level.

4.4 Final Summary: Conclusion and Recommendations

While true fire regimes extend for a longer time period than seven years, the data presented here is meant as a preliminary classification system, to which more recent additions can be added. Similarly, while some standard regime characteristics such as fire radiative power are lacking, the MODIS dataset is still the best currently available for fire activity on a national level for the time period considered. As other relevant variables become available, they can be incorporated into the dynamic process of regime characteristics.

If these metrics, once through troubleshooting and fully standardized, were added to the existing MODIS sorting algorithms, it would present a new degree of accessibility and standardization, a goal for which FIRMS was established. This set of regime classes could become a language of satellite active fire readings which could contain quantitative and categorical summaries –as displayed in this study's final summary tables – with each map outputted, automatically stratifying the landscape into clearly visible regions of fire risk. The accessibility afforded by this synthesis would be extremely useful for those planners and policy-makers involved with global emissions, land surface planning and transportation.

One particular project that could be accomplished soon is identifying optimal locations for future ranger stations in conservation forests, by identifying hot spots of anthropogenic causes in high-risk protected areas.

All future projects based along the plans of this study should seek a solution for the persistent cloud cover problem, through some combination of sorting algorithms, monthly cloud cover statistics per square kilometer, and a regional risk assessment.

Advancing the findings of this study would also require that FIRMS, MODIS and those managing the SERVIR system continue to ensure consistency in their data records so that long term comparisons of fire regimes may continue.

5. SOURCES

5.1 Sources: Acknowledgements

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- Camilo Grandi – Soberania forest ranger supervisor, provided interview and map data

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6. APPENDIX

6.1 Appendix: Schedule of Work

Schedule
Fig 13

Table 16: Schedule of Work			
Date	**Activites**	**Hours**	Notes
January 7	Cocktail, meet and greet	1	Met Eric Anderson, Roxanna Segundo, Africa Flores.
January 8	Orientation to SERVIR, climate 1-stop lectures, background research	9	Readings on El Nino 1983, predicted 2010.
January 14-15, 21	GIS tutorials, developed research question & work plan (this document)	24	Trumper, Kate. "The Natural Fix", 2009.
Jan 22	GIS tutorials, FIRMS data mining	8	*order LP 880* (unsuccessful)
January 25-30	Wrote geoprocessing procedure. Prepared report. Gathered map and satellite data. Request EO-1 images, planned areas for data mining.	45	Internship week See geoprocessing procedure. http://glovis.usgs.gov/
Feb 4-5	Refined work plan. Continued data collection, began analysis procedure.	20	Worked over weekend on work plan.
February 10	Request E-01 images	8	unsuccessful
February 13-20		0	Carnaval week
March 8-13	Field research with LP 880, conduct interviews of station marshals	40	SERVIR workshop 26 Feb – 2 March -LP 880 not ordered. -interviewed Camilo Grandi at Soberania

March 18	Informal presentation to other McGill groups. Collecting nearby sites to visit	8	SERVIR vulnerability 5-8 Mar
March 31	Designed methodology to record nearby burn site and compare to unburnt	8	Unable to locate burn site Recorded unburnt
April 1-4	Refine results	5	Easter, no internship
April 5-23	Finalizing report and presentation	110	UNEP 20-22 Mar
April 23	Final oral presentations	8	
April 26	Submission of executive summary, final report, product for host institution	1	
Total Hours		295	

6.2 Appendix: Budget and Tools

Tools / Budget

LP 880………………………………………………..N/A
Vehicle, transport…………………………………bus and taxi fares
Usb port…………………………………………….0
ARC Mapping software…………………..….…….0
FIRMS DATA……………………………………….0
Audio Recording Device (for interviews)…………….N/A