UEP MA Thesis
Final Draft
John VanderHeide
May 29, 2018

Impacts of Land Use Change on Guatemalan Food Sovereignty

A Thesis Submitted by:
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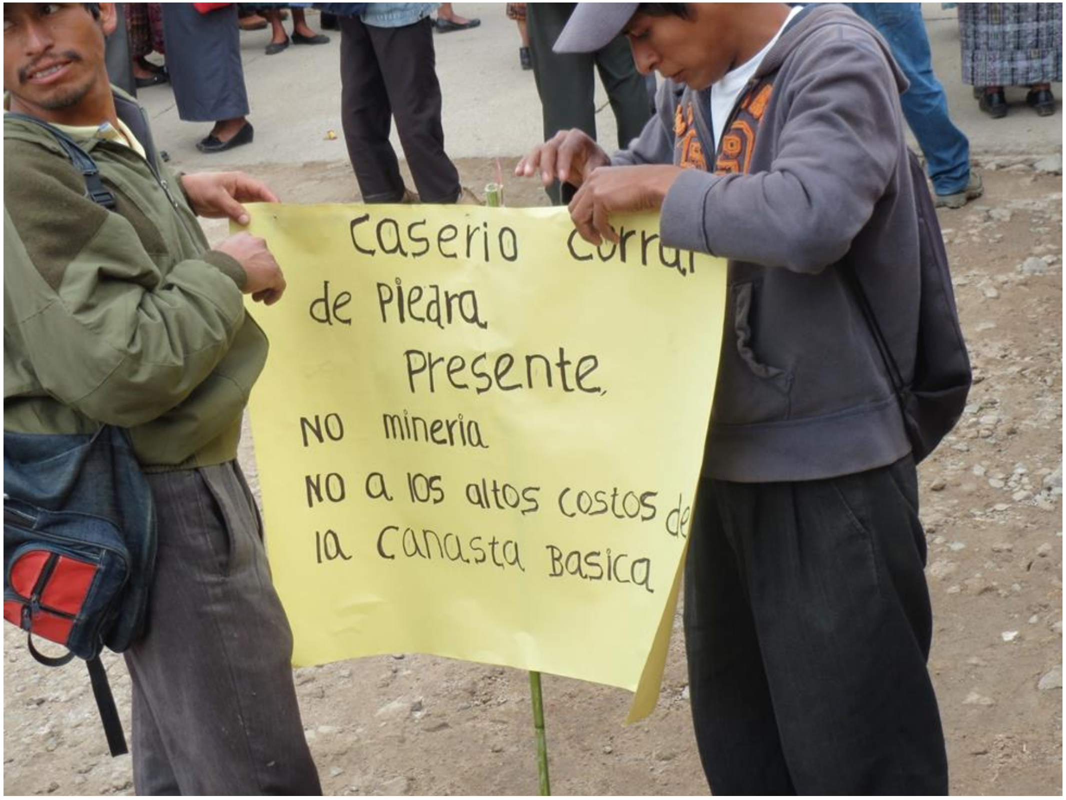

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Abstract

In 2014 the World Food Programme estimated that 130,000 smallholder farmers in Guatemala lost crops due to a drought[i]. That same year Guatemala also enjoyed 5-year highs in the production of water-intensive large-scale export crops: banana and sugar cane[ii]. This is one example of a series of food price and climate shocks that have caused many to question the impact of the global food system on the world's poor.

Guatemala is a particularly pointed example of the issues many countries face. Its fertile soil and varied climatic regions make it a productive place to grow food. This has led to it becoming an important producer of specific agricultural goods such as coffee, sugar, bananas, and oilseed palm, yet it struggles with one of the highest rates of malnutrition in the Western Hemisphere as well as pervasive food insecurity. Some have argued that this trend is due to the allocation of prime agricultural resources to export agriculture and the forcing of non-export agriculture onto marginal lands with high climate vulnerability. This research quantifies the geographic changes in Guatemalan export and non-export agriculture over the period of 2003-2010 and relates those changes to the vulnerability of the domestic food supply to climate change and international food price spikes. I find that non-export agriculture is moving onto more marginal land at higher elevations which both reduces expected yields and increases the likelihood of crop failure.

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Introduction

Figuring out how to feed the world's growing population will be one of the greatest challenges faced by humankind in the next century. Guatemala sits at an important juncture in this conundrum. Its fertile volcanic soil and varied climatic regions make it an incredibly productive and abundant place to grow food. This has led to it becoming an important producer of specific agricultural goods such as coffee, sugar, bananas, and oilseed palm[iii]. Yet, in the shadow of that lush production the country struggles with one of the highest rates of malnutrition in the Western Hemisphere[iv], as well as systemic and pervasive food insecurity[v].

There is a major disconnect between the crops Guatemala produces and the crops Guatemala consumes. For example, Guatemala is a net exporter of coffee and bananas while importing maize and wheat flour for consumption[vi]. As a result, there is an active national debate regarding what is the best path for the country: doubling down on the production of the high value crops for export to rich countries, or the support of local production and value chains that will hopefully reduce dependence on volatile international markets and be more sustainable in the long run.

In May of 2016 the Guatemalan Ministry of Agriculture Livestock and Food (MAGA) published its Gran Plan Nacional Agropecuario 2016-2020 (Grand National Plan for Agriculture 2016-2020). This document laid out a series of agricultural initiatives designed to continue to push Guatemala towards an export-heavy agricultural sector[vii]. This has raised concerns amongst civil society advocacy groups that see these programs as further weakening the Guatemalan food system by diverting resources such as prime farm land and water to export oriented agriculture, while continuing to push domestic production onto land that is environmentally marginalized and more prone to drought and climate shocks. Due to the Gran Plan, a number of civil society organizations—including my partner agency, the Pastoral de la Tierra of San Marcos—are interested in developing tools for assessing how the continued trajectory towards export production will impact the Guatemalan food system and the allocation of environmental resources.

In this paper I expand on the current literature in three ways. First, I provide a literature review on food insecurity and food systems shocks in Guatemala and which parts of the country are most vulnerable. Second, I assess recent agricultural land use changes in Guatemala to determine which kinds of agriculture are being impacted and how. Finally, I connect those trends to the categories of agriculture and portions of the Guatemalan economy that are critical for food security and hunger relief.

Literature Review

In this literature review I will address three main issues: endemic food insecurity and poor nutrition outcomes in the Guatemalan food system; land in equity and how land administration has impacted smallholder farmers; and water resource planning and how water resources have impacted smallholder farmers.

The Guatemalan food system and dependence on imports for basic food needs:

To be able to assess the impact of agricultural land use changes on food security and nutrition in Guatemala, it is first important to generate a basic picture of how the Guatemalan food system operates and where its vulnerabilities are. The most basic truism of the Guatemalan food system that needs to be understood is that corn is king. The statistical representation of this can be found in the FAO food balance analysis of the Guatemalan food system, which shows that a full third of calories in Guatemala are directly from corn (or maize) (see figure 1)[viii]. Apart from this numerical reality it is also important to note the immense cultural importance of corn in Guatemalan society. The Maya Mam (the indigenous language spoken in San Marcos department) differentiates between human being and ear of corn by only a single syllable. Corn and its derived products, such as tortillas and tamales, are and will continue to be important foods in Guatemala.

Sugar and wheat are the next two categories, and the resulting share of calories from carbohydrates is nearly 65%. Beans are the most prominent protein food and provide 4.6% of calories, with soybean oil being the most prominent fat source providing 4.3% of calories (Figure 1). These five commodities comprise greater than 73% of the calories consumed in Guatemala. Of these five commodities, only sugar is produced in sufficient quantities in Guatemala to meet domestic demand. This can be seen by investigating Guatemala's production of trade balance in these main commodities (Figures 2 and 3)[ix].

Figure 1: Top 5 Sources of Calories in Guatemala, 2013

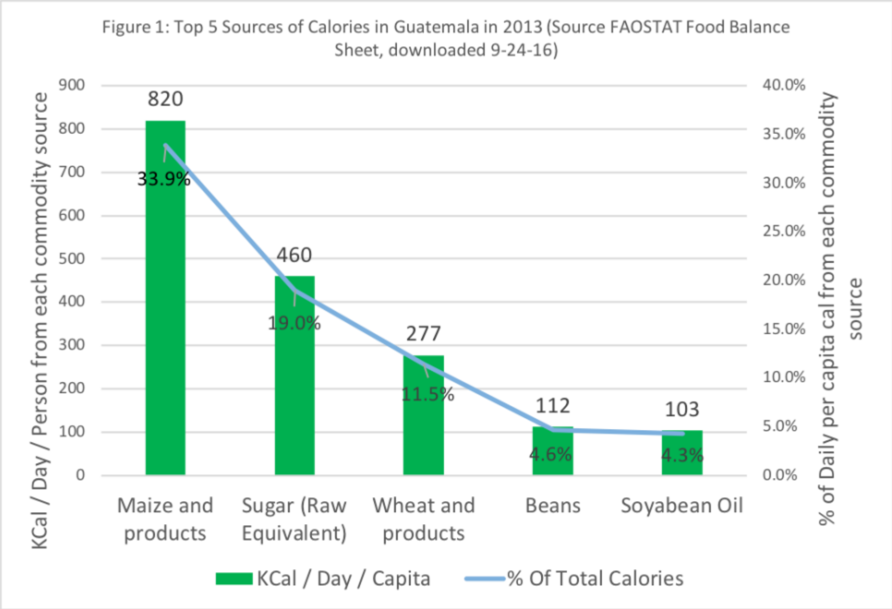


Figure 2: Trends in Guatemalan Production of Major Calorie Sources 1992-2013

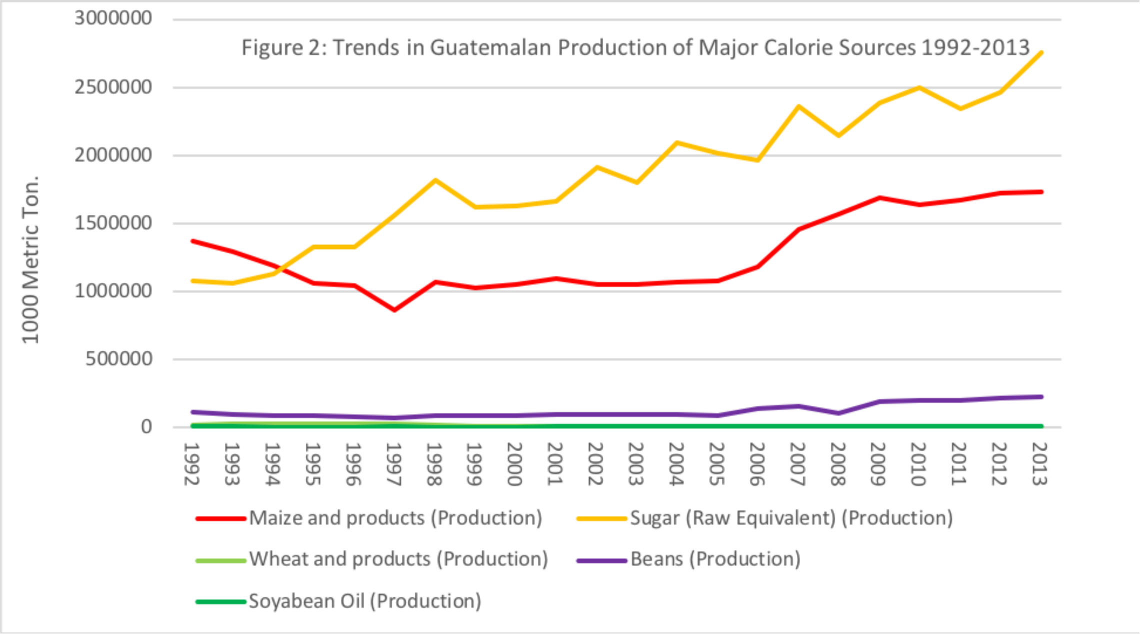
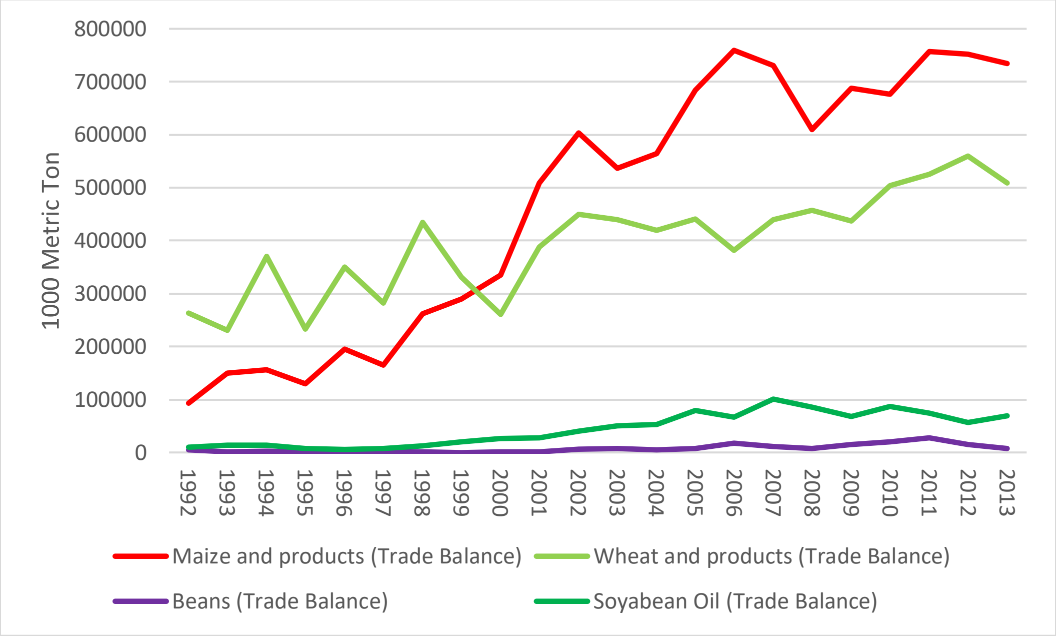


Figure 3: Trends in the Trade Balance for Major Calorie Sources in Guatemala.



Note the increasing production of sugar (a primarily export crop) and the relatively flat production of maize (corn) and beans (crops primarily for domsetic consumption). Also note the increased dependence on imported corn.

This pattern of increasing dependence on imported food has left Guatemala vulnerable to food price fluctuations. An example of this was that Guatemala experienced a muted version of the international food price crisis that was happening around the world between 2006 and 2008. Domestic prices for all foods rose and prices for staple crops rose sharply. The exact magnitude of these increases has been disputed but the most widely quoted source found that annual consumer price increases between 2006 and 2008 were on the order of 5.7% for beans, 14.2% for maize, 19.8% for rice, and 26.8% for bread.[x] The World Bank put the general consumer price index for 2007 at roughly 8%, meaning that all of the staple foods other than beans experienced price increases greater than the average rate of inflation, and up three times the rate of inflation in the case of bread.[xi]

There is additional evidence that food price increases were not evenly distributed across the Guatemalan population. The World Bank poor person's price index for 2007 in Guatemala was about 1% higher than the national average meaning that the impoverished in the country experience higher prices in general.[xii] In the case of the food price increases it is important to note that the staple crops that experienced the highest increases in price also make up the bulk of the diet of the poorest in Guatemala. It is not unusual for rural smallholder farmers to consume mostly maize with the addition of some vegetables or beans. Thus, the felt magnitude of the price increases were higher on the poor than the rich.[xiii] Producers also felt a different price increase than did consumers. Wholesale prices between 2006 and 2008 had annual percent increases of 10.7% for beans and 14.4% for maize.[xiv]

The implications of these food price increases were also not distributed evenly over the population. The reason for this is that the vast majority of the rural poor in Guatemala are farmers who are also net buyers of food. This group is particularly vulnerable to price increases because both their income and their expenditure are linked to food prices. As such an increase in the price of food causes their income to increase but their expenditure increases even more. This pattern was observed by multiple studies. Janvry and Sadoulet found welfare losses between 0.89% and 0.60% of expenditure for the rural poor of Guatemala[xv]. This resulted in a deepening of poverty for 66.3% of the rural population, drawing an additional 0.9% of the rural population into poverty.[xvi] The effects were similar on the urban population. Their welfare was reduced by between 0.62% and 0.74% of expenditure,[xvii] resulting in poverty deepening for 33.6% of the population and drawing an additional 1.2% into poverty[xviii].

The food price crisis also had a direct impact on the nutrition of the Guatemalan people. This burden again fell squarely on the backs of the urban and rural poor. There was a 9% increase in the percentage of the urban poor who fell below the caloric adequacy level, rising from 70% before the price shock to 79% after.[xix] A similar effect was seen in the rural poor with 85% below caloric adequacy before the shock and 91% afterward.[xx] Micronutrient intake was also negatively impacted. Econometric models of nutrient elasticities suggest that the likelihood of vitamin A, folate, and zinc deficiency in the poorest quintile of Guatemalans increased by at least 5% due to the price increases seen during the global food price crisis.[xxi] These trends are particularly concerning given Guatemala's history of poor nutritional outcomes for its poor population.

Any shocks that worsen this situation should be taken very seriously. As such this investigation will explore how shifts in agricultural land use make Guatemala vulnerable to food price shocks. In particular, I will explore if the land use changes have made the livelihoods of the rural poor more vulnerable.

Land inequity and implications on smallholder farmers:

In the context of a food system increasingly dependent on imported food, it is critical to understand the historical implications of land management and ownership in Guatemala and how they have impacted the rural poor, especially indigenous communities. Land tenure has been an intractable problem in Guatemala since the 1500's when the Spanish upended millennia of local systems and customs, converting the entire country to crown possessions[xxii]. As a result, Guatemala has one of the most unequal land distributions in the world, with 5% of the population holding formal title to 80% of the arable land[xxiii].

Inequality in this system contributes to significant social conflict and marginalization of smallholder farmers[xxiv], and the Sectratria de Asuntos Agrarios has registered hundreds of new disputes about land ownership in 2016 alone[xxv]. This conflict is compounded by the patchwork of land tenure systems employed in Guatemala, which are inconsistent from one community the next and often rated weak and opaque by international standards[xxvi] [xxvii]. This unequal distribution of land has historically favored the production of export crops because large land holders are able to consolidate holdings into plantations for the production of high value export crops.

An additional confounding problem is the long history of seasonal migration amongst indigenous communities in Guatemala. Many of the indigenous communities in the highlands have a centuries-long tradition of migrating to the coastal areas during the growing season.[xxviii] While there, they often are able to grow a large portion of the food that they will consume over the course of the year. This practice is often mediated through coastal land rental and is highly vulnerable to land conversion in the lowlands.[xxix] Land that is converted to export agriculture is removed from the rental market for migrating Guatemalans, and in many cases the number of plantation jobs created by the large export plantation is not equal to the number of farmers displaced by its creation.

While land ownership will not be addressed in my thesis project, I will be addressing the conversion of land from basic grain production to production for export. This conversion often happens when smallholders are bought out or have their leases voided in favor of a large land holder. Large scale expansions of export crops are only possible due to the unequal distribution of Guatemalan land.

Water equity and impacts on food security:

Guatemala is not a water scarce country in an absolute sense. One estimate suggests that the country has a total of 97 billion cubic meters of water available each year, or 7 times the threshold for water scarcity set out by international standards[xxx]. Yet the difficulty is that the distribution, both spatially and temporally, of that water is far from equitable or efficient. According to key informant interviews with producers and government employees in Guatemala, seasonal water shortage is a major limiting factor on the production capabilities of smallholder farmers, particularly in the mountainous regions of the country. This assertion is supported by numerous planning documents and development reports [xxxi] [xxxii] [xxxiii] [xxxiv] [xxxv]. Shocks to the system through either normal weather events or climactic shifts are also not equally distributed across Guatemala [xxxvi] [xxxvii], and have differing impacts on large and small producers based on their location and adaptive capacities[xxxviii].

Methods

To assess the impact of changing land use on Guatemalan food security I used a twofold process. I began with a series of framing interviews with key informants in Guatemala. To generate the sample for these interviews I relied on my personal and professional connections with NGOs and civil society actors in San Marcos Guatemala. This means that the sample for my interviews is biased towards the reality in San Marcos and not representative of the country. These interviews were used only for initial question framing and to explore potential data sources. The second phase of the analysis section was to use secondary geographic data to assess the patterns and impacts of changes in resource allocation in Guatemala. That process is described in detail in the next section.

Data

The main agricultural resources of concern in Guatemala are land and water. Many of the interviews that I conducted over the summer of 2017 indicated that campesino organizations are very concerned with how prime agricultural land and water resources are being diverted from non-export agriculture to export agriculture. To assess whether this was true, I developed a relational database connecting land use data with other data that relate to agricultural productivity. The data of interest are:

Land Use 2003 – Guatemalan Ministry of Agriculture
Land Use 2010 – Guatemalan Forest Institute
Elevation – 1 Arc-second SRTM dataset from NASA
Distance from Arterial Roads – Open Street Map
Slope – Calculated from elevation
Bio-climactic variables and climate change projections – WorldClim 1.4 database
  Mean Annual Temperature
  Mean Annual Precipitation
  Seasonality of Precipitation
Erosion Potential – IARNA
Population and Ethnicity Statistics – Guatemalan Statistics Institute (data from 2002)
Poverty Data – Guatemalan Statistics Institute (data form 2011)
USDA Land Use Classification – Guatemalan Ministry of Agriculture
Net Primary Productivity 2003 – NASA
Natural Disaster Risks – IARNA
  Areas at risk of Drought
  Areas at risk of Flood
  Areas at risk of Frost
  Areas at risk of Landslides

Data sets used for processing purposes:

Guatemalan Municipal Boundaries – Guatemalan Ministry of Planning, Segeplan
500m x 500m fishnet grid – generated in ArcMap 10.5.1
Points sampling frames – generated in ArcMap 10.5.1

Methodological Approach

Once all the data were properly cleaned and projected (WGS 1984, UTM 15N) I combined them using two different methods. The first was to spatially aggregate the data at the municipal level using zonal statistics. Using this methodology, each municipality had the prevalence of non-export agriculture as well as summary statistics such as population density, average elevation, and various bioclimatic variables added as attributes to its spatial polygon. This was useful for exploratory regressions estimating the correlation between many of the variables and changes in non-export agriculture land use. The second method for integrating the data was to use a points sampling frame. For this sampling frame, the value of the land use data and the other covariates were measured at each point in the points sampling frame and those values were added as an attribute matrix. This methodology was used because many of the rasters had different cell sizes. Using the points sampling frame, I was able to assess our best estimate of the land use at a given point and then also obtain my best estimate of the biophysical, bioclimatic, and social variables at that location, which can inform how productive any agriculture at that location would be and how vulnerable it might be to climate and social shocks. This approach was used in addition to spatial aggregation because of the incredible variation in some of these variables over small spatial scales. Guatemala is a small country with very tall mountains as well as tropical forests and ocean coasts. A given administrative district can have numerous soil types and climactic zones meaning that its suitability for agriculture and its vulnerability to shocks are not uniform. By choosing the points sampling frame I could investigate some of that heterogeneity.

The land use data is the critical for the questions that I am asking, so I used it to develop the sampling frame. The initial idea was to simply convert the cells of the 2003 land use raster into points and then sample the other data sets at each of those points, but the resulting feature class was too large to use efficiently. Instead a 2% sample of the points was selected by casting a 500m x 500m fishnet over Guatemala and placing 8 random points in each cell of the fishnet. The points were set to be a minimum of 36m apart so that they would never fall on the same cell of the land use raster. This process selected 8 of the 400 25m x 25m cells in each grid of the 500m x 500m fishnet. These points were then used to sample the other raster data sets measuring our best estimate of elevation, precipitation, temperature, land use classification, slope, and erosion potential at each of those locations. Basin-level water balance statistics and municipal-level social statistics were also spatially joined to the points to give us an understanding of some of the hydrologic and social contexts in which the farms operate. The result is a dataset of 3469066 observations. Due in part to the poor spatial quality of some of the social and water data I was unable to use it to draw conclusions with the point data.

To further investigate land use change dynamics, the data were subdivided into five elevation categories based on agro-climactic needs of the different export crops being considered. They were <100m, 100-300m, 300-

500m, 500-2000m, and >2000m. They correspond to zones associated with different crops:

<100m – Palm, Sugar, and Banana
100-300m – Additional Sugar and Palm, some Rubber
300-500m – Rubber
500-2000m – Coffee, Cardamom, and Misc. Crops
>2000m – Essentially No Export Ag

Non-export agriculture can be found in all of the elevation categories. The elevation density distributions of the categories can be found in figures 4 and 5. It is important to remember that the different elevation categories make up different portions of the country.

<100m – 540332 / 3469066 = 15.6%
100-300m – 1095630 /3469066 = 31.6%
300-500m – 365728 / 3469066 = 10.5%
500-2000m – 1128622 / 3469066 = 32.5%
>2000m – 338754 3469099 = 9.8%

Figure 4: Elevation Density of Non-Export (Annual) Agriculture in Guatemala

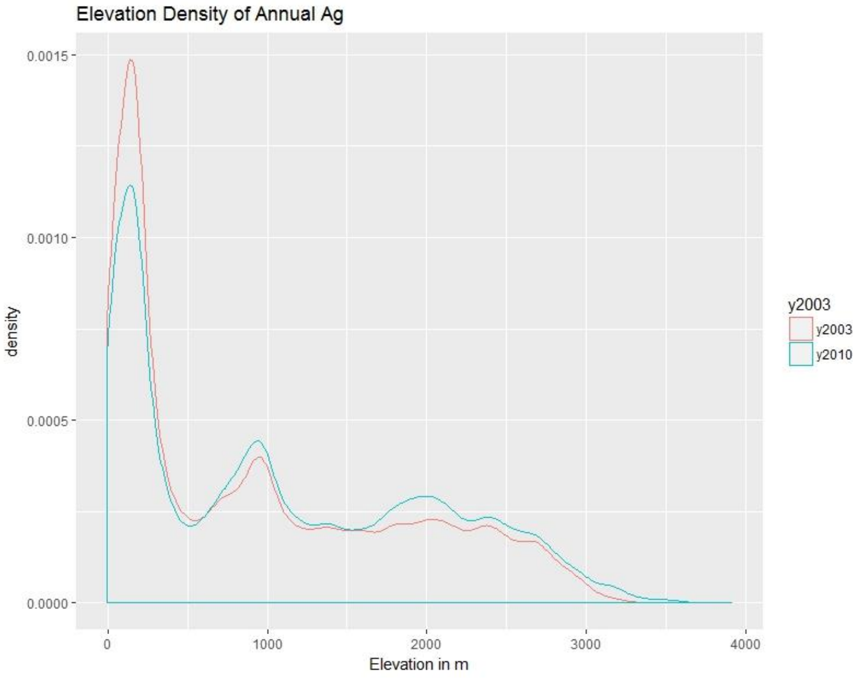
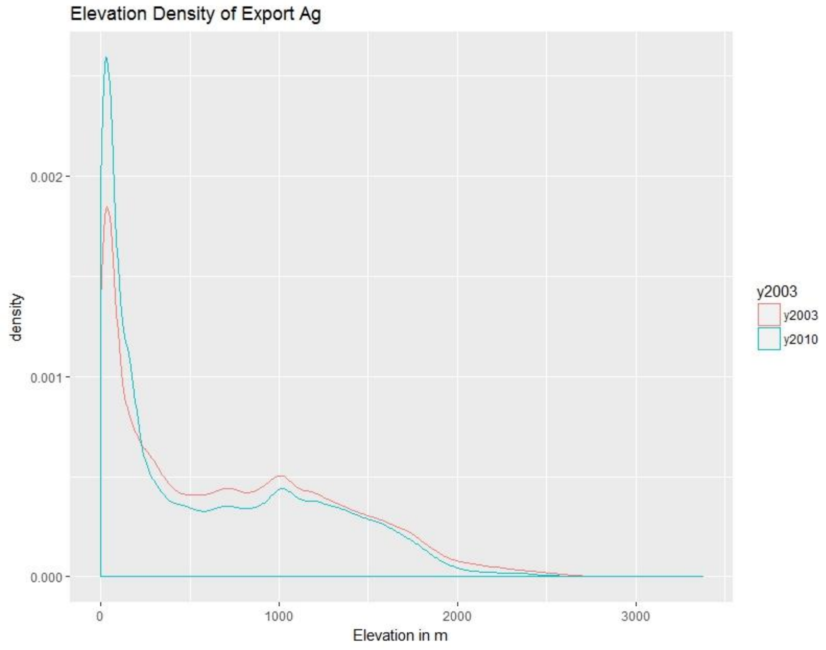


Figure 5: Elevation Density of Export Agriculture in Guatemala



Land use changes in each elevation category were assessed to look for patterns in both gross gain and loss, as well as the largest contributing exchanges. Once the land use changes had been assessed, I also calculated the changes in the descriptive statistics for various predictors of overall agricultural productivity and climate change vulnerability for non-export agriculture in Guatemala. This helped me assess how land use changes are impacting Guatemalan food security.

Results

Municipal analysis

My first question in this case is whether or not there is a spatial pattern in the change of land use to non-export agricultural acreage in Guatemala. To asses this the municipal non-export agriculture acreage in 2003 was subtracted from the non-export agriculture acreage in 2010 and the Moran's I statistic was calculated using a queen's contiguity matrix. Because the municipalities have very different total areas the change in non-export acreage was divided by the total area of the municipality and the Moran's I was calculated. Both of these tests found statistically significant positive spatial autocorrelation meaning that areas which either lost a large area of non-export agriculture or a large percentage of non-export agriculture were also near areas that experienced the same. These results can be seen in figures 6 and 7. This spatial clustering implies that there may be spatially important covariates that are helping to drive the underlying land use changes.

Figure 6:

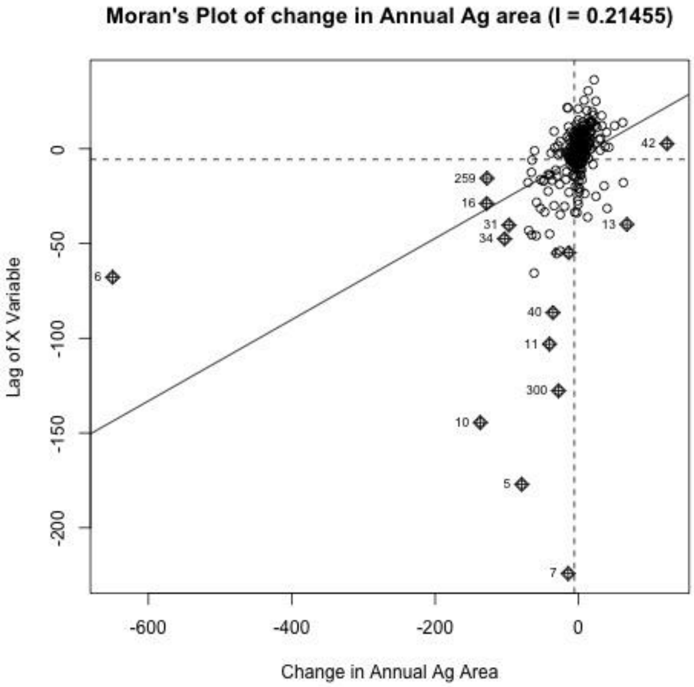
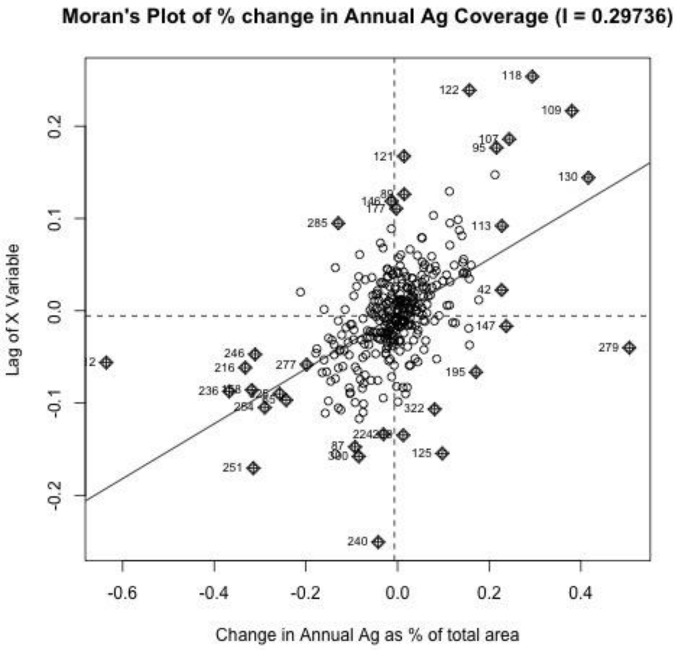


Figure 7:



To investigate what impact these changes might have on the overall productivity of non-export agriculture in Guatemala I ran regressions to see if important biophysical, bioclimatic, or social covariates were strong predictors of the change in non-export agriculture. Because of the large difference in the size of municipalities I used both the total change in non-export agricultural area and the change as a % of total area of the municipality as outcome variables for these regressions. Table 1 and table 2 show the results of OLS (Ordinary Least Squares) bivariate regressions for each of the variables as well as the multivariate regression for the collection of variables.

There are two main findings from these results. First is that the most powerful explanatory variables are not surprisingly the biophysical ones, particularly elevation and average USDA land use classification. Precipitation and net primary productivity also have a significant relationship that is apparent in the multivariate linear regression. The second main finding from this analysis is that both formulations of the outcome variable results in similar regression models. The signs and significance of the coefficients remain consistent.

Table 1 : Univariate regression analysis using gross change in Non-Export Agriculture as the outcome variable

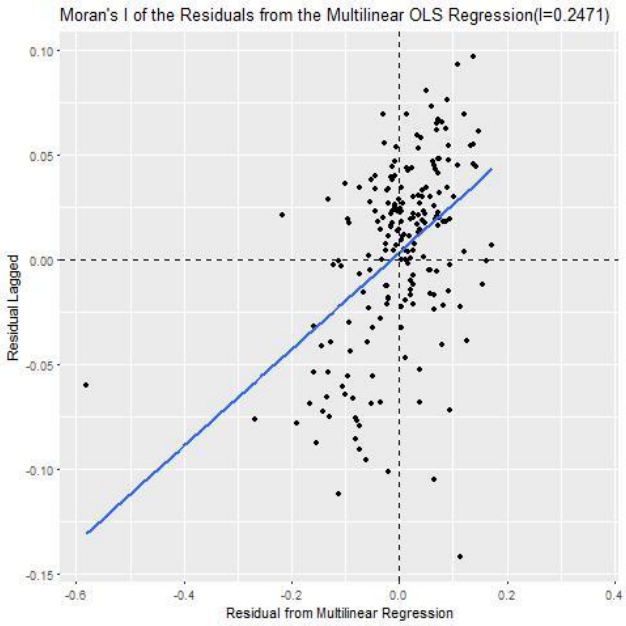
	Dependent variable:								
	Change in Non-Export Agriculture (km^2)								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Constant	-22.454^{***}	-27.450^{***}	-8.727^{***}	8.816	-1.314	-7.558^{***}	-8.484^{**}	-5.348	-12.090
	(4.460)	(9.774)	(3.047)	(15.476)	(6.019)	(2.731)	(3.709)	(4.427)	(19.373)
Average Elevation (100m)	**1.235^{***}**								**1.703^{**}**
	(0.284)								**(0.657)**
Average USDA Classification		**3.659^{**}**							1.546
		(1.608)							(3.337)
Average Erosion Potential (ton/Ha/yr)			0.039						0.026
			(0.026)						(0.033)
Average Annual Net Primary Productivity				-0.008					-0.026^{*}
				(0.008)					(0.014)
Average Annual Precipitation (mm)					-0.002				**0.011^{**}**
					(0.003)				**(0.006)**
Population Density (People/km^2)						0.006			0.010
						(0.005)			(0.020)
Percent of Population that is Indigenous							0.055		-0.092
							(0.059)		(0.091)
Extreme Poverty Rate								-0.048	0.046
								(0.170)	(0.190)
Observations	334	334	334	305	334	334	334	300	280
R^2	0.054	0.015	0.007	0.003	0.002	0.005	0.003	0.0003	0.082
Adjusted R^2	0.051	0.012	0.004	-0.00000	-0.001	0.002	-0.0005	-0.003	0.055
Residual Std. Error	42.202 (df = 332)	43.052 (df = 332)	43.242 (df = 332)	45.289 (df = 303)	43.342 (df = 332)	43.286 (df = 332)	43.332 (df = 332)	45.676 (df = 298)	45.849 (df = 271)
F Statistic	18.904^{***} (df = 1; 332)	5.177^{**} (df = 1; 332)	2.220 (df = 1; 332)	0.999 (df = 1; 303)	0.677 (df = 1; 332)	1.547 (df = 1; 332)	0.843 (df = 1; 332)	0.081 (df = 1; 298)	3.024^{***} (df = 8; 271)
Note:	$^{*}p<0.1$ $^{**}p<0.05$ $^{***}p<0.01$								

Table 2 : Univariate regression analysis using % area change in Non-Export Agriculture as the outcome variable

Table 2	*Dependent variable:*								
	Change In Non-Export Agriculture as a % of Municipal Area								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Constant	-0.050***	-0.094***	-0.013*	0.045	0.014	-0.009	-0.010	-0.004	-0.042
	(0.011)	(0.024)	(0.008)	(0.034)	(0.015)	(0.007)	(0.009)	(0.010)	(0.040)
Average Elevation (100m)	**0.003*****								**0.003****
	(0.001)								**(0.001)**
Average USDA Classification		**0.015*****							0.013*
		(0.004)							(0.007)
Average Erosion Potential (ton/Ha/yr)			0.0001						0.00001
			(0.0001)						(0.0001)
Average Annual Net Primary Productivity				-0.00003					**-0.0001****
				(0.00002)					**(0.00003)**
Average Annual Precipitation (mm)					-0.00001				**0.00002****
					(0.00001)				**(0.00001)**
Population Density (people/km^2)						0.00001			-0.00001
						(0.00001)			(0.00004)
Percent of Population that is Indigenous							0.0001		-0.0002
							(0.0001)		(0.0002)
Extreme Poverty Rate								-0.00002	-0.0002
								(0.0004)	(0.0004)
Observations	334	334	334	305	334	334	334	300	280
R^2	0.058	0.041	0.004	0.008	0.007	0.001	0.001	0.00001	0.112
Adjusted R^2	0.055	0.038	0.001	0.005	0.004	-0.002	-0.002	-0.003	0.086
Residual Std. Error	0.104 (df = 332)	0.105 (df = 332)	0.107 (df = 332)	0.100 (df = 303)	0.107 (df = 332)	0.107 (df = 332)	0.107 (df = 332)	0.105 (df = 298)	0.095 (df = 271)
F Statistic	20.520*** (df = 1; 332)	14.194*** (df = 1; 332)	1.379 (df = 1; 332)	2.475 (df = 1; 303)	2.364 (df = 1; 332)	0.202 (df = 1; 332)	0.197 (df = 1; 332)	0.004 (df = 1; 298)	4.273*** (df = 8; 271)
Note:	*p<0.1 **p<0.05 ***p<0.01								

To test if there was spatial autocorrelation in the error I ran a Moran's I of the residuals from the OLS regression (figure 8).

Figure 8:



This test indicated statistically significant clustering of the residuals from the regression implying that there were spatial dependency issues that needed to be accounted for in the model.

To address this the multi-linear regression was repeated using both spatial lag and spatial error specifications. I expect the spatial error model to be the most appropriate because of unmeasured similarities between neighboring municipalities. The data back up this expectation in that the spatial error model has a lower AIC and a more significant Lagrange Multiplier test. (Table 3) Even though the differences between the models are slight I still prefer the spatial error model. The main finding from that analysis is that both spatial specifications remove the autocorrelation of the residuals.

Using this spatial specification has an interesting effect on the significance of the coefficients. Notably the elevation coefficient is no longer significant. USDA Land Use Classification, Net Primary Productivity, and Precipitation remain significant while Erosion Potential becomes significant only at the 10% level. These changes are relatively unsurprising. All of these variables have an underlying spatial pattern that is actually mostly driven by elevation. This means that there is likely multicollinearity between the other explanatory variables and elevation. This is inflating the standard error on the elevation coefficient. The social variables remain statistically not significant in these models implying that they are poor predictors of which municipalities will gain or lose non-export agriculture. The reason for this is unclear. It may be that poverty, population density, and Mayan heritage are not influencing where non-export agriculture is gained or lost, but this seems unlikely given what is known about the cultural importance of maize to Mayan communities and the relationship between smallholder agriculture and poverty. Another explanation is that these social variables were measured at the municipal scale meaning that it their spatial scale is much more coarse than the bioclimatic and biophysical variables. As such, further analysis should seek social data at smaller spatial scales to explore the relationships between these variables and where non-export agriculture is gained or lost.

Table 3: Spatial Specifications of the Regressions Explaining the Loss of Non-Export Ag

	Dependent variable:		
	Change In Non-Export Agriculture as a % of Municipal Area		
	OLS	*spatial autoregressive*	*spatial error*
	(1)	(2)	(3)
Constant	-0.042	-0.031	-0.054
	(0.040)	(0.036)	(0.050)
Average Elevation (100m)	**0.003****	0.001	0.002
	(0.001)	(0.001)	(0.002)
Average USDA Classification	0.013*	0.012*	**0.015****
	(0.007)	(0.006)	**(0.007)**
Average Erosion Potential (ton/Ha/yr)	0.00001	0.00004	0.0001*
	(0.0001)	(0.0001)	(0.0001)
Average Annual Net Primary Productivity	**-0.0001****	**-0.0001****	**-0.0001*****
	(0.00003)	**(0.00003)**	**(0.00003)**
Average Annual Precipitation (mm)	**0.00002****	**0.00002****	**0.00004*****
	(0.00001)	**(0.00001)**	**(0.00001)**
Population Density (people/km^2)	-0.00001	0.00001	0.00003
	(0.00004)	(0.00004)	(0.00004)
Percent of Population that is Indigenous	-0.0002	-0.0001	-0.0002
	(0.0002)	(0.0002)	(0.0002)
Extreme Poverty Rate	-0.0002	-0.0001	0.0001
	(0.0004)	(0.0003)	(0.0004)
Rho		0.5285***	
		(0.0624)	
Lambda			0.5859***
			(0.0592)
Observations	280	280	280
Log Likelihood		287.506	289.516
sigma^{2}		0.007	0.007
Akaike Inf. Crit.		-553.011	-557.033
Wald Test (df = 1)		71.792***	97.956***
LR Test (df = 1)		42.349***	46.370***
Note:			*p<0.1, **p<0.05, ***p<0.01

Because the municipal analysis relies on spatial aggregation there is a loss of specificity but a gain in the simplicity of data processing. From this analysis I am able to draw conclusions about general trends in the dynamics of non-export agriculture. Those general trends are that non-export agriculture is moving into higher elevation municipalities with more marginal soils and lower net primary productivity.

Points Analysis

To assess land use changes the categories of land use mentioned in each of the land use data sets was reclassified into 5 simplified categories. This allowed me to create land use descriptive statistics that are useful for describing changes on spatial scales that are smaller than the municipality. Table 4 below shows the descriptive statistics for land use at the national level based on the 2% points sample that was used to build out points data set.

Table 4: Land Use Characteristics Simplified Categories.

	% of sample area in 2003	% of sample area in 2010
Urban Area	1%	1%
Pasture	13%	15%
Natural Area	63%	60%
Export Ag	11%	11%
Non-Export Ag	13%	12%

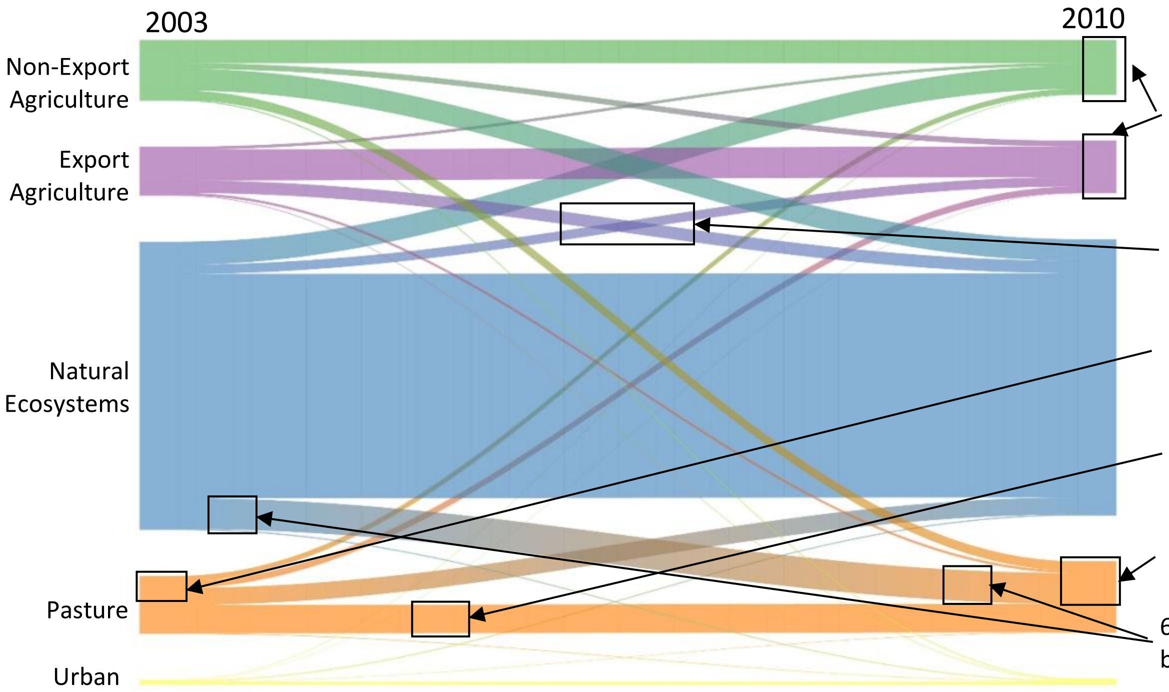
This table shows relatively stable overall land use categories in Guatemala between the years 2003 and 2010. That simplicity is misleading because there is significant flux between the land use categories. This can be seen in figure 9 which is a Sankey diagram of the flows between each category in our data set. It shows that there is significant flow between categories despite the fact that the overall quantity in each category is relatively consistent in the two time points. For example 9.3% (42,023/ 451,801 raster cells) of the area that was non-export agriculture in 2003 transitioned to become export agriculture in 2010 and 5.3% (20,808/ 406,870 raster cells) of the land in non-export agriculture in 2010 had been export agriculture in 2003.

Figure 9: Flows Between Land Use Categories in Guatemala 2003-2010

Below is a Sankey diagram of the land use changes in Guatemala between the years of 2003 and 2010. The diagram shows the flows between 5 categories of land use (listed to the right of the diagram). The width of a flow represents the proportion of the sampled land area that experienced that flow and the colors indicate the categories of the flow. For example, the flow marked by #6 in the diagram below represents the portion of the sample that was natural ecosystems in 2003 and transitioned to pasture in 2010.

This allows us to make several comparisons. First, the relative widths of the bars in a given year tells us about the relative prevalence of the different land use categories in that year. In the example below both non-export agriculture and export agriculture make up similar amounts of the sample in 2010 and this is seen by comparing the widths of the green and purple bars. (see #1). Second, since the sample is the same in both years, the portion of a bar that crosses the graph horizontally without changing categories tells us about the permanence of the category. For example, more than half of the pasture category in 2003 left to become something else while half of the pasture in 2010 was something else in 2003. (see #3, #4, and #5). The last important comparison that can be drawn from these diagrams is the relative quantities of land making reciprocal transitions. This information can be obtained by comparing the widths of lines as they cross at the midpoint. For example, a larger portion of land left export agriculture to become natural ecosystems than the reverse, this can be seen at #2.

Training Diagram



1. Relative quantities of land in the Non-Export Agriculture and Export Agriculture categories in 2010

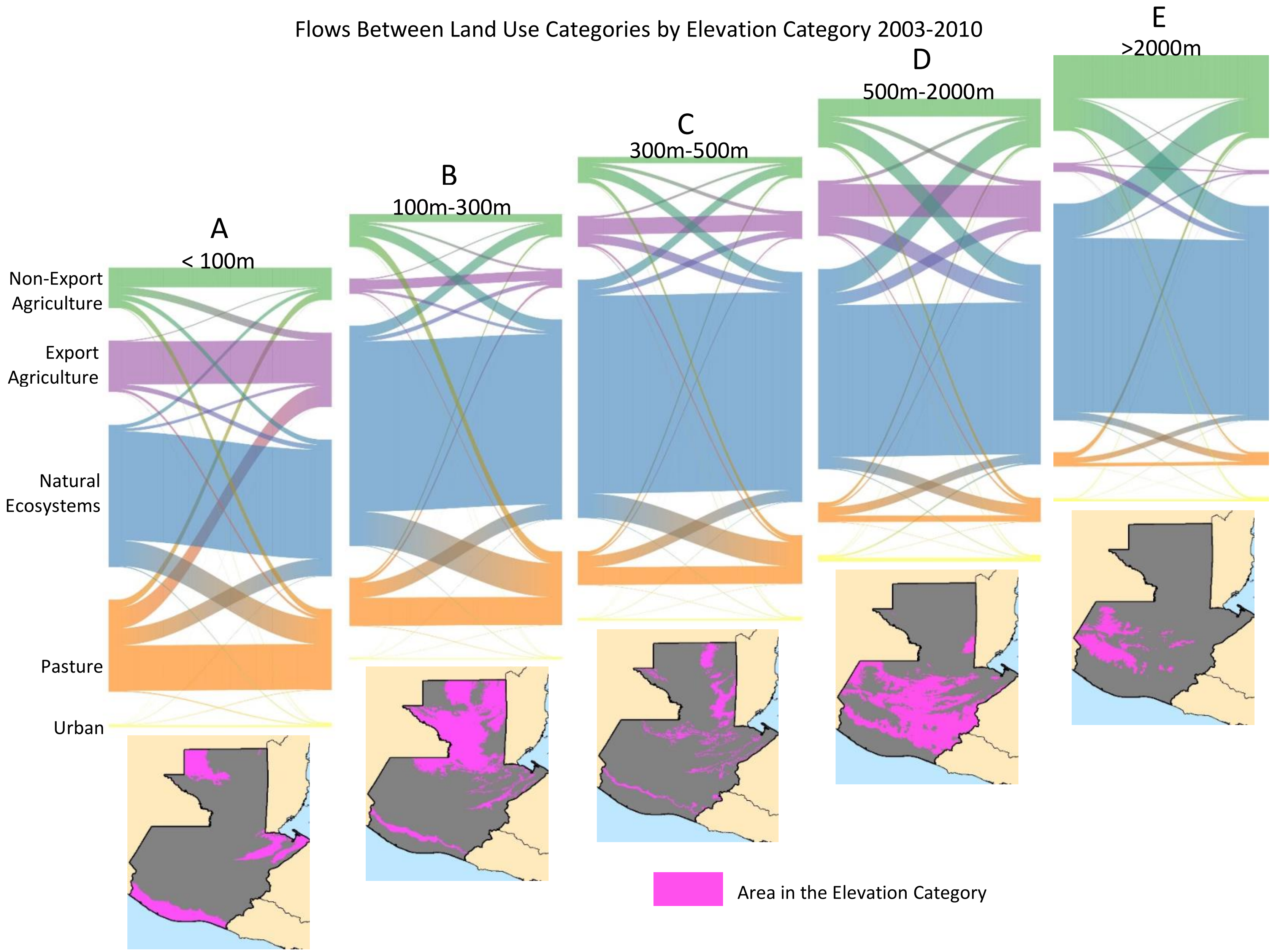
2. Comparison of the amount of land that transitioned from natural ecosystems to Export Agriculture and vice versa.

3. Portion of the area of Pasture in 2003 that was a different category in 2010

4. Portion of the area of Pasture in 2003 that remained Pasture in 2010

5. Portion of the area of Pasture in 2010 that was a different category in 2003

6. Portion of the area of Natural Ecosystems in 2003 that became Pasture in 2010



Flows Between Land Use Categories by Elevation Category 2003-2010

An additional complication is that these flows in land uses are different depending on elevation. For example, in the lowest elevation category 19% (12,290/ 64,732 raster cells) which were non-export agriculture in 2003 ended up as export agriculture in 2010 while only 2.8% (1,454/52,047 raster cells) of the area that was non-export agriculture in 2010 had been export agriculture in 2003(Figure 9 panel A). At the opposite end of the elevation spectrum export agriculture is so rare that it only accounts for roughly 1% of flows into and out of non-export agriculture(Figure 9 panel E). Tables 5 and 6, respectively show the flows out of and into non-export agriculture in each elevation category. Sankey diagrams of the overall land use flows in each elevation category can be seen in Figure 9.

Table 5: Flows From Non-Export Agriculture in 2003 to Other Land Uses

Flow from Non-Export Agriculture in 2003 to … numbers are sampled raster cells
(% are column normalized)

	Elevation Category					
2010 Land use Category	<=100m	100m-300m	300m-500m	500m-2000m	>2000m	
Non-Export Ag	31335 (48.4%)	26695 (23.3%)	6659 (23.5%)	60539 (36.4%)	45790 (56.8%)	This category indicates permanence in Non-Export Ag
Export and Other Ag	12290 (19.0%)	7935 (7.1%)	3854 (13.6%)	16767 (10.1%)	1177 (1.5%)	These Categories indicate loss of Non-Export Agriculture land to other land uses
Natural Ecosystems	8507 (13.1%)	40213 (35.9%)	12362 (43.6%)	70636 (42.5%)	29578 (36.7%)	
Pasture	11617 (17.9%)	35934 (32.2%)	5013 (17.7%)	15110 (9.1%)	2226 (2.8%)	
Urban	983 (1.5%)	1163 (1.0%)	436 (1.5%)	3183 (1.9%)	1799 (2.2%)	

Chi-squared = 75652 p-value < 2.2e-16

Table 6: Flows To Non-Export Agriculture in 2010 From Other Land Uses

Flow to Non-Export Agriculture in 2010 from … numbers are sampled raster cells (% are column normalized)

	Elevation Category					
2003 Land use Category	<=100m	100m-300m	300m-500m	500m-2000m	>2000m	
Non-Export Ag	31335 (60.2%)	26695 (34.3%)	6659 (29.0%)	60539 (36.5%)	45790 (51.9%)	This category indicates permanence in Non-Export Ag
Export and Other Ag	1454 (2.8%)	3598 (4.6%)	2402 (10.5%)	12163 (7.3%)	1191 (1.4%)	These Categories indicate gain to Non-Export Agriculture land from other land uses
Natural Ecosystems	6248 (12.0%)	39419 (50.7%)	10496 (45.8%)	80744 (48.7%)	34713 (39.4%)	
Pasture	12843 (24.7%)	7909 (10.2%)	3207 (14.0%)	10897 (6.6%)	5499 (6.2%)	
Urban	167 (0.3%)	205 (0.3%)	175 (0.8%)	1542 (0.9%)	980 (1.1%)	

Chi-squared = 45238 p-value < 2.2e-16

To assess the significance of these patterns I used a Chi-squared test on the fate of non-export agriculture and the source of non-export agriculture in each elevation category. Both of these statistical tests are reported in tables 5 and 6 respectively. They indicate that land use change patterns are distinct by elevation category.

At this point it is critical to assess the uncertainty in the category rasters used to asses these changes over time. Unfortunately neither the 2003 MAGA data set or the 2010-2012 INAB data set has a published confusion matrix that would allow us to directly assess how likely an observed transition was actually due to miss classification. What is left is a logical argument based on the similarity in appearance of different land use categories. In this case there are three main confusions that that I am interested in. First is the confusion between pastures and natural ecosystems. This confusion is generated by the land cover categories of “*arbustos*” or “brushland” and “*pastos naurales*” or "natural pasture". These two categories are in many cases interchangeable in on the landscape and the distinction depends more on whether or not there are grazing animals present on a piece of land than on some visible difference in the landscape. This means that they are often confused for each other when identified in remote sensing images. In this analysis "*arbustos*" was considered a natural ecosystem and "*pastos naturales*" was considered as part of pastures, therefore I would expect there to be an inflated amount of interchange between the natural ecosystem and pasture categories. With data available it is impossible to asses if this is actually a problem in our analysis but given that I are mainly concerned with interchanges between export and non-export agriculture this difficulty does not seem to overly hamper the general analysis.

There are two more additional areas of possible confusion that are much more concerning. These are between pastures and non-export agriculture and natural ecosystems and non-export agriculture. Because non-export agriculture in Guatemala is generally practiced as smallholder agriculture it's remote sensing fingerprint is very complicated. Unlike in Iowa, planting dates for maize can vary by a month or more even in the same elevation zone and harvest is usually done by hand meaning that there is a large amount of biomass left on the soil until clearing and planting for the next cropping cycle. This means that it can be quite difficult to distinguish recently harvested maize from scrub land or natural pasture. Upon review of the documentation that accompanied both the MAGA and INAB data sets this possible form of confusion was considered and minimized but remained. It is important to note that there is no reason to believe that this confusion would be larger in any given analysis than the other so while it would inflate the size of the into and out of flows between non-export agriculture and both pasture and natural ecosystems it should not have a large impact on the net flows. Net flows by land use transition and elevation category can be seen in Table 7.

Table 7: Net Flows Between Non-Export Agriculture and Other Land Uses between 2003 and 2010

Net flows … numbers are sampled raster cells

	Elevation Category					
2010 Land use Category	<=100m	100m-300m	300m-500m	500m-2000m	>2000m	
Non-Export Ag	0	0	0	0	0	This is defined as 0 because represents areas that did not transition
Export and Other Ag	-10836	-4337	-1452	-4604	14	These Categories indicate net flow between categories listed and Non-Export Ag. Negative numbers indicate net loss of Non-Export Ag land and positive numbers mean net gain of Non-Export Agriculture Land
Natural Ecosystems	-2259	-794	-1866	10108	5135	
Pasture	1226	-28025	-1806	-4213	3273	
Urban	-816	-958	-261	-1641	-819	

One area of encouragement from this analysis is that there is little reason to believe that export agriculture is easily confused with other land uses in the remote sensing analysis. The main export acreages are banana, African palm, sugar, rubber, and coffee. These crops are structurally distinct in both growth habit and seasonality from non-export agriculture, pastures, and natural ecosystems meaning that they are relatively easy to distinguish in remote sensing images. I expect the most common confusions in the export agriculture category to be between crops like bananas and African palm, but since these are internalized in the export agriculture category that confusion is of little concern. This means that I can be reasonably certain that transition to and from export agriculture are in fact transitions of interest. Urban areas are also very distinct in remote sensing data, but they make up a very small portion of the sample and are not of interest for this analysis.

Based on this information I can comfortably find that nationally non-export agriculture slightly decreased in area but the transition pattern is different based on what elevation is being examined. In areas below 300m in elevation is where the vast majority of all loss in non-export agriculture acreage appears to be happening. Secondly what is being replaced also appears to depends on the elevation category. Below 100m elevation export agriculture is the largest specific driver of the loss of non-export agriculture area. As you move up in elevation pasture is replacing non-export ag. Above 300m elevation the total loss in non-export agriculture slows down and in the higher elevation categories non-export agriculture is expanding at the expense of natural ecosystems.

Looking at the elevation distribution of non-export agriculture transitions to the specific spatial transitions gives us an even more detailed map of where and how non-export agriculture is being lost. Figure 10 is a map of the change in non-export agriculture in each 500m x 500m cell of the fishnet sampling frame across Guatemala and figure 11 shows Local Moran's I cluster analysis for that change in non-export agriculture.

Figure 10: Change in Non-Export Agriculture % 2003-2010

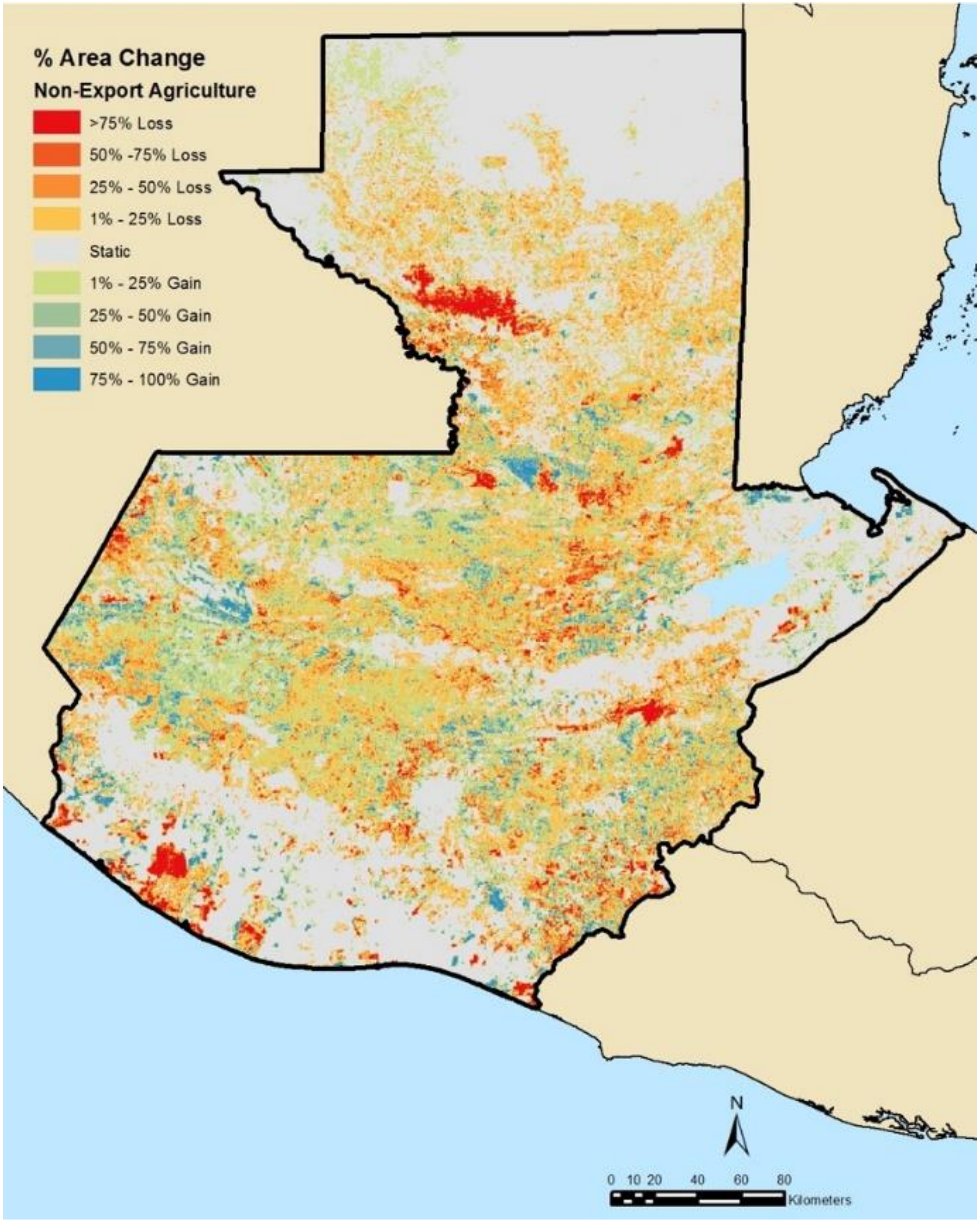
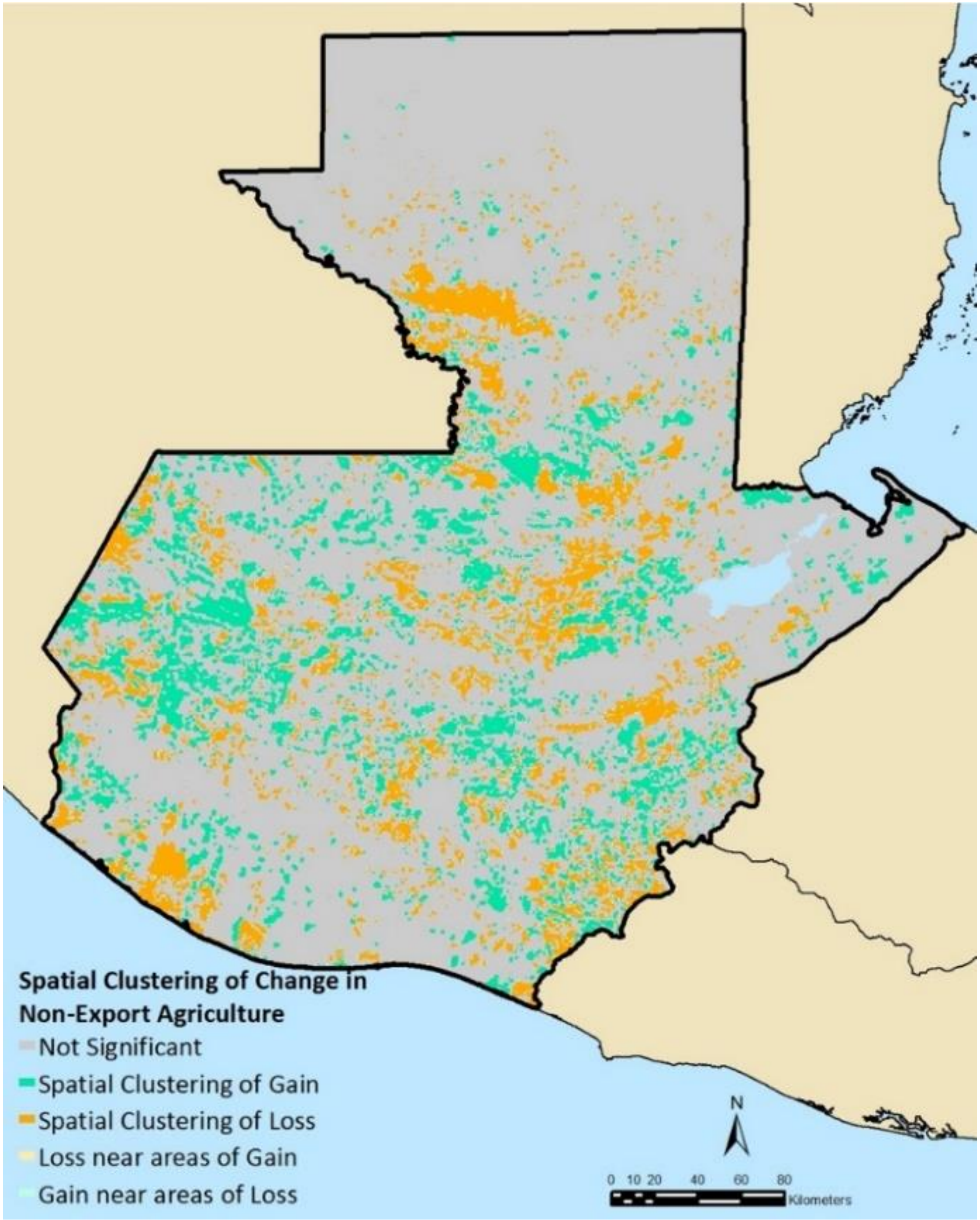


Figure 11: Spatial Clustering of the Change in Non-Export Agriculture 2003-2010



These spatial statistical analyses suggest that the gain and loss of non-export agriculture is a complex and irregular phenomenon that impacts communities differently. A community near one of the large clusters of loss of non-export agriculture will experience a drastic change in the agricultural landscape while a community in one of the static areas is not experiencing significant changes. This means that future analyses should look further into the characteristics of communities most effected. This analysis will look at the national level impacts of the transitions observed.

To assess the national level impacts I ran simple univariate regressions to assess the difference in means of a variety of bioclimatic and biophysical drivers of agricultural productivity between three different land categories. The categories are land that was in non-export agriculture in both 2003 and 2010 (persistent), land that was in non-export agriculture in 2003 but not in 2010 (leaving), and land that was not in non-export agriculture in 2003 but was in 2010 (entering). The process was repeated with the land base in export agriculture to assess how the land in each type of agriculture differed. These results can be seen in tables 8 and 9 respectively.

Table 8: Changes in Drivers of Agricultural Productivity and Risk for the Land base in Non-Export Agriculture.

Temperature Vulnerability

	Mean Elevation (m)	Mean Annual Temperature (C)	% at risk of frost
Persistent	1140 (±6)	21.0 (±0.03)	18.6% (±0.2)
Leaving	832 (±3)	22.5 (±0.02)	8.2% (±0.1)
Entering	1059 (±3)	21.3 (±0.02)	12.1% (±0.2)

Land Quality Vulnerability

	Erosion Potential (Tons/Ha/year)	USDA Land Use Classification	% At risk of landslides
Persistent	175 (±2)	5.1 (±0.01)	6.5% (±0.2)
Leaving	48 (±1)	5.4 (±0.01)	10.5% (±0.2)
Entering	280 (±1)	5.8 (±0.01)	10.9% (±0.2)

Water Vulnerability

	Annual Precipitation (mm)	% At risk of drought	% at risk of flood	Precipitation Seasonality (coefficient of variation)
Persistent	1695 (±6)	27.9% (±0.2)	24.2% (±0.4)	80 (±0.1)
Leaving	1901 (±3)	21.9% (±0.2)	24.9% (±0.2)	72 (±0.1)
Entering	1987 (±3)	22% (±0.2)	14.6% (±0.2)	73 (±0.1)

Aggregate Measure of Vulnerability

	Number of risks (Out of 4 possible)
Persistent	0.771 (±0.004)
Leaving	0.654 (±0.002)
Entering	0.595 (±0.002)

Table 9: Changes in Drivers of Agricultural Productivity and Risk for the Land base in Export Agriculture.

Temperature Vulnerability

	Mean Elevation (m)	Mean Annual Temperature (C)	% at risk of frost
Persistent	598 (±6)	24.4 (±0.03)	0.2% (±0.2)
Leaving	895 (±4)	22.5 (±0.03)	2.6% (±0.2)
Entering	597 (±4)	24.1 (±0.02)	0. 9% (±0.2)

Land Quality Vulnerability

	Erosion Potential (Tons/Ha/year)	USDA Land Use Classification	% At risk of landslides
Persistent	64 (±2)	4.3 (±0.02)	18.9% (±0.2)
Leaving	103 (±1)	5.9 (±0.01)	28.8% (±0.2)
Entering	111 (±1)	4.6 (±0.01)	17.3% (±0.2)

Water Vulnerability

	Annual Precipitation (mm)	% At risk of drought	% at risk of flood	Precipitation Seasonality (coefficient of variation)
Persistent	2631 (±6)	10.4% (±0.4)	36.7% (±0.4)	79 (±0.1)
Leaving	2617 (±4)	4.6% (±0.2)	10.1% (±0.2)	74 (±0.1)
Entering	2287 (±4)	17.1% (±0.2)	36% (±0.2)	76 (±0.1)

Aggregate Measure of Vulnerability

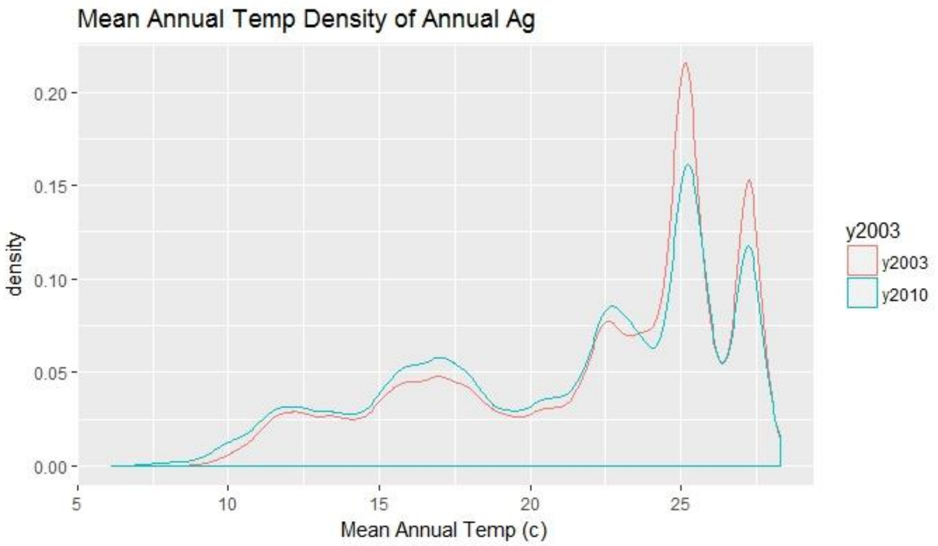
	Number of risks(Out of 4 possible)
Persistent	0.663 (±0.004)
Leaving	0.461(±0.004)
Entering	0.713 (±0.002)

Discussion

This analysis both supports and challenges the narrative of export agriculture in Guatemala. The national level analysis suggests that export agriculture is a main driver of land use change at low elevations while there are other dynamics happening at higher elevations. One way to explain this pattern is that export agriculture is pushing non-export agriculture up the elevation spectrum and thus forcing other land use dynamics in places where export agriculture cannot be practiced. This hypothesis is difficult to test with our current data sets because there is only two points in time. What can be said without qualification is that non-export agriculture is losing ground in the fertile and productive lowlands and is gaining ground in the less productive and more marginalized highland areas. This has several effects on the Guatemalan food system.

The first set of effects that I will discuss are effects that are felt at the national level. First of these relates directly to the elevation effect mentioned before. As you can see in Table 8 there is a 200m difference in the average elevation of the land entering non-export agriculture as opposed to the land leaving non-export agriculture. All agronomists and farmers with whom I discussed differing yields for non-export crops based on the elevation of the cultivation suggested significant losses in productivity as elevation increased. In their minds it was not a linear relationship, but rather a categorical difference between lowland and highland agriculture. The estimates for the difference between the two ranged from a 2-4 fold loss in productivity by cultivating in the highlands rather than the lowlands. These estimates, while not statistically rigorous, indicate the directionality of the yield trend in the absence of more reliable data. There are a several drivers of the relatively lower yield in highland non-export agriculture as compared to lowland cultivation. First is the general lack of heat units in the highlands. Maize and beans, the two main staple crops, are both generally heat loving crops. Maize in particular has growth requirements which are skewed towards warmer temperatures. Botany studies have suggested that maximal growth rates occur near temperatures of 28C[xxxix]. Table 8 shows the land area leaving non-export agriculture has a higher mean annual temperature than either the areas persistent in or entering non- export agriculture. This implies slower overall growth of maize and beans leading to fewer cropping cycles and reduced annual yields. While the apparent changes in mean temperature are small, the implications on the underlying temperature distribution are significant. Figure 12 shows the mean temperature density distribution for non-export agriculture in 2003 and 2010. At temperatures above 23.5C there is a reduction in non-export agriculture while at temperatures below 23.5C there is an increase in non-export agriculture. This shift has implications on overall yield potential for maize and beans cultivated in those areas.

Figure 12: Mean Temperature Density for Non-Export (Annual) Agriculture



The second temperature effect that moving up in elevation has on non-export agriculture in Guatemala is that it increases the chance of a frost risk. None of the main culturally important staple crops are frost resistant and a risk of frost can prevent year round cultivation in areas where it would otherwise be possible. According to Ministry of agriculture frost risk maps only 8.2% of land area that left non-export agriculture was at risk of experiencing a frost while 12.1% of the land that became non-export agriculture is at risk of frost. This means that a higher proportion of non-export agriculture will have to be seasonally left fallow to accommodate that frost risk. This also reduces the overall yield associated with the new footprint of non-export agriculture. Table 9 shows that the elevation, temperature, and frost risk trends are reversed for export agriculture. It is shrinking in areas of high elevation that are more prone to frosts and is expanding in the fertile low-lying areas.

Other than the temperature effects there are also land quality implications due to the changing footprint of non-export agriculture. In this case, as non-export agriculture has moved it has occupied more marginal land which is more prone to erosion. This can be seen by the increase in both the mean erosion potential and by the USDA land use classification. Both of these indices suggest that the land occupied by non-export agriculture is less arable and more prone to erosion. In the long run agriculture practiced on erodible marginal soils will lose soil nutrients and productivity. Despite the fact that non-export agriculture is moving onto more marginal and erodible land it is not more moving onto land that is more prone to landslides. According to the national land slide risk maps produced by the Univerisdad Rafael Landivar the land entering and leaving non-export agriculture is roughly equally prone to landslides. Table 9 shows that the trends are similarly mirrored for export agriculture. It is moving off marginal land (higher USDA classifications and higher landslide risk) and onto land that is more suitable for agriculture and less risky for landslides. Erosion potential is not meaningfully different between land entering and exiting export agriculture.

Water stress is the next major driver of agricultural production that I will address here. Generally there are two ways that water stress is present in

Guatemalan agriculture, floods and droughts. Both of these stresses came up in my conversations with farmers and NGOs in Guatemala but one recurring concern was a gross lack of reliable water planning data. For this analysis I relied heavily on data produces by IARNA from the Universidad Raphael Landivar. First I used their WEAP (Stockholm Environment Institute water planning software) modeled basin level water balance estimates which measure watershed water availability and provide predictions for changes in that availability due to climate change. Unfortunately, since these data were developed at the watershed level they did not distinguish between highland head water regions where water scarcity is a major issue and lowland areas where water is abundant and flooding is a larger concern. Improving the spatial scale of the hydrologic balance data is an important area for future study. In place of the water balance data I used a drought and flood risk map also developed by IARNA which used 30 years of weather and governmental disaster response data to identify areas of the country which were at risk of either drought or flood. These data had a much higher spatial resolution but the drought risk is reported simply as a binary (is at risk or not at risk). For drought, table 8 shows that land persistently in non-export agriculture has the highest proportion at risk of drought (27.9% of the area is at risk) while land entering and leaving is less likely to be at risk of drought (roughly 22% of the area is at risk of drought). As a comparison, only 10.4% of persistently export agriculture area was at risk of drought. This suggest that for drought non-export agriculture is practiced in areas which are risky but that land use changes are not directly increasing that risk. Flood risk shows a different story in that land entering non-export agriculture is markedly less likely to be at risk of flooding (table 8). This is a good trend if we are concerned with natural disaster vulnerability but is probably due to non-export agriculture's shrinking footprint in the fertile lowlands where flood risk is highest.

In addition to the specific risk data developed by IARNA I also calculated the average annual precipitation and precipitation seasonality for each of the three land use categories. Table 8 shows that persistent non-export agriculture has the lowest annual precipitation and the highest seasonality of precipitation, meaning that it gets the lowest overall precipitation and it is not distributed evenly in the year. By these metrics land exiting non-export agriculture is similar to land entering non-export agriculture. This is not entirely surprising because gross precipitation is not really of concern. Guatemala is generally a wet country but the timing of rain and the fact that water is difficult to store in the mountains has a larger impact on productivity. This again suggests that a fine scaled water balance assessment is an important next step in understanding agricultural vulnerability.

All of these assessments were conducted using historical data which suggests increasing vulnerability for the future of non-export agriculture in

Guatemala. Of additional concern in that the regional climate is expected to get significantly warmer and dryer due to global climate change.[xl] While an increase in temperature might make highland areas more amenable to non-export agriculture, a drying of the climate is incredibly concerning. One study suggested that maize yields in Guatemala could decrease by as much at 34% due to climate change[xli] and that areas of the Guatemalan highlands that are currently forested could lose their tree cover due to a drier climate[xlii]. These predictions mean that fine scaled water balance models of Guatemalan agriculture are even more important as policy makers look to the future look to the future.

Some of these impacts of climate change are already being felt. Guatemala has experienced several natural disasters in the past several years that have highlighted the vulnerability of its rural smallholder communities. WFP reports that a 2015 drought brought on by a strong El Nino resulted in 720,000 Guatemalans needing food assistance.[xliii] As climate change increases the variability of weather patterns and the severity of extreme weather, events such as this drought will become more common and marginalized communities will be in even greater need of support.

Limitations and Future Directions

There are several specific limitations of this analysis which I think can be improved upon in future work. First is the issue of data inputs. Tracking specific land use changes with only two time points of data is incredibly challenging. To improve our understanding of what exactly the pressures on non-export agriculture are it would be best to have multiple time steps so that I could trace change patterns through multiple land uses and so that I could correct for single time point misclassification. To generate multiple time points of the land use data would involve running a spectral classification analysis of the landsat remote sensing data in and of itself be an interesting project to take on and this is a potential next step.

A second data limitation is the hydrology and water use data. The spatial unit on these data sets is the watershed which is too large to be of use in this context. There are well developed methodologies for creating water balance rasters at small spatial scales[xliv] but these techniques are also quite intensive and fell outside the scope of this thesis. These fine scaled water balances would improve the assessment of the risk of drought and water stress and would also allow me to assess how changing land use patterns inside a watershed might be impacting local water balances. This is critical because climate change and land use change both impact water availability in independent and additive ways. Developing a fine scaled water balance model for Guatemala is also an important next step.

Apart from the limitations caused by the data itself there was a limitation induced in the processing of the data. I used three different spatial units over the course of this thesis. The smallest was the 25m x 25m raster cell of the land use data. This is the smallest unit possible because of the limitations of the satellite data used to generate the land use data layers. To join this data to other data layers with different spatial units I treated the 25m x 25m cells as points and sample other data layers at those points. While this plan has the advantage of the highest possible spatial resolution it also created a data set that was too large for me to handle with my programming skills. As such a random 2% sample of the points was selected to get a picture of what was happening in Guatemala. This was used for all of the points analysis. Replicating this analysis with the entire data set is a critical next step to explore more possible nuance that will only be apparent with the entire data set.

The largest spatial unit that I used was the entire country of Guatemala. I did this because there are interesting questions to be asked about what is happening at the national level, but as you can see in figures 10 and 11 there are interesting and important dynamics around land use change that are happening at smaller spatial scales. An important future direction for this work is to look at the impacts at the community level.

Connections to Policy

It is a common argument in agricultural development circles that there are pro poor methodologies for developing export agriculture so that it can improve cash income and food security of smallholder farmers. This is undoubtedly true in ideal situations but is unlikely to be the case with the expansion of export agriculture that we are seeing in Guatemala. This is for a variety of reasons. The most notable is that the expansion is heavily in bananas, African palm, and sugar which are crops whose market structure and labor demands are usually not aligned with small scale farmers while crops such as coffee, whose production and marketing can be pro-poor if designed correctly, are actually decreasing in acreage and productivity.

Table 10: Gain and Loss of specific export crops.

		n		Percent of Country		Percent Change
		2003	2010	2003	2010	
Non-Export Agriculture		452265	389439	13.0%	11.2%	-13.9%
Export Agriculture		305320	307941	8.8%	8.9%	0.9%
	Banana	9780	15858	0.3%	0.5%	62.1%
	African Palm	14874	35385	0.4%	1.0%	137.9%
	Coffee	195153	144860	5.6%	4.2%	-25.8%
	Sugar	85513	111838	2.5%	3.2%	30.8%

If we then accept the argument that the current expansion of export agriculture is not directly itself pro poor the next question is whether there are other policies in place to address the concerns of smallholder farmers so that they are able to weather the food price shocks that are likely to increase as a result of these macro trends in Guatemalan land use. To asses that I can look at the 2008 food price spike as an example of how the Guatemalan Government responded and what was the effectiveness of that response. There were three aspects to Guatemala's social safety net program as a response to the 2008 food price spike. They included a school feeding program, a fertilizer subsidy, and a conditional cash transfer[xlv]. Very little data is available about the school feeding program and the fertilizer subsidy. What information is available are observations made by researchers such as "casual observations suggest only partial implementation, weak targeting of fertilizer subsidies on smallholder farmers, and lack of complementary technical assistance to help make good use of additional inputs."[xlvi] This observation is in direct accordance with my personal observations from 2013-2015. In those years government subsidized fertilizer often arrived too late for the planning season or was horded by a political party and doled out for favors rather than to program beneficiaries. Because of the lack of actual data on the impacts of these programs there is no way to know what their impact was. Yet, according to Guatemala's own statistics bureau rural poverty has worsened since the implementation of these programs[xlvii] suggesting that at the very least they are insufficient to address the needs of rural communities.

The conditional cash transfer program was called Mi Familia Progresa. It provided 150Q ($25ish) per month to families for their participation in either health or nutrition activities. There were opportunities for additional money if children were kept in school[xlviii]. In 2010 it was reaching 3,253,635 people, which was 24% of the total population of the country.[xlix] Very little evaluation has been published about this program, in fact a search of Web of Science returned only three results for “Mi Familia Progresa”. None of them was a formal econometric evaluation and all three focused on the politicization of the program. The politicization of the food price crisis and any response to it in Guatemala has been part of the problem from the start. 2008 was an election year in Guatemala and the incoming president was slow to react to the crisis as it was unfolding[l]. In addition the “Mi Familia Progresa” program, once established, became closely linked to the sitting president Alvaro Colom and his political party which used the program to buy votes and benefit its supporters[li]. The transparency of this program became such a significant political issue that a mere 2 years after its initiation, opposition parties successfully sued to have its list of beneficiaries made public for audit[lii]. This political drama more than likely contributed to the defeat of Colom’s party in the next election in 2012 when the right wing party “Partido Patriota” took over. The incoming president suspended Mi Familia Progresa, changed the name, and then restarted the program using it in much the same way that Colom’s party had[liii]. It is therefore unsurprising that researchers have found Mi Familia Progresa, and the subsequent conditional cash transfers that have replaced it, to have been ineffective at addressing the poverty increases caused by the food price crisis in Guatemala[liv].

Guatemalan food prices fell in late 2008 and remained relatively low until 2011. Since that time retail prices for maize and wheat products have risen steadily and alarmingly[lv]. A particularly concerning trend is the continued increase in retail prices despite falling wholesale prices. The reason for this trend is not immediately apparent. When taken in conjunction with the Guatemalan Government's failed rural development plans, rising food costs are clearly having impacts on the country. Poverty and social unrest have been increasing since 2008 and there have been no structural changes to reduce the vulnerability of the poor, particularly the rural poor, to current or future price increases. The analysis presented here indicates that changing land use patterns in non-export agriculture is increasing the likelihood that food prices will increase and be volatile with the international market.

The photo on the cover page of this paper was taken at a march in the Maya Mam community of Concepcion Tutuapa in the Department of San Marcos. The sign reads "*No a la los altos costos de la canasta basica*" "No to the high costs of the basic food basket." That march was part of a nationwide movement that happened in the fall of 2014 in response to the passing of legislation allowing the enforcement of agricultural intellectual property rights in Guatemala. The rural smallholders demonstrating in the picture were afraid that they would lose access to their ancestral maize varieties as international companies imported genetically engineered crops. In reality, the protest was more of a reaction against the governments general lack of a coherent rural and agricultural development plan. The government at the time was headed by a right-wing party, Partido Patriota, that was known for promoting the expansion of mining and hydroelectric power generation as its rural development strategy, effectively continuing the marginalization of smallholder farmers by forcing them to sell their land to make way for these industries.

In August of 2015 Otto Perez Molina, the ruling Partido Patriota president, was forced from office by a massive wave of demonstrations. The focus of the demonstrations was blatant and pervasive corruption in his regime that extended all the way to his office. In the ensuing election Guatemala chose a reformist candidate and former comedian, Jimmy Morales. In May of 2016 the Guatemalan Ministrio de Agricultura, Ganaderia, y Alimentacion published a “Gran Plan Nacional Agropecuario” or Grand National Plan for Agriculture.”[lvi] This plan was an exciting opportunity for Guatemala to address its rural development issues in a coherent way and possibly build resilience in its most impoverished communities. A close reading of this plan reveals that it is a continuation of the agricultural path that Guatemala has been on for the past 30 years, namely a movement towards the production of specialty crops for the export market rather than grains and staples for the domestic market. This is not necessarily a problem given the fact that there are ways to develop an export agriculture market with a pro-poor alignment, but the plan as published does not provide sufficient detail to evaluate if that is how it will develop. During my visit in 2017 all of the NGO partners with whom I spoke mentioned a lack of coherence in rural development as a problem they faced. Again, these interviews were limited to my professional network in San Marcos but at the very least the indicate there has not been a correction of course since the end of the Partido Patriota period.

Conclusion

My analysis shows that Guatemala's non-export agriculture is shifting onto land that is more marginal, increasingly exposed to climate change, and generally less productive. The opposite is observed for export production which is moving onto less marginal land in less climate sensitive regions where it is expected to be highly productive. In some contexts, particularly in the lowest elevation areas, export agriculture is directly replacing non-export agriculture on the landscape. This trend is in line with the decades old policies of the Guatemalan government to promote export agriculture and to import food for its people. This pattern has been shown to increase the exposure of poor households in Guatemala to international food price spikes which the Guatemalan government is ill equipped to address. Action is needed to promote pro-poor non-export agriculture and rural livelihoods in Guatemala to strengthen the food system and reduce its vulnerability to food price spikes such as what happened in 2008.

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