What Drives Forest Fragmentation in the Brazilian Amazon? Examining Spatial Patterns

Nicholas Hurwit
Adviser: Alex Pfaff
April 24,2009

Abstract

Understanding forest fragmentation and deforestation patterns with respect to human presence and development is important for governing bodies to provide adequate protection for vulnerable tropical ecosystems. In recent decades, Brazil has seen increasing pressures to clear rainforest in the interior of the Brazilian Amazon through increased agricultural production and government infrastructure initiatives. As a result the area of cleared forest in Brazil is currently larger than France, and continues to increase annually. This project looks at the statistical relationships between forest fragmentation, deforestation rates, and census variables such as agricultural investment and population trends. Agricultural production and income can be linked to forest fragmentation and deforestation as more contemporary drivers.

The Brazilian Amazon

The Amazon Basin is one of the world's most biologically diverse regions in the world. It contains over 40% of the world's remaining tropical forest and has been said to sustain a higher number of wildlife species than most any other region on the planet (Myers & Myers, 1992) (1). Covering 5,000,000 square kilometers, the Brazilian Amazon (also referred to as the Legal Amazon) Region includes nine different Brazilian states: Acre, Amapa, Amazonas, Mato Grosso, Para, Rondonia, Roraima, Tocantins, and a portion of Maranhao (2). The Brazil Socio-Geographic Division recognizes Amazônia Legal as large and relatively underdeveloped when compared to the eastern and southern regions of Noredestre and Centrol Sul. The area extends west encompassing a large amount of the Amazon Basin along with vast tracts of rainforest still untouched by Brazilian development schemes.

Though due to its large size the Legal Amazon is not considered a highly populated region, the last three national censuses conducted in Brazil indicate a pattern of continued increasing migration to the area. Between 1980 and 2000 the resident population has grown from 11,984,927 to 21,056,532, indicating increasing urbanization in the region (3). The average annual growth rate for the region for the 1980's and 1990's was 3.0%, with the highest rates belonging to Roraima and Rondonia (9.1% and 7.6%, though these two states are relatively small in population size. Nonetheless, significant growth has been noted in even the two larger states of Para and Amazonas (with populations of 6,192,307 and 2,812,557, respectively), which have experienced average annual percent growth rates of 3.4% and 3.5% (3). Even though a census has not been conducted since 2000, the annual growth rates for every state between 1980 and 2000 far exceed Brazil's estimated annual growth for 2008. The Central Intelligence Agency's *2008 World Factbook* says Brazil experienced 1.228% growth in 2008 (4).

The nine states making up the Brazilian Amazon have been subject to Brazilian Government policies aimed to stimulate development, colonization and occupation (2). These government initiatives which have helped created financial incentives for many to expand construction and development within the interior of the Amazon have worked in concert with other factors to further deforestation. Though government directed infrastructure development has been rather specific in its goals (e.g. to increase the potential for soybean export, an important economic asset of Brazil), other more unpredictable, indirect, and local causes of forest clearing have contributed to the loss of rainforest and biodiversity substantially over the past thirty years.

Figure 1. Legal Amazon and States

(5)

Rates

Brazilian Amazonia is a region consisting of predominantly tropical rainforest, and likely sustains more species of plants and animals than any other comparably sized region in the world. Despite the inherent and potential economics values of maintaining such staggering biodiversity, the rainforests have been cleared for a wide range of reasons. Since the 1960's the eastern and southern regions have been subject to the most intense deforestation. These areas include the Brazilian states of Para, Maranhao, Rondonia, Acre and Mato Grosso. An interesting analogy of the Brazilian Amazon lost in recent decades helps put the numbers in perspective: the original extent was comparable to that of all of Western Europe, areas of forest cleared annually now approach the size of Belgium. (9). As of 2000, the area equivalent to that of France had been cleared in the Legal Amazon alone, and the pace at which these lands are disappearing has only accelerated since then (1).

Historically, deforestation in the Amazon over the past 30 or 40 years has been anything but constant. A superficial analysis of the annual rates of clearing is an exercise in causative futility, though some the drivers of forest loss are discussed in this paper. Prior to the 1970s there had not been considerable clearing of rainforest in the Amazon, at least with respect to substantial losses on a percentage basis. As of 1975 approximately 3,000,000 hectares, or 0.6% of the entire Brazilian Amazon, had been lost to deforestation (7). Beginning in the late 1970's, with 1978 used frequently by scientists as a starting point for analyzing forest loss data, deforestation has become an issue of growing concern as clearing has followed an increasing trend. Between the late 1970s and late 1980s a relative plateau of annual clearing rates had been reached, only then to see sudden drops and increases in deforestation through the mid 1990s. Since then, the general consensus is that cumulative deforestation and annual rates are not the only indicators on the rise, but also accelerating forest loss rates.

One must keep in mind that notable differences in forest loss quantification studies have led to varying estimates on the estimated areas if forest loss. These differences are functions of the current limits of technology, and are propagated by three general factors; (1) differences in the stratification of forest, cerrado, and water, (2) estimates of secondary growth which can appear very similar to intact forest, and (3) positional accuracy, interpretation, and boundary generalization (8). A strong reliance upon Geographic Information Systems (GIS) is needed to continually assess spatial patterns of human development and the resulting effects on such regions as the Amazon. It is important to consider the limitations of the spatial assessment of such a massive area as factors such as cloud cover and stratification directly alter deforestation estimates.

The 1980s is a time period over which there is contention concerning the rates of annual clearing. Fearnside (2005) found that annual rates to be highly constant from 1978 to 1988, with an area of 20.4 x 10^3 km2 of forest lost in each of those years (9). Others have come up with quite different numbers for years in this same time period. Mahar (1988) found there to be an accelerating trend early on, though the estimate for 1980 was lower than that of Fearnside at 12,500,000 hectares (7).

Since the early 1990's there has been variation in the estimate annual rates of deforestation. In the early nineties brought a recession to Brazil during which fiscal incentives to clear land were suspended by decree on June 25, 1991(10). In the past 15 years there has been considerable variability in annual rates with the highest rates approaching 30,000 square kilometers in 1995, 2002, and 2005 (11).

Causes and Drivers of Deforestation

In comparing the causes of forest loss in the Amazon to other tropical regions across the globe, one finds the drivers affecting Brazilia to be distinct and complex. In fact, the causes of deforestation tend to vary significantly even within the Amazon Basin (7). Deforestation in Indonesia is directly caused by expansion of agriculture, while in Malaysia approximately 90% of the deforested land has been used for plantation agriculture (7). These two countries have relatively transparent causes of clearing, while the story in Brazil still needs further investigation.

The amount of devastation brought onto the Brazilian Amazon cannot be attributed to any one single cause. A large number of factors help to drive forest loss in a manner in which only a multidisciplinary approach allows for an accurate analysis and evaluation. These deforestation drivers can be broken down in to three basic categories: (i) financial incentives to acquire and develop land, which result in the privatization of land (ii) government-planned movements to increase infrastructure in the Amazon interior, including highway construction, and (iii) natural indicators associated with varying levels of clearing. Though there are many indirect effects stemming from these forces that contribute to clearing, it is economic advancement that appears to have been the underlying theme during the recent decades of forest loss.

A wide range of studies has been conducted on the roles of factors that potentially alter rates of deforestation within the Legal Amazon at a statistically significant level

There have been studies focused on natural characteristics of the land correlated with variation in clearing. Pfaff (1999) found land characteristics (such as soil quality and vegetation density) can be used to predict forest loss (12). Chomitz and Thomas (2003) found that land used for agriculture and cattle ranching is more likely to be located in areas with lower rates of precipitation, furthering the argument that natural indicators exist for predicting clearing in the Amazon (13).

Pfaff discovered that factors associated with increasing transport costs (distance to market) affected deforestation rates (12). Government development projects had significant effect, while credit infrastructure did not (12). Deforestation also rises in census tracts with no roads when a road investment is made in a census tract within the same county (within 100 km of the road-less census tract) (14). Interestingly, data indicates a negative correlation between road construction and deforestation (though with inconsistent significance) at distances between 100 and 300 km from the target census tract (121). While these findings are useful in understanding a generalized picture of how indirect human factors alter clearing rates, Pfaff acknowledges that further investigation is needed in order to better understand the roles of infrastructure expansion and population increase.

It is important to distinguish roles between large-scale farming operations and that of smaller farms on the scale of 100 hectares in area or less. Government initiatives aimed to expand infrastructure and develop within the Amazon have been a significant driving force since the mid-1970's. Starting in 1971, a Program of National Integration (PIN) was instituted by President Medici with the goal of building major highways connecting the Amazon Basin internally and to the south of the country. In addition to highway construction, government officials aimed to move 100,000 families into newly formed settlements and service communities in the first five years of the program. A policy shift three years later, in 1974, was propagated by the changing costs of settling the interior with small farmers. President Geisel made the declaration that large-scale entrepreneurs would be more effective at developing the Amazon. As a result, land was divided up in large areas and only 6,000 families had moved in the designated time period. Some have estimated that less than 4% of the deforestation in the 1970s is attributable to smaller farmers (15) (7). Since then smaller-scale farming has played an increasingly important role as a forest loss driver.

Larger farms have continued to make their presence felt in more recent years as well as evidence by that location of clearings. In 1991 the state of Mato Grosso accounted for over 25% of the total annual clearing (11.1 x 10^3 km2) while holding the highest percentage of privately owned land run by ranches and farms greater than 1000 hectares (84%). Contrastingly, Rondonia – which is notorious for habitat destruction by small farmers - was responsible for approximately 10% of that years forest loss (9). By taking a close look at policy directives from as far back as the 1960s and 1970s one can see how government decisions can dictate not just how many people are associated with development within the Amazon, but can also distinguish the types of people with respect to economic potential and progress.

Fragmentation

When considering the effects of forest loss on wildlife and biodiversity, fragmentation should be distinguished from generalized deforestation, though doing so has proven difficult in the past. There are a number of different definitions of forest fragmentation. The Forest Service defines it as "The splitting or isolating of patches of similar habitat, typically forest cover, but including other types of habitat...Habitat can be fragmented naturally or from forest management activities, such as clear-cut logging"(16). Other definitions have linked fragmentation to population growth. For the sake of this paper, we will consider fragmented forest as the general break-up of forested areas into smaller, separated patches of forest.

Fragmented areas of forest in the Amazon can experience changes in forest dynamics, structure, composition and microclimate. They are also increasingly vulnerable to droughts, fires, and period climate events such as El Niño-Southern Oscillation (1). Changes in simple, yet critical processes, such as nutrient cycling and pollination, have been linked to increasingly fragmented landscapes (1). Past research has found increases in tree mortality rates, as well as damage and canopy-gap formation as a result of increased desiccation and wind turbulence near forest edges (17).

With respect to biodiversity, wildlife in the Amazon relies heavily on healthy rainforest ecosystems for survival. For one, even small forest clearings can prevent tree-dwelling mammals and birds from moving freely within the forest. Dale et al (1994) identified the inability to cross clearings, and large home-range size as two characteristics that will increase the vulnerability of invertebrates to forest fragmentation (1). Given the trend of increased deforestation within the Amazon, those animals that are tolerable of modified habitats are likely to persist, while those that avoid cleared areas will tend to decline (1). Fragmentation is a destructive process within the Brazilian Amazon that must be considered seriously because of the threat of decline in biodiversity.

Methods of Investigation

In order to assess Amazon forest loss rates on both a small-scale and large-scale, there is a need for extensive and detailed data. The data used for this statistical investigation came from two distinct, yet credible sources: the Brazilian Federal Government and the Universidade Federal Fluminense, a large federally-funded university in the state of Rio de Janeiro, Brazil. These two sources provided enough information to analyze the relationships between annual forest loss in the Legal Amazon, measures of forest fragmentation, and human activity in the region as provided in the form of national census results.

In Brazil, the census is conducted and results are managed by the Instituto Brasiliero de Geografia e Estatistica (Brazilian Institute of Geography and Statistics) (IBGE) (19). Census information is available for all nine states included within the Legal Amazon, thus allowing for more comprehensive regional evaluation. Because not all census information in Brazil is collected in the same years, the resulting available census data is somewhat staggered in fashion. For the years 1985 and 1996 the first set of agricultural census information is available (Cows, agricultural GDP, etc.). Set 2 (income, life expectancy, etc.) is available in the years 1991 and 2000. This difference, along with the listed census variables can be seen in Table 1. Forest loss data was available for the years 1986, 1992, 1996, and 2000. Even though the spatial and census datasets did not match up exactly, I still used a contemporaneous analytical approach matching up the 1985 and 1991 data with 1986 and 1992, respectively.

The data analysis for this investigation can be divided into three distinct, yet potentially related parts. These involve determining relationships between: (1) fragmentation and deforestation, (2) deforestation and census data, fragmentation and census data, and (3) fragmentation, deforestation, and census data. The general idea behind this methodology is to determine the interconnectedness between the three classes of data. Per the lack of literature linking forest loss and the levels of fragmented habitat, the overall goal of the analysis is to provide an in-depth look at the fragmentation as a critical indicator of forest loss within Amazonia.

Methods of study evolved over the course of the investigation. In order to determine more appropriate relationships among the data I transformed a number of different variables so that they are density-dependent, not entirely based on the area of the county. For example, I divided the number of *cows* in a county by the area (square hectares) to get a resulting number in cows per hectare. Without performing such a transformation the analysis would be skewed by the size of a county, instead of a percentage-based perspective.

An additional modification to the study was focusing on one particular measure of fragmentation, instead of considering all. Through some initial tests I found *Core Area* to be the most appropriate measure of focus, as the amount of core forest within a county has statistically significant relationships with forest as well as county-level census information.

All analyses were performed using the STATA/IC 10.1 statistical computer program. Considerable reformatting of the data was necessary in order to read in the modified .csv files. Using STATA I ran multiple regressions in order to investigate forest fragmentation patterns.

Three Part Statistical Analysis

The first step was to determine the statistical relationships between percent deforestation in a given county and the various measures of fragmentation (see Table 2). To do so I ran regressions in STATA assessing the degree of variability forest loss accounts for with respect to each fragmentation metric. A sample script within STATA reads: *regress CoreArea PercentDeforestation*. This script directs the program to run a regression between the dependent variable (*Core Area*) and the independent variable (*Percent Deforestation*).

Connecting rates of forest loss to the amount of habitat and forest fragmentation within the same counties provides an opportunity to better understand spatial patterns within the Amazon. As previous research indicates it is possible to identify and even quantify the drivers of deforestation. Here the focus is on determining, and quantifying if possible, the drivers of fragmentation. Analyzing the relationship between these two variables allows us to see the changes in habitat size and shape attributed to percent deforestation alone, over a 15-year period.

Next was assessing the level of changes in deforestation and fragmentation that can be attributed to changes in demographic and agricultural data. Using the same procedure within STATA I ran separate regressions using the census data. *Fragmentation* *(x)* and *Deforestation(x)* are representative functions of the regressions, with 'x' representing a particular variable (e.g. GDP). Census variables were considered both collectively and on an individual basis in order to better understand their relationships.

In order to capture the effects of both the census information and deforestation levels on the amount of fragmented forest in a county, I included all three sets of information in a third set of multiple regressions. With *core area* size as the dependent variable, I looked at the combined statistical effects of percent deforestation and human activity and development. The goal here was to explore the interactions between forest loss and human activity with respect to the change in forest fragmentation.

Table 1: Census Variables

Variable	**1985 & 1996 (Set 1)**	**1991 & 2000 (Set 2)**
Cows	X	
Gross Domestic Product (GDP)	X	
Agricultural GDP	X	
Agricultural Investment	X	
Area Established	X	
Permanent Farming	X	
Temporary Farming	X	
Natural Bushes and Forests	X	
Planted Bushes and Forests	X	
Natural Pasture	X	
Planted Pasture	X	
Tractors	X	
Households		X
Income		X
Life Expectancy		X
Rural Population		X
Urban Population		X
Literacy		X

Table 2. Fragmentation Metrics: 1986, 1992, 1996, 2000

Metric	Description
Core Area	Represents the area in the patch greater than the specified depth-of-edge distance from the perimeter. Note, that a single depth-of-edge distance can be used for all edges or the user can specify a edge depth file that provides unique distances for each pairwise combination of patch types.
Largest Patch Index (LPI)	LPI equals the area (m2) of the largest patch of the corresponding patch type divided by total landscape area (m2), multiplied by 100 (to convert to a percentage); in other words, LPI equals the percentage of the landscape comprised by the largest patch.
Patch Density (PD)	PD equals the number of patches of the corresponding patch type (NP) divided by total landscape area, multiplied by 10,000 and 100 (to convert to 100 hectares)
Mean Patch Size (MPS)	MPS equals the sum of the areas (m2) of all patches of the corresponding patch type, divided by the number of patches of the same type, divided by 10,000 (to convert to hectares).
Area-weighted Mean Shape Index (AWMSI)	AWMSI equals the sum, across all patches of the corresponding patch type, of each patch perimeter (m) divided by the square root of patch area (m2), adjusted by a constant to adjust for a circular standard (vector) or square standard (raster), multiplied by the patch area (m2) divided by total class area (sum of patch area for each patch of the corresponding patch type). In other words, AWMSI equals the average shape index (SHAPE) of patches of the corresponding patch type, weighted by patch area so that larger patches weigh more than smaller patches
Mean Core Area Index (MCAI)	MCAI equals the sum of the proportion of each patch that is core area (core area of each patch [m2] divided by the area of each patch [m2]) of the corresponding patch type, divided by the number of patches of the same type, multiplied by 100 (to convert to a percentage); in other words, MCAI equals the average percentage of a patch of the corresponding patch type in the landscape that is core area based on a specified edge width.
Percent Deforestation	*
Patch Size Standard Deviation (PSSD)	Patch Size Standard Deviation (PSSD) - PSSD equals the square root of the sum of the squared deviations of each patch area (m2) from the mean patch size of the corresponding patch type, divided by the number of patches of the same type, divided by 10,000 (to convert to hectares); that is, the root mean squared error (deviation from the mean) in patch size. This is the population standard deviation, not the sample standard deviation.

Core Area Results

Core Area (Deforestation)

Focusing specifically on the measure *core area* as a function of deforestation, I found a statistically significant correlation between the two over all four years. Looking at Table 3 we can see the p-values for each of the four years is well below the .05 threshold, thus indicating statistical significance at a 95% confidence level. The correlation coefficients indicated negative relationships between core area size and percent deforestation for 1986, 1992, and 1996. This indicates that core forest area within a county decreases as overall deforestation increases. A decrease in core area size implies increased fragmentation. Contrasting the first three years of study, analyzing the 2000 data I found a notably decrease in regression strength, as well as a change from a negative relationship to positive relationship.

The next step in investigating the effect of deforestation on fragmentation, and specifically core area, is to use semi-parametric and non-parametric analytical methods. During the study, I utilized logarithmic and quadratic transformations of *percent deforestation* to capture to capture the effects of forest loss. There was variation in the results. However, the reported results are using simply the reported percent clearing within a county.

Table 3: Statistical Relationship Between Fragmentation and Deforestation: 1986-2000

Core Area as function of Deforestation	1986	1992	1996	2000
R^2 value	0.05	0.37	0.25	0.01
p-value	0.00	0.00	0.00	0.0099
Number of Observations	482	484	359	421
Coefficients	-.0048774	-.008241	-.006444	0.024196
With State Dummy Variables				
R^2 value	0.37	0.51	0.45	0.05
p-value	0.00	0.00	0.00	0.007

Deforestation & Core Area (Development)

The second part of the analysis involved looking at the effects of human development, by way of available national census data, on both forest loss and fragmentation, separately. Table 4 provides a statistical summary of the relationships between human development and deforestation from 1986 to 2000. As was the case with deforestation and fragmentation, the relationships for all four years were found to be statistically significant with all four p-values at 0. The results of the multiple regression results show some consistency with respect to human development affecting deforestation, with 1996 as an exception when it accounted for 36 percent of the forest loss within the Brazilian Amazon.

W must keep in mind there exists a distinction between the census data used. For the years 1986 and 1996 I used agricultural data, while in 1992 and 2000 I was able analyze information based more on demographics and wealth within the counties. With that in consideration, there is more variability within the effects of agricultural factors on deforestation than when looking at demographic information.

Table 4: Contemporaneous Statistical Relationship Between Deforestation and Human Development (Census Data)

Deforestation as a function of Census Data	1986	1992	1996	2000
R^2 value	0.14*	0.10	0.36	0.17
p-value	0.00	0.00	0.00	0.00
Number of Observations	523	359	421	415
With State Dummy Variables				
R^2 value	0.23	0.33	0.55	0.42
p-value	0.00	0.00	0.00	0.00

*A multiple regression using only cows and pasture as independent variables produced *R^2 value* of 0.10, a p-value of 0.00, and t-values of 4.35 and 4.05, respectively.

An important part of the analysis is to note the effects of individual census variables. Table 5 shows the t-values for each variable within the agricultural data for 1986 and 1996. The most significant variable affecting forest loss is cow density within a county. We see that the positive correlation means that as there are more cows per hectare, deforestation is more likely to occur. There was a jump in relationship strength between the two from 1986 to 1996, as the respective t-values for those years are 4.73 and 7.87. Two more factors related to increased forest loss are agricultural investment and non-natural pasture. Given the positive relationships for both measures, we can infer that as agricultural investment and pasture area within a county increases, forest loss tends to increase.

Cows and pasture accounted for 10% of deforestation (14% explained by all agricultural variables), while in 1996 cows, area established, and agricultural investment explained 33% (of the 36% total) of the variability in forest loss. Here we see the number of cows as a consistent variable of correlation, while the move from pasture to area established and agricultural investment indicating a more direct relationship with financial incentives. Looking at *agricultural investment* independently produced an R^2 *value* of 0.16. This value likely captures some of the variability associated with cows, as there is a correlation between the two. For these two years, all five variables mentioned are associated with increased deforestation, while area established has a negative correlation, indicating decreased forest loss.

Individual agricultural measures do not seem to have the same strength of effect on core area as they do on forest loss. It does appear as though temporary farming has the most consistent relationship with core area size, albeit one that promotes forest fragmentation. The t-values for agricultural GDP and core area are -4.29 and -0.77 for 1986 and1996, compared to the respective values (when tied to deforestation) of 0.43 and 0.49. For 1986, agricultural GDP can be tied to a decrease in core area size, thus leading to increased fragmentation of forest.

One particularly interesting result is the perceived decrease in individual agricultural census effects on core area size, while the overall statistical strength of the multiple regressions increased from an r-squared value of 0.18 in 1986, to 0.20 in 1996. This implies interactions among the census measures that accounts for increased fragmentation. In order to provide a more detailed look at the trends, a census-level analysis is needed and would provide an optimal resolution for analysis. It would also be useful to look at more detailed measures of agricultural investment and development such as fiscal behavior related to building and farm construction and road development.

Table 5: Effects of Individual Census Variables on Forest Loss & Core Area – T-values

Census Measures	1986		1996	
	Defor	Core Area	Defor	Core Area
Cows	**4.73**	-1.43	**7.87**	-0.97
GDP	0.49	**-2.22****	0.71	-1.09
Area Established	-1.73	-0.28	**-7.75**	0.36
GDP Agr	1.74	1.27*-	**2.10**	**-2.52**
Agricultural Investment	0.43*	**-4.29****	0.49	-0.77
Permanent Farming	-1.34	1.74	0.44	0.28
Natural Plants	-1.67	0.59	-1.45	-0.32
Plants - Planted	1.40	0.46	0.07	0.27
Pasture –Natural	-0.43	0.18	0.28	**-2.13****
Pasture- Planted	**3.71**	1.63	0.04	0.17
Tractors	-0.42	**-1.98**	-0.20	-1.20
Temporary Farming	-1.41	**-2.57****	0.33	-2.03

* Indicates relationship that is now statistically significant with use of dummy variables, though was not considered significant previously

** Indicates previously statistically significant relationship that is not so when including dummy variables in the analysis

Bold indicates statistical significance at 95% confidence level

Table 6: Contemporaneous Statistical Relationship Between Fragmentation and Human Development (Census Data)

Core Area as a function of Census Data	1986	1992	1996	2000
R^2 value	0.18*	0.19	0.20	0.05
p-value	0.00	0.00	0.00	0.00
With State Dummy Variables				
R^2 value	0.24	0.19	0.48	0.07
p-value	0.00	0.00	0.00	0.0019

*A multiple regression using only GDP, Agricultural GDP, and temporary farming independent variables produced *R^2 value* of 0.13, a p-value of 0.00, and t-values of -1.90, -3.35, and -3.84, respectively.

With respect to individual census measures for the years 1992 and 2000, there is considerable variability in the relationships with deforestation. Looking at Table 7 we see a notable decrease in regression strength of *life expectancy* on deforestation as the t-value went from -5.46 to -1.66 in 1992 and 2000, thus implying life expectancy in a county has a decreasing effect on forest loss over time. Despite the lack of statistical significance in 2000 for deforestation, life expectancy showed the most consistent relationship as higher life expectancy can be associated with decreased levels of deforestation and larger core forest area.

Income became increasingly correlated with deforestation and core area between 1992 and 200, with t-values 2000 at -.053 to 8.82, respectively. Not only was there a large increase in relationship strength between income and forest loss, but the change from a negative to positive correlation means that in more recent years higher income is more readily associated with higher levels of deforestation. Both *rural population* and *urban population* were statistically significant in 1992 for *core area*, and in 2000 for *deforestation.* I find this interesting because it would make sense for population to affect deforestation and fragmentation simultaneously, though obviously there is an unexplained distinction that must be made between the two.

I found more consistency with respect to correlation sign (positive versus negative) when looking at core area size. Fragmentation decreased as *life expectancy* and *number of households* per county increased, increased as literacy, and rural and urban population increased, given that a higher *core area* value implies less fragmentation. In 1992, population density had more of an effect on core area than deforestation.

Table 7: Effects of Individual Census Variables on Deforestation & Core Area – T-values

Census Measures	1991		2000	
	Defor	Core Area	Defor	Core Area
Life Expectancy	**-5.46****	**5.80****	-1.66	**2.99****
Literacy	1.00	**-3.22**	0.46	-1.73
Number of Households	-1.68	**4.82**	**2.09****	0.89
Income	-0.53	0.61	**8.82**	**4.23**
Population Rural	1.67	**-5.01**	**-2.43**	-1.12
Population Urban	1.80	**-4.88**	**-2.17****	-0.91

** Indicates previously statistically significant relationship that is not so when including dummy variables in the analysis

Bold indicates statistical significance at a 95% confidence level

Core Area (Deforestation, Development)

Table 8 summarizes the collective effects that deforestation and human characteristics and activity have on core area. As indicated by the low *p*-values, the multiple regressions provided statistically significant results for all four years. In 1992, forest loss and agricultural activity accounted for 47% of the variation in county core area size.

When considering forest loss and agricultural variables together, the effect of cows on core area decreased substantially, with the t-value going down to -0.74. Deforestation likely captures much of the variation in core area size through cattle ranching. There is an increase in relationship strength between tractors and temporary farming, and core area when including deforestation in the regression. Another intriguing result is the variation in coefficient signs when considering pasture. It produces a positive sign for both deforestation and core area, thus simultaneously associating with increased deforestation and increased core area size.

Table 8: Statistical Relationship Between Fragmentation, Deforestation, and Human Development (Census Data)

Core Area as a function of Deforestation and Census Data	1986	1992	1996	2000
R^2 value	0.21	0.47	0.34	0.06
p-value	0.00	0.00	0.00	0.00
With State Dummy Variables				
R^2 value	0.44	0.58	0.51	0.08
p-value	0.00	0.00	0.00	0.0016

State Dummy Variables

In order to provide an additional level of analysis, I ran each regression a second time using dummy variables for each state, creating them within STATA. Including the dummy variables in the regressions produced results similar to the originals, though with higher overall r-squared values since eight of the nine states are now included. Looking at Tables 3, 4, 6, and 8, we can compare the dummy results with the initial analysis. As a general result, the new regressions produce less variability among the r-squared values over the fifteen year period. More specifically, the r-squared values increased considerably, with the exception of 2000, which produced relatively low values for each step of the analysis.

More important than the general trends is the effect on the individual relationships between census variables and forest loss. Looking at Table 5, we see that the *agricultural investment* went from a statistically significant, negative relationship with *core area*, to a statistically insignificant, positive relationship, with respective t-values of -4.29 and 0.96. Interestingly, for 1986 including dummy variables resulted in none of the agricultural variables having an effect on core area, and in 1996 only agricultural GDP remained statistically significant. There were no changes in the significance of the relationships with respect to percent deforestation.

Table 7 shows even more relationships changes. First, the new analysis finds that life expectancy does not have an effect on deforestation or core area for 1991 and 2000. Household density and population density for 2000 also returned insignificant results, furthering the argument that the individual demographic measures used in his study do not generally have an effect on deforestation. Income remained significant for both in 2000, though with positive correlations suggesting that higher income can be related to both increased levels of deforestation and larger core forest area within a county.

Discussion and Conclusions

The fact that deforestation proved to be a statistically significant factor of fragmentation, and also that human activity and development affects both deforestation and fragmentation, is not surprising given historical trends of infrastructure and agricultural development in the Brazilian Amazon.

Intriguing are the relationships trends between the spatial forest information and census data. Looking at the regression strength between overall deforestation within Brazilian counties and the percent core forest area comprising a county's area, the drastic increase and decrease indicates substantial variation among the drivers of forest fragmentation. A key point to note with respect to this relationship is the particularly strong correlation strengths in 1992 and 1996. The early 1990's brought an economic downturn in Brazil, thus decreasing the amount of investments made in developing areas of the Amazon wilderness. Since deforestation is associated with decreased core forest areas during this time, one could potentially infer that a economic recession leads to variability or a decrease in the strengths of other factors driving fragmentation. Curiously, during 1992 and 1996 multiple regressions utilizing the census variables accounted for the most fragmentation out of the four years, with r-squared values of 0.19 and 0.20 respectively. There are likely additional factors associated with increased forest fragmentation not included in this particular study, and these could very well have been affected by a reduction in federal spending on development projects.

A critical goal was to explore the potential interactions between deforestation and human activity, with respect to their effects on core area size. Comparing the regressions strengths between deforestation and human activity with fragmentation, separately, to the last explored relationship, which includes all three at once, we can break down the sources of variation. With the exception of 2000, in all other years:

$$Frag(Defor, X) < Frag(Defor) + Frag(X),$$

$$\text{and in 2000 } Frag(Defor, X) = Frag(Defor) + Frag(X)$$

One reason percent forest loss and census information account for more variation in core area when considered separately is because human activity also accounts for variation in deforestation. Had I found $Frag(Defor, X) > Frag(Defor) + Frag(X)$, I could make the assumption that interactions exist between deforestation and development that increase fragmentation. Given the results, I am more inclined to assume that looking at forest loss and development, together, captures some of the same variability in core area.

Looking at trends in individual development relationships we see that higher cow density within a county is linked to higher overall levels of deforestation. This is consistent with previous research that has found cattle ranching to be one of the largest contributors to forest loss. Between 2000 and 2005, cattle ranches accounted for 60% of deforestation in the Amazon (17).

As the results show, income and agricultural GDP had an increasingly strong effect on deforestation and fragmentation over time, supporting the claim that agricultural production is a driver of deforestation, though we cannot identify it as a cause of deforestation given the scope of the analysis. While I would expect agricultural investment to be linked similarly to deforestation as cows, such was not the case. Specific forms of agricultural capital should be investigated to provide a more complete look at which specific development factors are attributable to the highest levels of forest loss.

Something to bear in mind when taking a comprehensive look at the drivers of forest loss and habitat fragmentation is the issue of correlation strength over time. In 1992, forest loss and demographics census data accounted for 47 percent of the variation in county core area, and this is the strongest of the multiple regressions included in this study. While 47 percent is considerable, this leaves 53 percent variability unaccounted for. There is considerable room for further study. Including road and highway construction, soil quality, precipitation, mining efforts, and logging all have the potential for affecting forest patch size.

The disparities between some of the results imply differences in how any particular variable affects deforestation and core area. For instance, while income has a positive relationship with overall deforestation in 2000, income had a positive relationship with core area, indicating decreased fragmentation. I did not expect any specific variable to decrease habitat quality through increased forest loss, while at the same time increasing habitat quality through an increase in core forest area. There is the possibility of many unknown interactions among that variables that led to the relationships discovered through this study.

There a number of different avenues for continued research on the issue of fragmentation drivers in the Brazilian Amazon. Data limits prevented an even further look at time-trends, and it would be interesting to get a clearer picture of how variables affect fragmentation using yearly data without multi-year gaps in between. Also, a limited number of census variables were included, thus preventing a more comprehensive look at how development and demographics can be associated with forest loss.

References

1. Laurance, WF. Vasconcelos, HL. Forest loss and fragmentation in the Amazon: Implications for wildlife conservation. *Web of Science.* ORYX 34 (1): 39-45 JAN 2000

2. Alves, Diogenes S. *Deforestation and Frontier Expansion in the Brazilian Amazonia*. Open Meeting of the Global Environmental Change Research Community. Rio de Janeiro, 6-8 October, 2001.

3. Perz, Stephen G. *Population, Land use and Deforestation in the Pan Amazon Basin: A comparison of Brazil, Bolivia, Colombia, Eduador, Peru and Venezuela.* Environmental, Development and Sustainability. 2005

4. Central Intelligenge Agency. *The World Factbook.* Brazil. 2009 https://www.cia.gov/library/publications/the-world-factbook/geos/br.html

5. Tropical Rainforest Information Center. Map Products Library Brazilian Amazon. (http://www.trfic.msu.edu/products/images/legal_amazon_map.gif)

6. Fearnside, Philip M. *Deforestation in Brazilian Amazonia: History, Rates, and Consequences.* Conservation Biology. Vol. 19(3), pp. 680-688. June 2005.

7. Moran, Emilio F. *Deforestation and Land Use in the Brazilian Amazon.* Human Ecology. Vol. 21 (1), pp. 1-12. March 1993.

8. Skole, David. *Tropical Deforestation and habitat Fragmentation in the Amazon: satellite data from 1978 to 1988.*

9. Fearnside, Philip M. *Deforestation in Brazilian Amazonia: History, Rates, and Consequences.* Conservation Biology. Vol. 19(3), pp. 680-688. June 2005.

10. Fearnside, Philip M. Deforestation in Amazonia. *Instiuto Nacional de Pesquisas da Amazonia – INPA.* September 27, 1994.

11. Butler, Rhett A. Deforestation in the Amazon. Mongabay.com. http://www.mongabay.com

12. Pfaff, Alexander. What drives deforestation in the Brazilian Amazon. *Journal of Environmental Economics and Management.* 37(11): 26-43. 1999.

13. Chomitz, Kenneth M. Thomas, Timothy S. Determinants of Land Use in Amazonia: A Fine-Scale Spatial Analysis. *American Journal of Agricultural Economics*: 85(4) November 2003: 1016-1028.

14. Pfaff, Alexander. Road Investments, Spatial Spillowers, and Deforestation in the Brazilian Amazon. 2007.

15. Browder, J. (1988). Public Policy and deforestation in the Brazilian Amazon. In Repetto, R., and Gillis, Mm *Public Policies and the Misuse of Forest Resources*. World Resources Institute and Cambridge University Press. Washington, D.C.

16. William F. Laurance, Leandro V. Ferreira, Judy M. Rankin-de Merona, Susan G. Laurance (1998) RAIN FOREST FRAGMENTATION AND THE DYNAMICS OF AMAZONIAN TREE COMMUNITIES. Ecology: Vol. 79, No. 6, pp. 2032-2040

17. Forest Fragmentation. Sustainable Forests Partnership. 2008. http://sfp.cas.psu.edu/fragmentation/what.htm

18. Instituto Brasiliero de Geografia e Estatistica (IBGE) http://www.ibge.gov.br/english/estatistica/populacao/censodem/default.shtm