AGRICULTURAL DRIVERS OF LAND USE CHANGE IN PARAGUAY

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Executive Summary

In recent years, Paraguay has become one of the top five countries with the highest acceleration in deforestation rates. Between 2000 and 2015, Paraguay lost 4.8 million hectares of forest, equal to 19.7 percent of its tree-covered area. The two main drivers of deforestation in Paraguay are land clearing for cattle pastures and for soybean farms. Agriculture and ranching are encroaching on the country's unique ecosystems, including the Gran Chaco in the West and Paraguay's remaining portions of the biodiverse Atlantic forest in the East.

Since 2000, Paraguay's beef and soybean output have each increased by close to 2.5-fold. Despite its relatively small size, the country now ranks as the world's fourth leading exporter of soybeans and the eighth leading exporter of beef. Paraguay's contribution to world food supplies is projected to increase.

This study presents a statistical and spatial analysis of Paraguay's changing land use patterns. I review the trends that led Paraguay to become an expanding soybean frontier within the context of the Latin American soy boom that started in the 1970s. I use remotely sensed data and governmental statistics to explore land use change patterns in Paraguay on a national and sub-national basis. I address the following questions:

- What land use change is driving deforestation in Paraguay?
- What is the relationship between cattle ranching and soybean farming in Paraguay?
- What do trends indicate for future land use change in Paraguay?

I examine governmental policies and voluntary agreements affecting agriculture and deforestation in Paraguay using a literature review and background interviews with analysts and stakeholders in soybean supply chains. I spatially analyze maps produced by the Round Table on Responsible Soy to determine the extent of future land in Paraguay that could be developed. I also synthesize previous research conducted on the soybean frontiers in Brazil.

Results indicate that soybean land area and cattle herd size in Paraguay are strongly correlated, particularly in the decade leading up to 2016, when both soybean harvested area and cattle herd size were growing at nearly the same rate, over 3 percent annually. There is a strong correlation between expanding soybean farms in Paraguay's Eastern Region and expanding cattle herds in the Western Region. This corroborates the assertion that ranchers in Paraguay's Eastern Region are selling pastureland in the East to soybean farmers and clearing forested land

in the Western Region for new pasture. Almost no soy has been planted in the Western Region; however, research under way may make western soybean expansion a possibility in the future.

Both cattle herd size and soybean harvested area exhibit a strong negative correlation with deforestation in Paraguay at national, regional, and departmental levels. As soybean fields and cattle ranches grow, forested areas shrink.

Further research is required to determine the effects of economic trends and policy on deforestation in Paraguay. There is a possibility that stricter anti-deforestation policies and voluntary agreements among land users in Brazil could increase deforestation pressures in Paraguay. Evidence exists that Brazil may have decoupled agricultural expansion and deforestation, at least in the Amazon region. Whether Paraguay can follow a similar path of decoupling remains to be seen.

Overall, growing international demand for both beef and soybeans threatens Paraguay's remaining forests. Much of the Atlantic forest in the Eastern Region has already been cleared, and the remaining portions are severely fragmented. The Chaco in the Western Region still contains extensive uninterrupted habitat, but its longevity depends on national policies—both their implementation and enforcement—and the actions of a relatively small group of players in global commodity supply chains.

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Introduction

Agricultural expansion has led to the loss of natural forests and biodiverse ecosystems around the world. As the world's farmers produce more food to feed a global population growing by over 80 million people each year (U.N. Population Division, 2016), pressures on such natural systems are set to increase.

In a review of the world's potentially farmable land, Lambin and Meyfroidt (2011) found that of the world's 13.3 billion hectares, around 4 billion hectares were "suitable for rain-fed agriculture," with the largest concentrations in Latin America. Groups like the Inter-American Development Bank and the Global Harvest Initiative—a private sector consortium of major agribusiness companies, are looking at Latin America as the "next global breadbasket" (Nakata & Zeigler, 2014). In 2017, agriculture ministers of six South American countries, Argentina, Brazil, Paraguay, Uruguay, Chile, and Bolivia, jointly issue a ministerial declaration through the World Economic Forum affirming the importance of Latin American agriculture in feeding the world. The ministers expressed the desire to ramp up agricultural production throughout Latin America, noting that the region currently produces about 11 percent of the world's food and is home to one quarter of the world's arable land and one third of the world's freshwater resources (Tedeneke, 2017).

Yet the forests that regulate hydrological flows are under threat. Commercial agriculture is considered to be responsible for nearly 70 percent of recent deforestation in Latin America (FAO, 2016). Between 2000 and 2010, four South American countries experienced net gains in agricultural area and net losses in forest area: Argentina, Brazil, Paraguay, and Peru (FAO, 2016). Three of these countries, Argentina, Brazil, and Paraguay (FAO, 2017; USDA, 2017), are major frontiers for expanding production of soybeans, which now occupy more land in the Western Hemisphere than any other crop (FAO, 2017; USDA, 2017). These three countries also are major producers of beef (USDA, 2017).

This study focuses on the relationship between deforestation and agriculture in Paraguay, which is the least-studied of the three major South American soybean producers and has the fastest accelerating deforestation rate (Petersen, Sizer, Hansen, Potapov, & Thau, 2015). It begins by examining the expansion of soybeans in the Western Hemisphere and then uses Paraguay as a case study to address the following questions:

- What land use change is driving deforestation in Paraguay?
- What is the relationship between cattle ranching and soybean farming in Paraguay?
- What do trends indicate for future land use change in Paraguay?

Background

The Soybean Moves West

The soybean was domesticated in China over 3,000 years ago (Hymowitz & Shurtleff, 2005). It reached the United States in the mid-1700s but languished as an ornamental crop for nearly 200 years until World War II (Hymowitz & Harlan, 1983). Shortages of dairy and animal fats on the home front prompted American food processors to mix plant oils with animal fats in margarine blends, but soybean oil's fishy odor and foul taste prohibited it from being used in large amounts (Dutton, 1977; Dutton, Lancaster, Evans, & Cowan, 1951; Dutton, Moser, & Cowan, 1947). Techniques learned from investigating bombed out food processing plants in Germany allowed American food processors to transform soybean oil into an important commodity (Dutton, 1977).

By the middle of the twentieth century, the soybean had become a valuable crop, both for its oil and as livestock feed, with the United States the world's major supplier (Dutton, 1977; Dutton et al., 1947). The soybean is now the world's highest valued agricultural export (see Appendix A) (FAO, 2017).

U.S. soy acreage expanded from 4 million hectares in the mid-1900s to over 33 million hectares in 2016 (USDA, 2016). Soy is an American agricultural staple; soybean fields cover 74 percent more acreage than wheat, and soybean production rivals corn (USDA, 2016). Iowa, with some of the most fertile soils on the planet, is the world's soy powerhouse: each year Iowa produces more soybeans than all of China while also growing more grain than Canada (USDA, 2016, 2017).

In 1965, U.S. farmers harvested 23 million tons of soybeans, three quarters of the global output of roughly 30 million tons (USDA, 2017). Now the United States produces over 100 million tons of soybeans each year, yet its share of the global harvest has dropped to a third. This is because of the rapid rise of the soybean in the two players that together supply half the world soy market: Brazil and Argentina (USDA, 2017).

Soybeans in South America

The South American soybean expansion didn't start until after 1973. At that time, the United States was the world's largest soy producer and exporter, and Japan was the largest buyer. Rising U.S. domestic food prices prompted President Richard Nixon's administration to restrict soybean exports. The ban was short-lived, but it encouraged Japan to seek out other sources for exports. The country offered financial support in both Argentina and Brazil that helped seed an expanding soy industry (Conlon, 2009; McVey, 2000; Oliveira, 2016).

Today the soybean dominates agricultural crop area in the Western Hemisphere (FAO, 2017; USDA, 2017). Northern Argentina is practically a soy monoculture. Nearly 20 million hectares were devoted to the bean countrywide in 2016, mostly on the fertile plains known as the pampas. This is quadruple the area used for corn or wheat, the next most prevalent crops (FAO, 2017; USDA, 2017). The presidential administration that took office in Argentina in late 2015 reduced Argentine agricultural export tariffs that had been in place since 2000 and disincentivized soybean exports. Following this move, the area planted in soy in Argentina is projected to increase (Costa, 2016; O'Donoghue & Hansen, 2017).

In Brazil, soy covered 34 million hectares in 2016, twice the country's area planted in wheat and three times the area in sugarcane (FAO, 2017; USDA, 2017). Initially agronomists did not believe that the acidic soils of the Brazilian *cerrado*—the biologically diverse savanna and woodland ecosystem that covers much of the countryside—were rich enough to withstand largescale commercial farming. The discovery that adding lime to the land could counteract the acidity allowed the *cerrado* to become a major source of soybeans for the world (Scheid Lopes, 1996).

Since 2001, farmers have plowed about half of Brazil's *cerrado* to plant soybeans (Gibbs et al., 2015; Spera, Galford, Coe, Macedo, & Mustard, 2016). Soybeans have also made their way into the Brazilian Amazon rainforest, one of the world's largest and most biodiverse forest ecosystems in two ways: One, over 2 million hectares of Brazil's Amazon rainforest have been converted to soy farms (Gibbs et al., 2016; Gibbs et al., 2015). And two, soybean farms have displaced cattle ranchers into forest boundaries (Arima, Richards, Walker, & Caldas, 2011).

Direct rainforest loss to the soybean in Brazil appears to have slowed following the introduction of the Soy Moratorium, a voluntary ban among major soybean traders on purchasing soy from Amazonian land deforested after mid-2006 (Macedo et al., 2012). An analysis by Gibbs

et al. (2016) indicates that the Soy Moratorium has been more successful at curbing Amazonian deforestation than domestic Brazilian policies. The moratorium was set to expire in 2016, but in May of that year parties decided to extend it indefinitely (Adario, 2016).

At question is whether Brazilian land use policies and voluntary agreements like the Soy Moratorium have resulted in increased deforestation into other areas, including in the Brazilian *cerrado* and in neighboring Paraguay. The following case study reviews the soybean expansion in Paraguay. It also examines soy's relationship with cattle ranching, the other major agricultural activity.

Study Site: Paraguay

Paraguay Geography

Paraguay is a landlocked California-sized country covering nearly 40.7 million hectares in the heart of South America (Molinas M., 2012). It is bordered by Brazil, Argentina, and Bolivia, and split into two regions by the Paraguay River (see Figure 1, and political map, Appendix B).

Figure 1. Map of Paraguay Ecoregions. Source: Clark (2013).

Rainfall diminishes from east to west, from over 1,600 mm per year for most of the Eastern Region to less than 600 mm per year in the far Western Chaco (see Appendix C) (MAG, 2017). A full 97 percent of the country's 6.8 million people live in the 14 departments that make up the country's wetter Eastern Region, known in Spanish as the Región Oriental (DGEEC, 2015). The Eastern Region contains Paraguay's share of the biodiverse Atlantic forest ecoregion, which formerly extended from northeastern Brazil to northern Argentina (Huang et al., 2007). Considered a biodiversity hotspot, the Atlantic forest contains some 20,000 plant species, half of which occupied land in Paraguay. Over 84 percent of the Atlantic forest in Brazil has been converted to other uses, including urbanization and agriculture, and remaining patches are small, with over 80 percent less than 50 hectares in size (Ribeiro, Metzger, Martensen, Ponzoni, & Hirota, 2009). According to Huang et al. (2007), Paraguay's Atlantic forest was largely intact as recently as the 1940s, but by the early 2000s, over 75 percent was lost.

The Western Region, or Región Occidental contains three departments that make up 60 percent of Paraguay's land area. Known as the Chaco after the predominant landscape, or informally called "green hell," it largely made up of dense dry woodlands, heavy with thorn trees and difficult to penetrate. Other ecosystems present in the Chaco include shrub-filled steppe, palm forests, and even wetlands in the more humid parts. Some 80 percent of the Chaco's annual rainfall arrives in summer (Glatzle & Stosiek, 2006).

The Paraguayan Chaco is part of the 70-million hectares Gran Chaco and Chiquitano woodlands, which are "one of the largest remaining continuous extents of native vegetation in South America," second to the Amazon in their expanse (de Waroux, Garrett, Heilmayr, & Lambin, 2016). They occupy land area in Paraguay, Argentina, and Bolivia. The name "Gran Chaco" signifies "productive hunting grounds" to the native Guaraní people, with large native mammals including guanacos, tapirs, deer, jaguar, and giant armadillo (Riveros, undated).

Agriculture in Paraguay

Paraguay is an important agricultural player on the world scene. The country now ranks as the world's fourth leading exporter of soybeans and the eighth leading exporter of beef (see Appendix D) (USDA, 2017). Agriculture drives the economy, contributing a quarter of Paraguay's gross domestic product (GDP), 26.5 percent of national employment, and 90 percent of exports (MAG, 2016; Molinas M., 2012). After electricity, Paraguay's top exports by value

are soybeans and soybean products, totaling $3.1 billion USD, and beef and leather, totaling $1.2 billion USD (see Table 1) (Comtrade, 2017).

Paraguay Exports Exceeding $50 Million USD in Value, 2016		
Product	Weight	Value
	Thousand Metric Tons	Million USD
Electricity	n.a.	2,132
Soybeans	**5,381**	**1,816**
Soybean Meal	**2,460**	**850**
Beef, frozen	**166**	**582**
Beef, fresh	**111**	**519**
Soybean Oil	**702**	**463**
Corn	2,160	339
Rice	598	196
Electrical Wiring	6	149
Wheat	806	147
Leather and Hides	**49**	**116**
Sugar	111	76
Plastic Packaging	39	64
Gold: semi-manufactured	0.0019	61

Table 1. Paraguay Exports Exceeding $50 Million USD in Value, 2016. Source: UN Comtrade (2017).

Agricultural land has historically been concentrated in Paraguay's Eastern Region, close to the Paraguay River. Two laws passed in 1963 promoted the colonization of lands further afield: Law 852, which created the Instituto de Bienestar Rural (Institute of Rural Welfare) and Law 854, which established the Agrarian Statute. The Agrarian Statute formalized the "March toward the East": the moving out from the central parts of the country to develop eastern agricultural colonies. It also attempted to encourage development of the Chaco. Settlers could own up to 10,000 hectares in the Eastern Region and 20,000 hectares in the Chaco without facing taxes. Between 1960 and 1980, the number of rural lots increased from 130,433 to 258,281 (Hanratty & Meditz, 1988; Molinas M., 2012).

Two agricultural censuses have been carried out since the end of 35-years of military rule by General Alfredo Stroessner in 1989, one in 1991 and one in 2008. They indicate the trend of farm consolidation: fewer farmers own farms, and the farms are larger than before. By 1991, Paraguay was home to 307,221 farms and ranches occupying 23.82 million hectares nationwide. By 2008, the number of farms and ranches had shrunk 5.7 percent to 289,649, while the area under agriculture and grazing grew to 31.09 million hectares (MAG, 2008). The majority of

farms, 63.3 percent in 2008, were smallholdings of fewer than 10 hectares, amounting to 2.8 percent of the total agricultural area. Just 1.6 percent of the farms were larger than 1,000 hectares, but together they occupied 79.0 percent of the total agricultural area (MAG, 2008).

In 1991, farmland was about evenly divided between the Eastern Region and the Western Region, at close to 12 million hectares of farmland on either side of the Paraguay River. By 2008, eastern farmland grew by 17.6 percent to 13.4 million hectares. Western farmland grew faster, by 42.4 percent to 17.6 million hectares. Western farms are significantly larger; in 2008 the average farmholding in the East was 107 hectares; in the West it was twenty times larger: 2,155 hectares. Cattle dominates holdings in the West; soybeans dominate in the East (MAG, 2008).

Data Collection and Methods of Analysis

This study analyzes patterns of agricultural expansion and deforestation in Paraguay. To understand the context surrounding the research topic, I conducted informal background interviews with academics, with government analysts, with representatives of stakeholders in the soy supply chain, and with staff members of non-governmental organizations. My literature review covered peer-reviewed research in the Web of Science as well as grey literature from government agencies, non-governmental organization, and funding agencies. I used information from these sources to compile a table of key policies and laws in Paraguay related to agriculture and forests.

I also used interviews and published material to examine the potential analogies or lessons from Brazil, which preceded Paraguay into large scale soybean expansion.

I collected historical time series statistical data on cattle stocks and crop production, area, and yield at the national and department-levels for Paraguay to compare with remotely-sensed data on forest cover, discussed in the following sections.

Agriculture

To determine Paraguay's top agricultural products and trends over time, I analyzed national production, area, yield, and trade data from the U.S. Department of Agriculture's Foreign Agriculture Service (USDA, 2017), the U.N. Food and Agriculture Organization (FAO, 2017), and the Government of Paraguay (Ministerio de Agricultura y Ganaderia, various years). I also reviewed trade data from Comtrade (2017).

I compiled subnational data for crops covering at least 10,000 hectares in 2016 from Paraguay's Agricultural Censuses (2008 and 1991) and statistical compilations by Paraguay's Ministry of Agriculture and Livestock (Ministerio de Agricultura y Ganaderia, various years). Determining that soybeans occupy the largest extent of cropland in Paraguay, I focused analysis on soybean harvested area.

Soybean harvested area is larger than the physical land area covered by soybeans, because in some areas two soybean crops are planted on the same land during the course of a year (Sandoval, 2016). The first crop of the year (called *zafra*) is planted in September and October, and the second crop (*zafrina*) is planted in January and February. The USDA agricultural attaché (Sandoval, 2016) notes that Paraguayan farmers first started the "agronomically unwise" practice of double cropping soybeans after soybeans in the 2011/2012 crop season. While double cropping would somewhat inflate harvested area measurements as compared to a direct analysis of land area, it is not expected to substantially affect the results of this analysis.[1]

Paraguay's Agricultural Censuses (2008 and 1991) and annual statistical compilations by Paraguay's Ministry of Agriculture and Livestock (Ministerio de Agricultura y Ganaderia, various years) also provided annual cattle herd sizes for each of Paraguay's 17 departments, which I used as a proxy for pasture area.

Certain studies, e.g., the examination by Barona, Ramankutty, Hyman, and Coomes (2010) of cattle, soy, and deforestation southern Brazil, use data on cattle herd size to estimate cattle pasture area. The conversion from cattle stock numbers to pasture area are based on typical stocking patterns for a given geographical area, generally reflecting increasing stocking density over time. Such cattle stock density data is not readily available in official Paraguay government statistics. Given the difference in the landscapes and rainfall in eastern and western Paraguay, cattle stocking rates vary geographically. Glatzle and Stosiek (2006) note that "Stocking densities on range, bush land and sown pastures vary from about 10 (Alto Paraguay) to 0.2 hectares (Central Department) per head of cattle, depending on the agro-ecological conditions

[1] The USDA attaché office (Sandoval, 2016) projects that the practice of planting a second crop of soy will decline and corn will rotate in more frequently. It also notes that "there is some speculation among industry observers that the government could intervene and restrict *zafrina* soybean production. However, this is still only speculation and no formal plan or intention has surfaced." Brazil places stricter limits than Paraguay on the timing of soybean planting and double cropping, largely to curtail the spread of crop disease by giving fields soy-free time.

and feed and supplement availability." I also expect that stocking rates vary temporally, as pasture management techniques have evolved. Because of the uncertainty regarding stocking practices, I analyzed cattle stock numbers rather than converting stock numbers to pasture area.

Forest Cover

To examine the loss of forest over time within each of Paraguay's departments, I used tree-covered area estimates from remotely sensed data. Huang et al. (2009) estimated forest coverage by department in Paraguay for the years around 1990 and the years around 2000 based on Landsat observations. Additional detail on Paraguay's Atlantic forest, with Landsat data from the early 1970s, came from Huang et al. (2007). Because of changes in satellite imaging technology and processing techniques, these were not directly comparable to the latest available satellite assessment from Hansen et al. (2017), but were used to discern general trends.

The most recent forested area and tree cover loss estimates for Paraguay came from Hansen et al. (2017) via Global Forest Watch (GFW), an updated and re-processed version of the maps described in Hansen et al. (2013). The data are from Landsat satellite imagery of the earth's land areas at a 30 meter by 30 meter resolution. They indicate annual tree cover loss for the years 2001 to 2015, over a year-2000 baseline. I subtracted annual tree cover loss estimates from the estimated tree cover extent for the year 2000 to derive the forested area in each department for the years 2001 to 2015.

In the dataset, trees are defined as vegetation greater than 5 meters tall. For this analysis, I consider forest those areas with tree cover of at least 30 percent. This is a common threshold to use for semi-arid forest cover. It captures the Chaco woodlands, which have sparser tree cover than the wetter Atlantic forest. The MODIS Vegetation Continuous Field of tree cover dataset indicates that while the Atlantic forest ecoregion has roughly 70 to 80 percent canopy cover, the Chaco woodland has a wider distribution from roughly 35 to 55 percent canopy cover (Huang et al., 2009). Furthermore, 30 percent is also the minimum density for tree reserve requirements on new properties in the Chaco under the 2011 Resolution 1136, articles 2 and 3 (de Waroux et al., 2016).

Land Use Conversion

To better understand the land use change patterns, I qualitatively assessed spatial patterns based on remotely sensed images in Google Earth Engine (Google Earth Engine Team, 2017

(update of 2015 product)). Google Earth Engine shows a composite of cloud-free images from Landsat and Sentinel-2 satellites for each year since 1984.

Responsible Soy Expansion

To examine prospects for future soybean expansion in Paraguay, I analyzed a 60-meter resolution map of Paraguay's potential "responsible" soy area (see Figure 2) developed by the Round Table on Responsible Soy (RTRS, 2015). According to RTRS (undated), "The Maps and Guides for Responsible Soy Expansion were developed in view of the expected increase of soy production into new areas, including High Conservation Value Areas. If this would take place without regards for the environment, it could badly affect natural ecosystems by causing deforestation, draining wetlands, advancing on natural grasslands, affecting local communities' rights and degrading cultural values, among other negative impacts." The maps characterize land in one of five categories:

- No expansion allowed (per stakeholder agreement regarding critical biodiversity hotspots),
- Expansion potentially allowed after High Conservation Value Areas (HCVA) assessment,
- Responsible expansion as per legislation,
- No land available for expansion,
- Areas deforested after 2009.

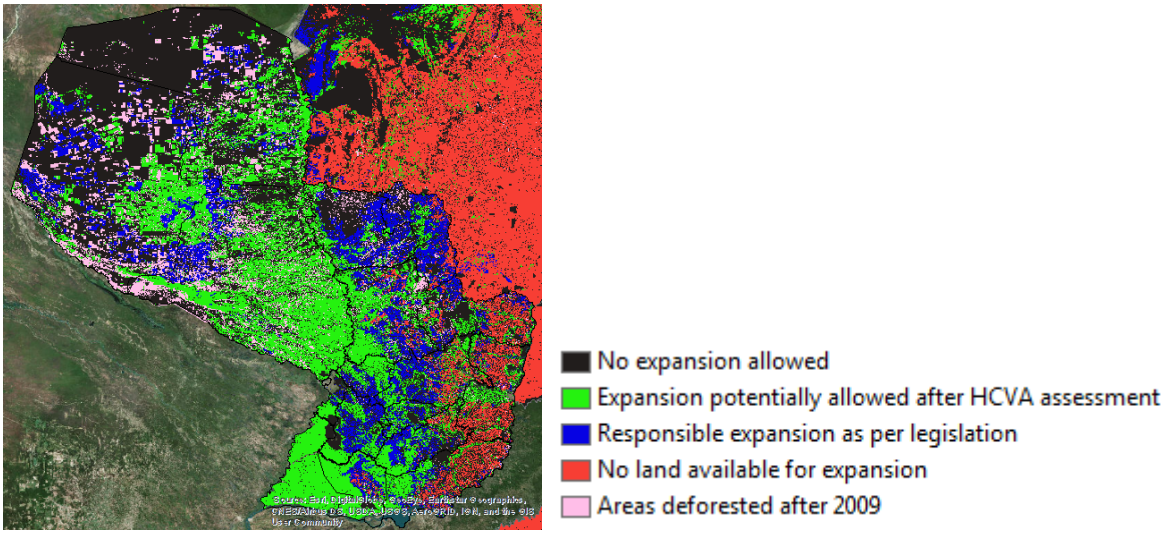


Figure 2. Map of RTRS Designations in Paraguay. Source: RTRS (2015).

I processed the RTRS maps in ArcMap with shapefiles (Global Administrative Areas, ADM_1) from Hijmans (2015) to determine the area covered by each category in each of Paraguay's departments.

I combined the agricultural and forestry data for analysis in Tableau, and also compared historical trends to RTRS maps. To determine the highest possible amount of land that could be "sustainably" developed in each department under the RTRS, I added together the area with potential expansion after HCVA assessment and the area where legislation allows for responsible expansion.

Results

This section reviews the research findings on agriculture and forests, first separately and then together.

Agriculture

Soybeans dominate Paraguayan agriculture and occupy the largest area of any crops in the country (See Figure 3). Soybean production began to scale up in Paraguay in the late 1970s, and by 1978 the soybean harvest overtook corn to become the country's leading crop (see Appendix E) (USDA, 2017). Afterwards the gap between soybeans and all other crops widened. In 2016 soybeans were harvested on 3.5 million hectares in 2016 (including double cropping), out of an estimated 4.8 million hectares of arable land (FAO, 2017; USDA, 2017). Paraguay's 2016 soy harvest was estimated at 9.2 million metric tons, a ten-fold increase above production in the early 1990s.

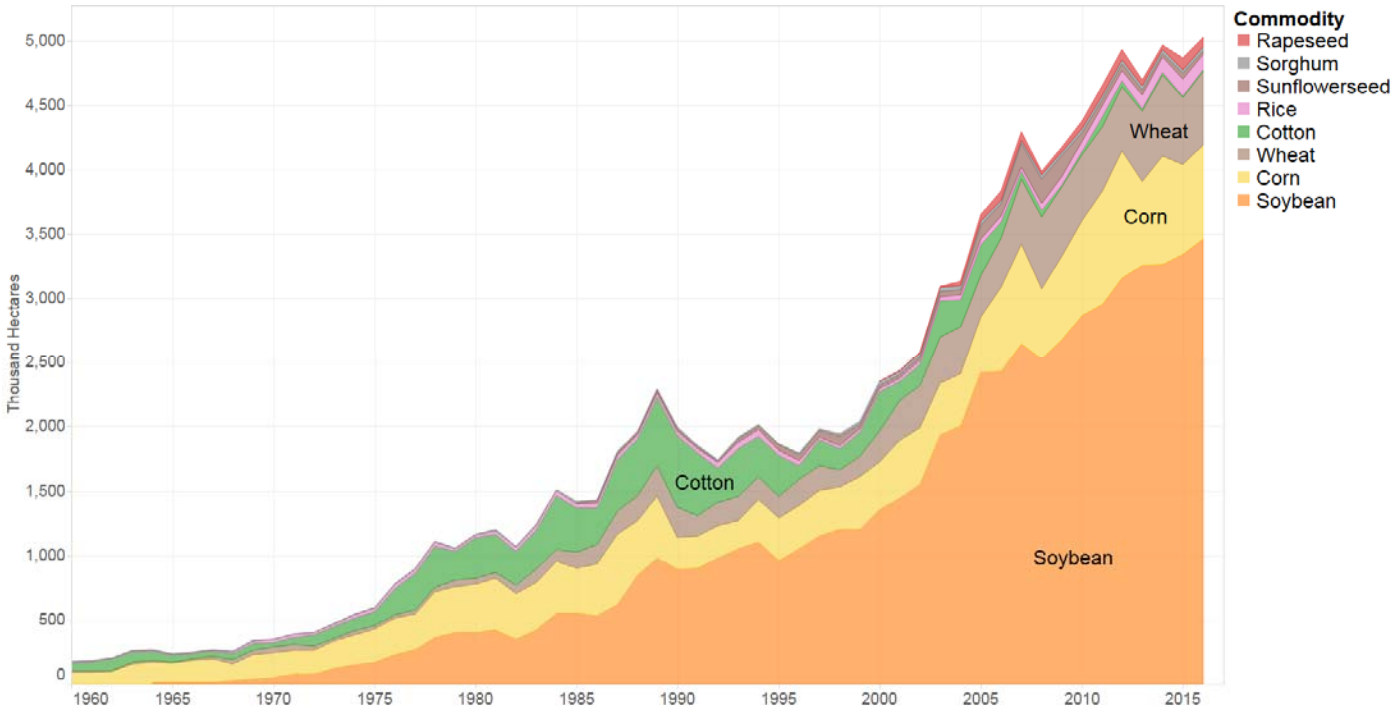


Figure 3. Harvested Area for Major Crops in Paraguay, 1960–2016. Source: USDA (2017).

Soybeans are used domestically in Paraguay in animal feed rations, largely for pigs and poultry, as cattle are still primarily pasture-fed (Sandoval, 2016; USDA, 2017). Close to 5.4 million tons, or 58.9 percent, of the 2016 harvest was exported as whole beans. Nearly all of the remaining beans were also destined for the export market after processing in domestic crushing facilities into soybean meal and soybean oil (see Appendix F) (USDA, 2017).

Major soy export destinations[2] included Russia, Turkey, Argentina, Brazil, and countries in the European Union (see Appendix G) (Comtrade, 2017). Research from the Stockholm Environment Institute and the Global Canopy Programme (SEI & GCP, 2017) indicate that the top companies exporting soy from Paraguay in 2016 including the four largest U.S.- and European-based agribusiness corporations, ADM, Bunge, Cargill, and Louis Dryfus (via Mercantil Comercial S.A.) (See Appendix H).

[2] While Paraguay does not engage in direct trade with China—the world's leading soy importer—because the Paraguayan government has diplomatic relations with Taiwan, interviews indicate that soybeans sent from Paraguay to Argentina and Brazil indirectly make their way to China. China drives global soybean demand, taking in over 60 percent of all soybeans traded on world markets to feed its growing hog farm operations and other livestock and poultry (USDA, 2017).

Pasture for grazing cattle is the other dominant use of land in Paraguay. National stocks grew from 4.3 million head of cattle in 1970 to 8–9 million head by the early 1990s. From 1995 to 2005, stock growth was relatively flat. Growth picked up after 2006, with the national herd size exceeding 14 million head by 2014 (see Figure 4) (FAO, 2017).

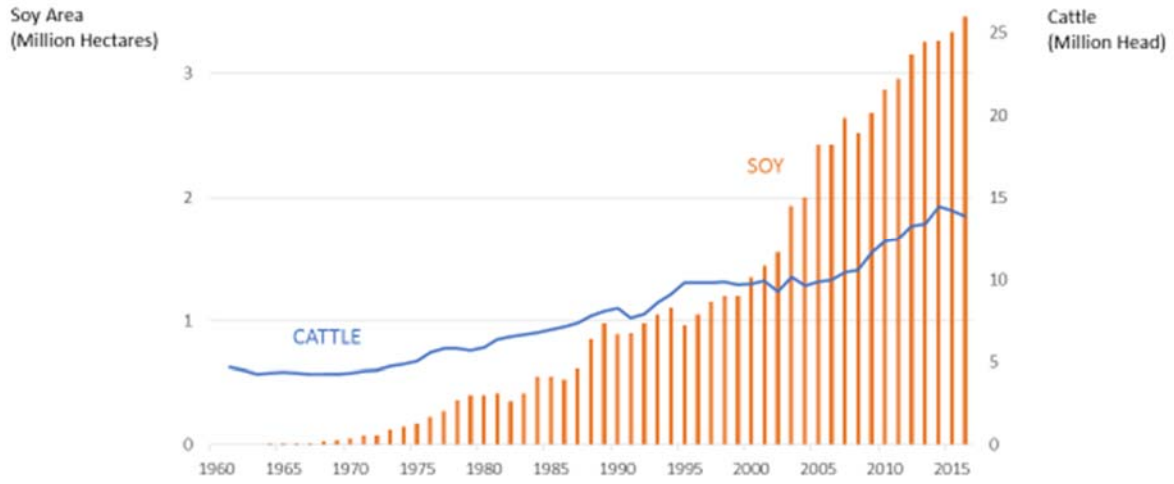


Figure 4. Soybean Harvested Area and Cattle Herd Size in Paraguay, 1961–2016. Source: USDA (2017); MAG (2016).

Comparing the growth of soybeans and cattle between the mid-1960s and 2016 reveals interesting patterns. Overall, in the half century from 1967 to 2016, soybean area grew 247-fold, while the cattle herd tripled. Soybean area was strongly correlated with cattle herd size (R^2 = 0.91) at the national level over this 50-year period, but there were differences in the relationship between soy and cattle among the decades (see Figure 5 and Table 2).

Cattle was the more established industry when soybean production began to take off at the start of Paraguay's modern major agricultural expansion in the mid-1960s. From 1967 to 1976, cattle herds expanded by 2.7 percent annually, while soybean area started from a small base grew and quickly, at a compound annual growth rate of 32.1 percent. Over the two decades from 1977 to 1996, soybean area grew at roughly twice the annual pace of cattle herds. Then between 1997 and 2006, soybean area and cattle herd size lost their correlation (R^2 = 0.09) as cattle stocks experienced virtually no growth while soybean area grew by over 9 percent each year. The positive correlation between soybean area and cattle numbers was strong in the most recent decade (2007–2016, R^2 = 0.90), when cattle numbers resumed growth. Both soybean area and cattle herds expanded in lockstep, at 3.3–3.5 percent annually. In fact, it was not until this latter period when cattle herd growth exceeded soy growth.

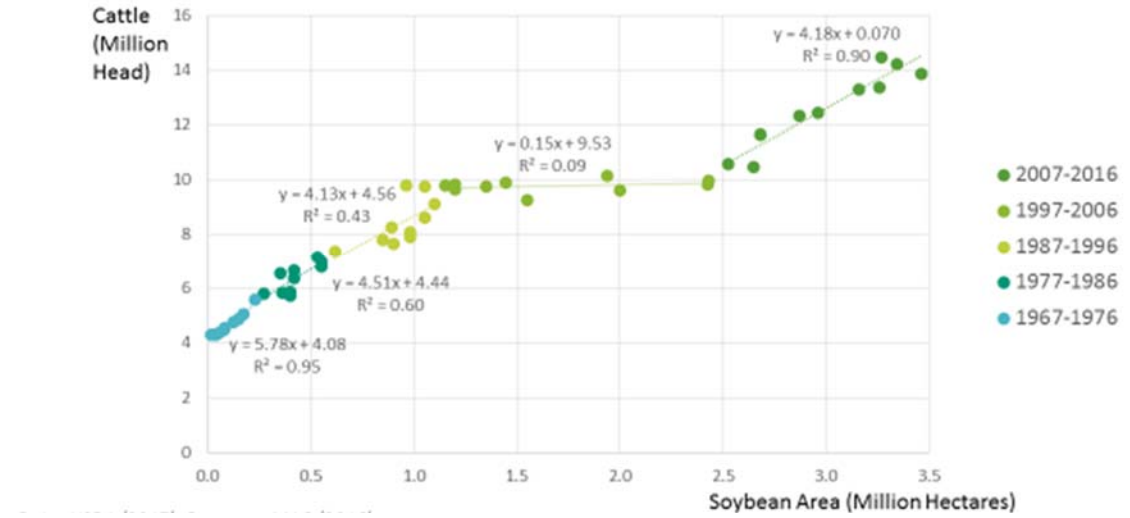


Figure 5. Soybean Harvested Area versus Cattle in Paraguay by Decade, 1967–2016. Source: USDA FAS (2017); FAO (2017); MAG (2016, 2017).

Time Period	Soybean Area Compound Annual Growth Rate	Cattle Herd Compound Annual Growth Rate	Soybean Area Decadal Growth Rate	Cattle Herd Decadal Growth Rate	Cattle-to-Soybean Area Average Ratio	R-Squared	Cattle-to-Soybean Trendline
	Percent	Percent	Percent	Percent	Ratio	Coefficient	Equation
1967-1976	32.11	2.67	1,125.45	26.73	24.35	0.9535	y = 5.7772x + 4E+06
1977-1986	7.82	2.52	96.86	25.06	12.67	0.6029	y = 4.5125x + 4E+06
1987-1996	6.10	3.11	70.43	31.77	8.64	0.4324	y = 4.1265x + 5E+06
1997-2006	9.19	0.33	120.62	3.04	4.04	0.0940	y = 0.1452x + 1E+07
2007-2016	3.32	3.46	34.21	35.81	4.13	0.9037	y = 4.1755x + 70668
Note: For all Annual and Decadal Averages and Ratios, three-year averages are used for start and end points to minimize the effect of annual fluctuations.							

Table 2.Paraguay Soybean Harvested Area and Cattle Decadal Trends, 1967–2016. Source: USDA FAS (2017); FAO (2017); MAG (2016, 2017).

At the regional level, virtually all (99.9 percent) of Paraguay's 3.4 million hectares of soybean fields in 2016 were located in eastern Paraguay. The department with the most area harvested in soy is Alto Paraná, in the heart of the Atlantic forest ecoregion, holding 27.4 percent of the soybean area. It was followed by Canindeyú, with 19.2 percent of the soy area, and Itapúa, with 17.9 percent.

Eastern Paraguay also held 7.9 million cattle in 2016, 57.1 percent of Paraguay's cattle stocks. The Eastern Region's cattle herds have declined 8.7 percent since peaking in 2014. This

contrasts with the West, where cattle herds have grown steadily, increasing 52.4 percent since 2007 (see Figure 6, with detail by department in Appendix H). The Western Region held 5.9 million cattle in 2016, 42.9 percent of the nation's herd, with 18.0 percent in Presidente Hayes, 13.6 percent in Boquerón, and 11.3 percent in Alto Paraguay (MAG, 2017).

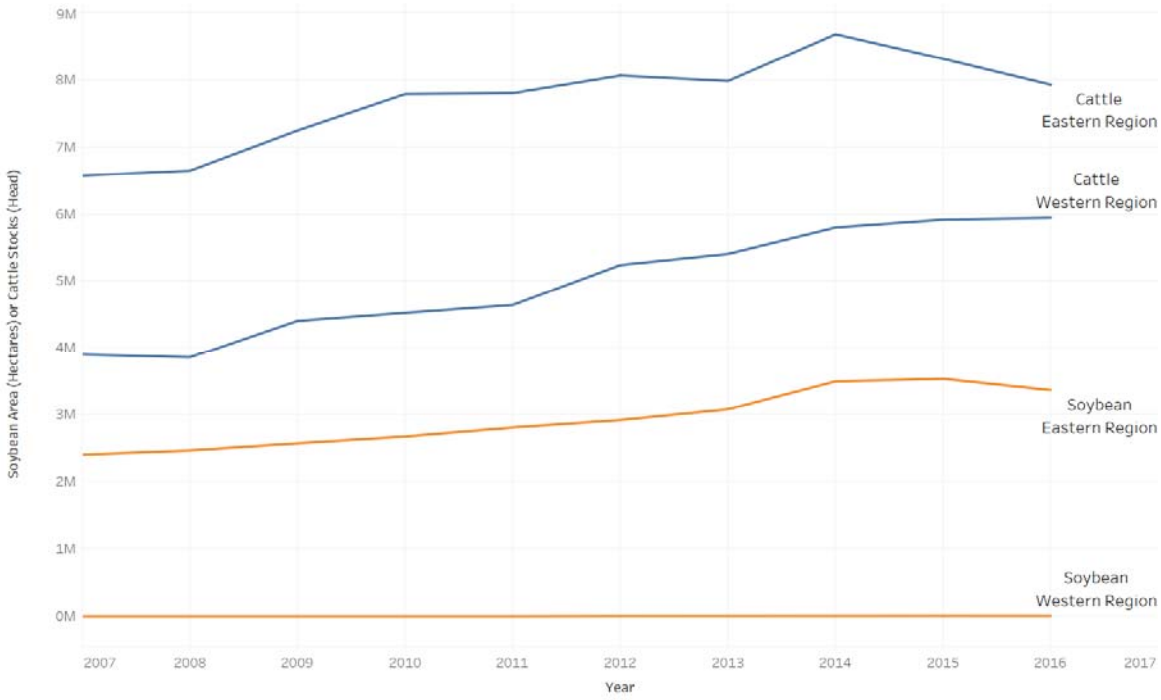


Figure 6. Cattle Herds and Soybean Harvested Area by Region in Paraguay, 2007–2016. Source: MAG (various years).

For the years 2007 through 2016 for which department level data are available, western cattle stocks were more closely correlated with eastern soybean area ($R^2 = 0.95$) than with eastern cattle ($R^2 = 0.79$) (see Figure 7). The trend line indicates that western and eastern cattle are increasing at close to the same rate (slope = 1.05), while eastern soy is expanding faster than western cattle (slope = 1.85).

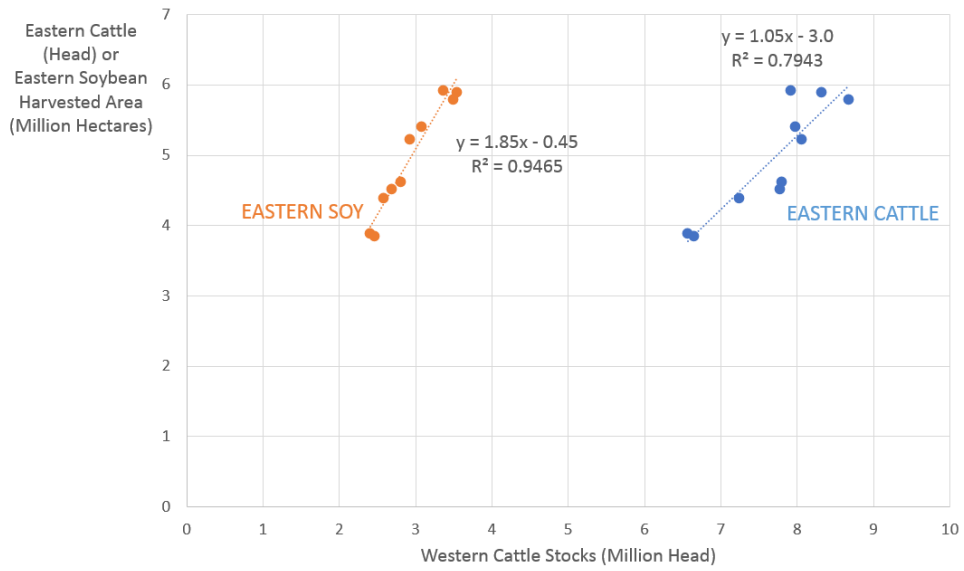


Figure 7. Annual Western Cattle Stocks Compared to Eastern Cattle Stocks and Eastern Soybean Harvested Area, 2007–2016. Source: MAG (various years).

Forests

As of 2015, close to half (49.0 percent) of Paraguay's land area is covered by trees at a canopy density of at least 30 percent (Hansen et al., 2017; Huang et al., 2009). As cattle herds and soybean fields expanded in Paraguay, tree-covered areas shrunk. Earlier studies (e.g., Huang et al., 2007; Huang et al., 2009) indicate that much of the tree cover loss in Paraguay's Eastern Region occurred in the latter decades of the twentieth century. This study examines the early years of the twenty-first century, when tree cover loss was dominated by land clearing in the West.

Paraguay stands out as a deforestation hotspot between 2000 and 2015 (see map of South American deforestation, Appendix I). During this period, Paraguay lost 19.7 percent of its forest, or 4.78 million hectares (Hansen et al., 2017). Forest loss over this period was concentrated west of the Paraguay River; the Western Region lost 2.6 million hectares of forest (15.8 percent of the remaining tree covered area), while the East lost 0.5 million hectares (7.7 percent of the remaining tree covered area). The large northwestern department of Boquerón lost the most forest of any department—over 1.89 million hectares—most of which was deforested after 2007. This was followed by the other two western departments, Alto Paraguay at 1.3 million hectares and Presidente Hayes at 0.6 million hectares (see Figure 8). As a percentage basis, the three

departments of San Pedro, Canindeyú, and Boquerón each lost close to 27 percent of their year-2000 tree-covered area (Hansen et al., 2017) (see Appendix J).

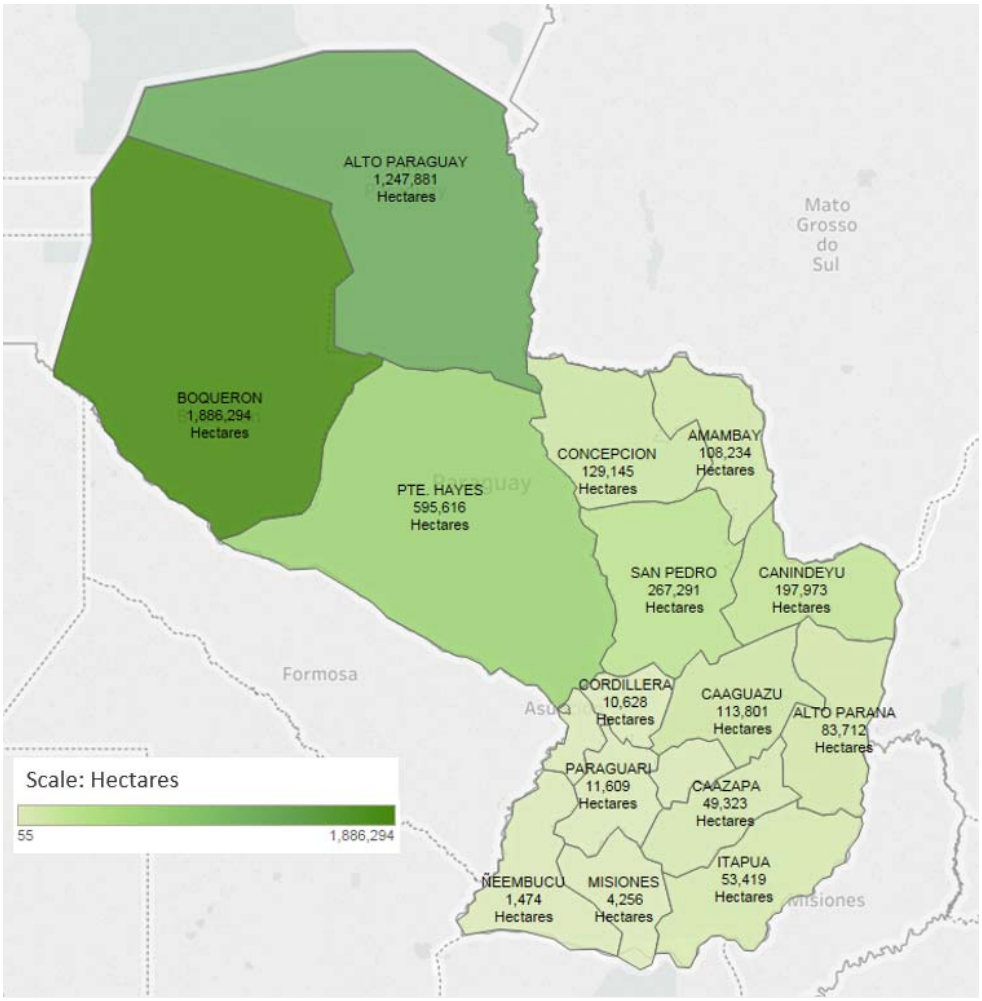


Figure 8. Paraguay Forest Loss by Department, 2001–2015. Source: Hansen et al. (2017). Base map courtesy OpenStreetMap.

Looking annually, the satellite data indicate that there was an uptick in deforestation after 2006, largely in departments in Paraguay's Western Region. The highest deforestation rates over the study period were between 2007 and 2012. Annual loss peaked at 0.5 million hectares in in 2012 and averaged 38.5 percent lower over the following three years (see Figure 9).

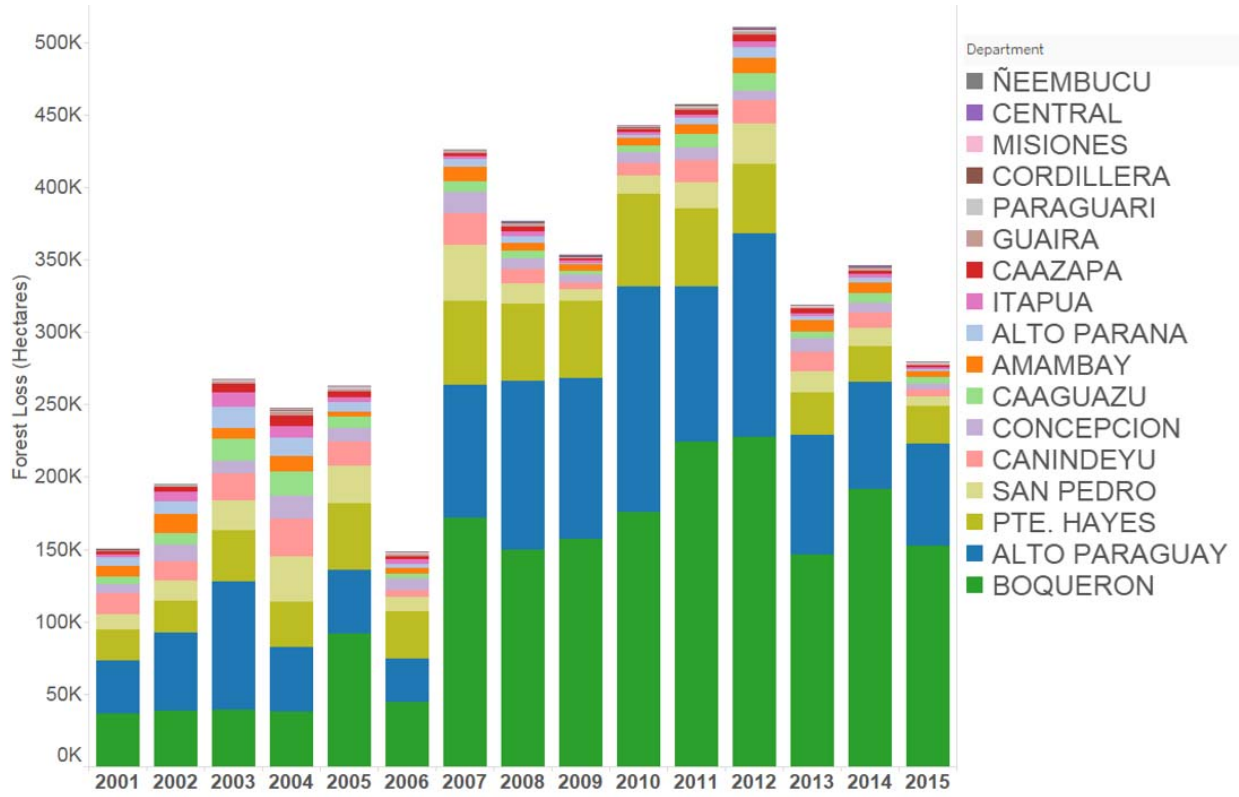


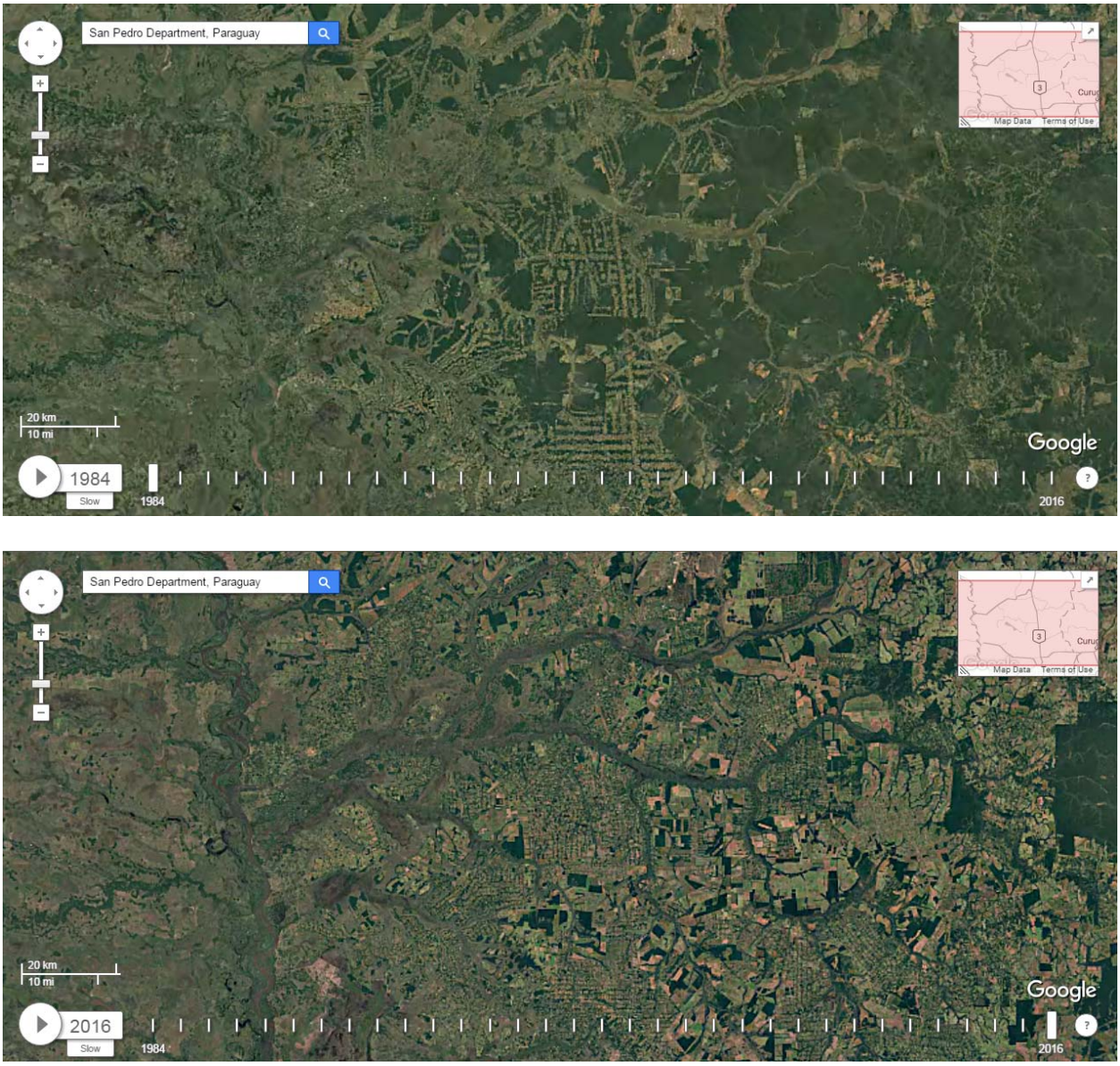
Figure 9. Annual Tree Cover Loss in Paraguay by Department, 2001–2015. Source: Hansen et al. (2017).

Land patterns evident in satellite imagery available since 1984 and data from the government of Paraguay indicate that land use changes in the three western states of Boquerón, Alto Paraguay, and Presidente Hayes were for the conversion of tree-covered area to cattle pasture. Land clearing patterns show the opening of a new frontier. The appearance of new rectangles of pasture amid the natural vegetation, accelerates after the early 2000s. Figure 10 illustrates land use changes in Boquerón between 1986 and 2016.

Note: Time lapse video is available at https://earthengine.google.com/timelapse/#v=-21.98125,-60.96502,6.292,latLng&t=3.23

Figure 10. Land Use Change Imagery in Boquerón, Paraguay, 1986 and 2016. Source: Google Earth Engine (2017).

In the East, the forest area lost since 1984 is more frequently from parcels that were already fragmented. New crop fields fill out the area around roads in fish-bone patterns and fill in open space between cleared areas. Figure 11 illustrates this process in San Pedro department, to the east of the Paraguay River (see Appendix K for additional detail).



Note: Time lapse video is available at https://earthengine.google.com/timelapse/#v=-24.3351,-56.33665,7.855,latLng&t=0.23

Figure 11. Land Use Change Imagery in San Pedro, Paraguay, 1984 and 2016. Source: Google Earth Engine (2017).

Forest and Farm Connections

Examining forest area alongside the soy and cattle data reveals interesting trends (see Figure 12). Between 2000 and 2015, as Paraguay's tree-covered area fell by 19.7 percent, the number of cattle grew by 46.0 percent and the soybean harvested area increased by 147.4 percent.

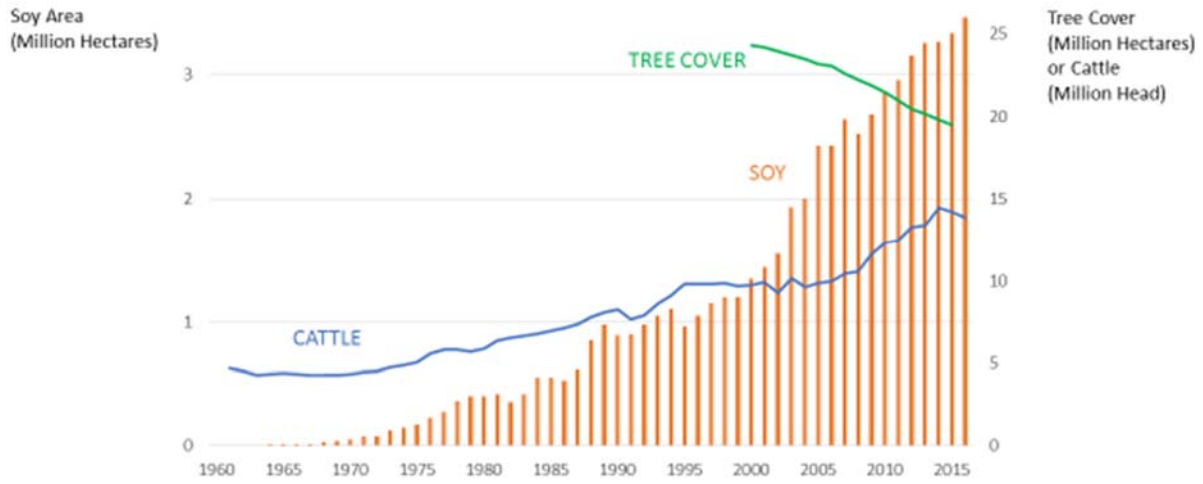


Figure 12. Soybean Harvested Area, Cattle Stocks, and Forested Area in Paraguay, 1961–2016. Source: Hansen (2017); USDA FAS (2017); FAO (2017); MAG (2016, 2017).

Both cattle herd size and the soybean harvested area are negatively correlated with the loss of tree cover in Paraguay. As soybean harvested area grew, forests shrank ($R^2 = 0.91$). The negative correlation between cattle herd size and forested cover is even stronger ($R^2 = 0.94$) (see Figure 13).

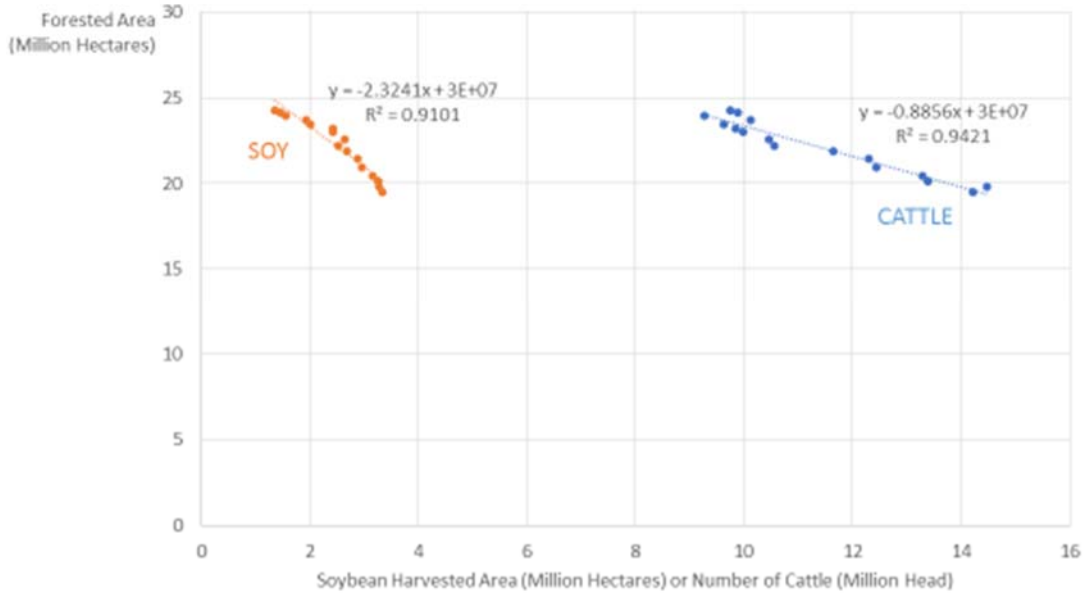


Figure 13. Forested Area versus Soybean Harvested Area and Cattle Herd Size in Paraguay, 2000–2015. Source: Hansen (2017); USDA FAS (2017); FAO (2017); MAG (2016, 2017).

Looking regionally, western cattle, were strongly negatively correlated with forest cover nationally ($R^2 = 0.970$) and in the West ($R^2 = 0.969$). Eastern soy was negatively correlated with forest cover nationally ($R^2 = 0.93$) and in the East ($R^2 = 0.94$). Eastern cattle were also negatively correlated with forests nationally ($R^2 = 0.89$) and in the East ($R^2 = 0.85$) (See Appendix L). Western soy had no significant correlation with deforestation. This is not surprising as the only soy in the vast Western Region is a 5,000-hectare demonstration project developed in Boquerón. The Paraguayan Chamber of Exporters and Traders of Cereals and Oilseeds (Capeco), the United States Department of Agriculture, the University of Missouri, and the cooperatives Chortitzer and Fernheim are involved with research projects on this land to develop soybean varieties tolerant to high temperatures ("Soja tolerante a altas temperaturas triplicará producción," 2016). Interviews indicate that the experiments are thought to be going well; conservation groups are concerned that if the project proves successful it could open the door to large-scale soybean expansion in the Chaco.

Future Development

Land maps from the Round Table on Responsible Soy (RTRS, 2015) indicate that 60.1 percent of Paraguay's land area should be off-limits for future responsible production of soybeans, either because no land is available physically or legally, or the areas were deforested after 2009 (and before the maps were completed in 2015). Recently cleared land is not considered available for responsible production as a deterrent to a race to clear forests in advance of legal or voluntary restrictions. A further 28.1 percent of Paraguay's land is considered potentially available for responsible soy production pending an assessment for high value conservation areas (HCVA). This leaves 11.8 percent of Paraguay's land area, or over 5 million hectares, available for new "responsible" soybean cultivation, within legal limitations (See Figure 14).

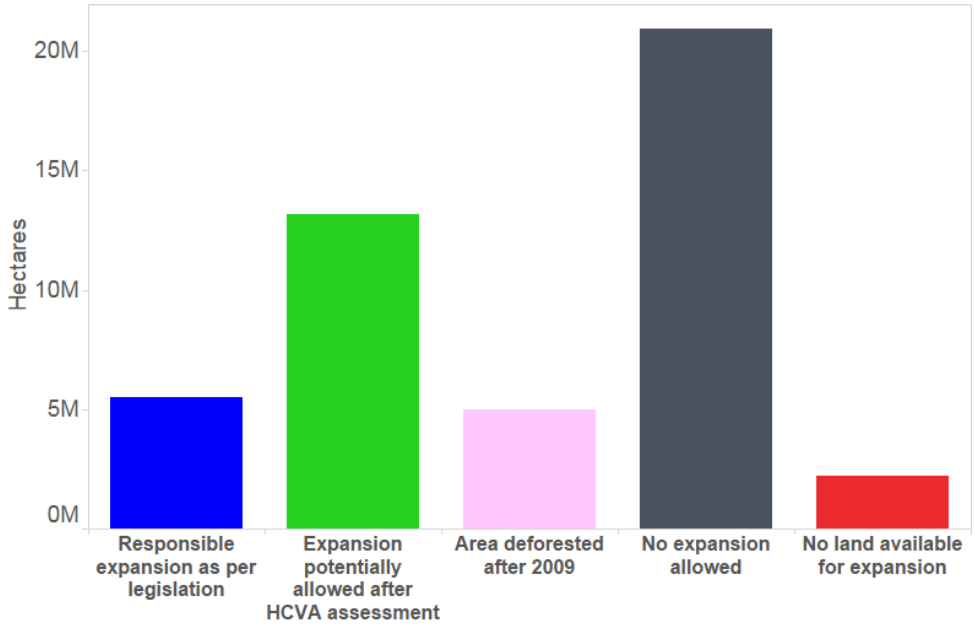


Figure 14. Responsible Soybean Area Classifications for Paraguay, 2015. Source: RTRS (2015).

The western department of Presidente Hayes contains the largest potential area for soy expansion: 4.6 million hectares (56.0 percent of the department's surface area), 89.1 percent of which requires HCVA assessment before responsible development could be considered. (See Figure 15 and Appendix M.) Neighboring Boquerón is second in potential soy extent, with 2.7 million potential acres, or 26.1 percent of the department's land area (RTRS, 2015). Satellite images reveal that the heart of this potential soy area is in the Dry Chaco ecoregion where woodlands were previously cleared for pasture (World Resources Institute, 2016).

Four departments have roughly two-thirds or more of their surface area classified as potentially open for soybean expansion: Paraguarí (66.3 percent), Cordillera (70.8 percent), Misiones (79.7 percent), and Ñeembucú (91.8 percent). These four departments are located in Paraguay's southern humid Chaco and Mesopotamian grasslands ecoregions that border Argentina (Clark, 2013). Overall, if Paraguay were to expand soybeans to all the land designated as potential responsible soy area under the RTRS, it would nearly double its soybean area (assuming part of current soybean harvested area is double cropped).

Five departments have two-thirds or more of their surface area classified as off-limits to soy expansion. They include Itapúa (68.30 percent), Canindeyú (73.4 percent), and Alto Paraná (77.4 percent), all in the Atlantic forest ecoregion, and Boquerón (73.9 percent) and Alto Paraguay (78.4 percent), both in the western Chaco.

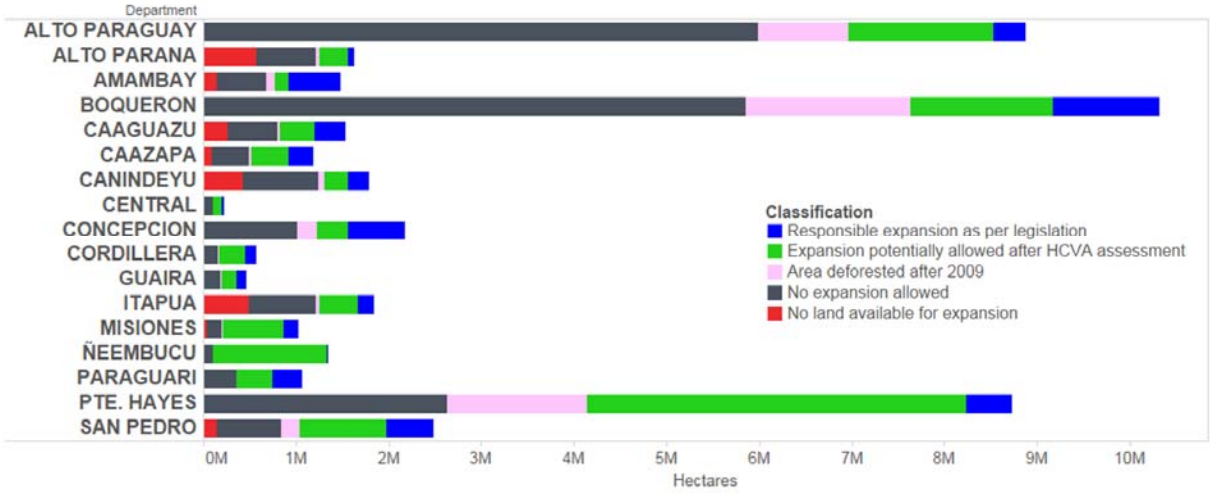


Figure 15. Responsible Soybean Area Classifications for Paraguay Departments, 2015. Source: RTRS (2015).

Policy Context

A number of policies and laws have affected the development of agriculture and land use change in Paraguay. This analysis focuses on national legislation and decrees that are particularly relevant to deforestation. While a thorough review of fiscal and monetary policy is outside the scope of this study, as a general rule economic policies and tax structure in Paraguay have been favorable to business and investors, including foreign entities and large agribusiness players in the cattle and soybean sectors (Paniagua & Kamenov, 2014). For instance, the Paraguayan government has historically collects relatively little revenue from large-scale agricultural interests as compared to Argentina and Brazil. Discussion has been raised to implement export taxes of 10 percent on soybeans, but the agricultural sector, a powerful lobby, has successfully opposed such implementation (Markley, 2014).

Furthermore, background interviews revealed that enforcement of policies and laws in Paraguay is lacking. The absence of enforcement of existing environmental protection measures or anti-deforestation regulations increases the attractiveness of Paraguay as a place to do extractive or land-clearing-business.

WWF notes that among the drivers of deforestation in Paraguay are “disconnected and contradictory laws and incentive systems,” “high levels of corruption within the state institutions charged with the administration of forest resources, and impunity against prosecution for those of can afford it,” and “weakness of government institutions to implement forest law—including low budgets, poor salaries and under-valued human resources” (Hutchison, 2011).

The following matrix (Table 3) reviews selected policies and laws related agriculture and forests since the passage of the 1963 agriculture laws that launched the colonization and clearing of Paraguay's uninhabited wildlands.

One particularly notable policy is Paraguay's "Zero Deforestation Law," which was passed in 2004 and later extended in 2006, 2008, and 2013, ultimately to be in force through the year 2018. The Zero Deforestation Law made it illegal to clear forests in Paraguay's Eastern Region. WWF, which helped propose the moratorium, claims that this law reduced deforestation rates in the Upper Parana Atlantic forests by 90 percent, as compared to 2002 rates (Hutchison, 2011). The satellite data from (Hansen et al., 2017) indicate that forest loss still continued in eastern Paraguay after the passage of this law.

Table 3. Selected Policies and Laws Related to Agriculture and Forests in Paraguay

Year	What	Type	Description
1963	1963 agricultural laws: Rural Welfare (Law 852/63) and Agrarian Statute (Law 854/63)	Law	Law 852 created the Instituto de Bienestar Rural (Institute of Rural Welfare) and Law 854 established the Agrarian Statute. They incentivized the clearing of "unproductive" land (i.e., forests) for agricultural production and formalized the "March toward the East": the moving out from the central parts of the country to develop agricultural colonies in the East, which led to large scale deforestation. Settlers could own up to 10,000 hectares in the Eastern Region and 20,000 hectares in the Chaco without facing taxes.
1973, 1975, 1986	1973 Law 422: The Forest Code, and supplemental Decrees 11,681/75 and 18,831/86	Law	Law 422 required properties to keep 25 percent of their area in natural forest, prohibited clearing of steeply slowing or riparian land that would be prone to erosion, and designated penalties for illegal deforestation: fines of 1,000–500,000 guaraní and potential suspension of permits for infractions. Windbreaks of 100 meters were required around each 100 hectare plot. A World Bank document (World Bank, 1994) notes that this law was not enforced and indeed was viewed as ineffective since most forested land was privately owned and thus subject to owner discretion for its use. A USAID report (Catterson & Fragano, 2004) explains that the law contained a loophole, while opened the possibility for the 25 percent forest reserve to be transferred to another owner for clearing, resulting in forest reserves in the Eastern Region below 10 percent.

1992	New constitution approved	Constitution	After 35 years of dictatorship, the country established new leadership and approved a new constitution. It declared private property inviolable. Granted indigenous communities the right to own land communally and required payments made before land expropriation. Declared agrarian reform fundamental to achieving rural well-being. Proclaimed the adoption of a tax system that stimulates production but discourages large-scale land ownership while promoting small and medium-sized farming.
1995	Law 542/95 Forest Resources Law	Law	The 1995 Forest Resources law repealed the 1973 Forest Code and instituted new fine for deforestation from 1 to 1,500 minimum daily wage.
1996	Law 716/96	Law	Established fines of 500 to 2,000 minimum daily wage and 3 to 8 years imprisonment for clearing or burning forests that affect the ecosystem or converting forests in "Reserve Areas"
2000	Resolution 729, a regional ratification of Decree 18.831 for the Western Region	Resolution	This law specified many of the stipulations of the 1986 national Resolution 18,831 for the Chaco, including the 100 meter windbreaks in addition to reserves of 15 percent.
2004	Law 2419/04 created the Instituto Nacional de Desarrollo Rural y de la Tierra (National Institute of Rural Development and Land)	Law	In creating the National Institute of Rural Development and Land, this law was aimed at revitalizing agrarian reform.
2004	Law 2424/2004, Land Conversion Moratorium for the Atlantic Forest of Paraguay ("Zero Deforestation Law")	Law	The Zero Deforestation Law made it illegal to clear forests in Paraguay's Eastern Region through 2006. WWF, which helped propose the moratorium, claims that this law reduced deforestation rates in the Upper Parana Atlantic forests by 90 percent (compared to 2002 rates). It was later renewed in 2006, 2008, and 2013.
2006	Extension of Zero Deforestation Law	Extension	Law 2424/04, the Zero Deforestation Law, was extended through 2008.
2006	U.S.-Paraguay Debt for Nature Agreement	Inter-national Agreement	The Agreement between the Government of the United States of America and the Government of the Republic of Paraguay Regarding the Reduction of Certain Debts Owed to the Government of the United States and Its Agencies released Paraguay of certain debt obligations in exchange for certain tropical forest protection in furtherance of the amended U.S. Tropical Forest Conservation Act of 1998 and various U.S. Government appropriations acts.
2008	Extension of Zero Deforestation Law	Extension	Law 2424/04, the Zero Deforestation Law, was extended through 2013.
2009	Law 3742/09 on the Control of Phytosanitary Products for Agricultural Use	Law	Reduced buffer limitations and supervision for the use of pesticides in soybean plantations.

2010	Decree 3929	Decree	Fines for serious cases of illegal deforestation were set at 2,000 to 5,000 minimum daily wages.
2011	Resolution 1136	Resolution	Limits Chaco deforestation to 15 to 25 percent of property parcels, depending on proximity to protected areas. Trees on new properties must have a minimum density of 30 percent.
2013	Extension of Zero Deforestation Law	Extension	Law 2424/04, the Zero Deforestation Law, was extended through 2018.
2013	Law 5012/13	Law	This law established the Alianza Público Privada (APP), a public-private alliance promoting private investment in public infrastructure to hasten project development. The USDA attaché responsible for Paraguay notes that projects that improve soybean movement, such dredging of the Paraguay River to allow for multiple barges to pass, have been facilitated by this law.

Source: compiled by the author from the following: (Catterson & Fragano, 2004; de Waroux et al., 2016; FAO Legal Office, 2017; Guereña, 2013; Hanratty & Meditz, 1988; Hutchison, 2011; Law Office of Peroni Sosa Tellechea Burt & Narvaja, 2014; Markley, 2014; Molinas M., 2012; Paniagua & Kamenov, 2014; President of Paraguay, 1986; The Republic of Paraguay, 1992-2011; U.S. Government & Government of Paraguay, 2006; World Bank, 1994; WWF, 2013)

Discussion

Deforestation in Paraguay is linked to both cattle ranching and soybean farming. Background research and interviews corroborated the spatial and statistical results reported above. Earlier research (e.g., Huang et al, 2007; Huang et al., 2009) indicates that agricultural expansion prior to 2000 led to the clearing of much of the biodiverse Atlantic forest. This study indicates that over the years since 2000, land clearing in Paraguay has accelerated, with rapid forest loss particularly evident in the western Chaco ecoregion after 2008. This year was a pivotal year for a number of reasons. One, it was the start of the global financial crisis. Two, it came on the heels of food price spikes that started in 2007, where world market prices of key agricultural commodities nearly doubled in a matter of months (Chicago Board of Trade data from CME Group (various years)). Together these events precipitated a global flurry of land investment.

The soybean link to deforestation in Paraguay's Western Region is indirect, at least thus far. The land and climate east of the Paraguay River are more suited for soybean production than land in the West, though the 5,000-hectare soybean demonstration plot in Boquerón is intended to facilitate the development and use of heat- and drought-tolerant soybeans that could more easily grow in the Chaco (EFE, 2014). Current soy planting in Paraguay is up to 97 percent genetically modified varieties (Sandoval, 2016), though largely made up of seeds designed to

tolerate the use of herbicides rather than withstand climate fluctuations. The U.S. Department of Agriculture (USDA) attaché office responsible for Paraguay notes local analyst assertions that soybean production in the Chaco could grow by 2 million hectares, yet it couches that point with the caution that "this area is notoriously difficult for crop production due to extreme climate patterns and poor soil quality" (Sandoval, 2016).

As for the indirect effects of eastern soybean expansion on western conversion of forests to pasture, several interviewees noted that agribusiness companies were purchasing pasture in Eastern Paraguay for soybean farming, displacing ranchers to cheaper and often forested land in the Chaco. This finding is corroborated by a study by de Waroux et al. (2016) examining the drivers of tree clearing in the Gran Chaco and Chiquitano woodland of Argentina, Brazil, and Paraguay. The team interviewed 82 companies with properties covering 2.5 million hectares in Argentina (61.8 percent of the land area), Bolivia (0.07 percent), and Paraguay (45.5 percent). They found that companies were more likely to purchase forest land for clearing in areas where enforcement of deforestation regulations was low. Companies that cleared land were more likely to purchase land in places with fewer legal restrictions on deforestation. Land with forests averaged $1,157 cheaper per hectare than land that had previously been cleared for agriculture. Forestland also is more readily available than already cleared agricultural land, particularly for large purchases, because the agricultural land market is less dynamic.

Paraguay Soybean Patterns May Follow Those in Brazil

The soybean expansion in Paraguay is somewhat reminiscent of that in Brazil in earlier years. As in Paraguay, soybeans are Brazil's top valued agricultural product (FAO, 2017). They took hold in the early 1970s, and by the latter part of the decade the harvest had grown close to 10 million tons, near Paraguay's output today. (Brazil had a larger base of land to work with; while Paraguay's land area is comparable to California, Brazil's land area is comparable to the entire contiguous United States.) Farming originally occupied flat fertile lands in Brazil's south, close to port infrastructure. As soybean farming became more profitable, farmers began to push ranchers closer to the Amazon rainforest, creating what is known as the "arc of deforestation."

In recent years a number of scholars have researched the links between soybeans, beef, and Amazonian deforestation (Arima et al., 2011; Barona et al., 2010; Boucher, Roquemore, & Fitzhugh, 2013; DeFries, Herold, Verchot, Macedo, & Shimabukuro, 2013; Fearnside, 2001, 2005; Garrett, Lambin, & Naylor, 2013; Gasparri & de Waroux, 2015; Gibbs et al., 2016; Gibbs

et al., 2015; Godar, Tizado, & Pokorny, 2012; Laurance et al., 2002; Macedo et al., 2012; McAlpine, Etter, Fearnside, Seabrook, & Laurance, 2009; Meyfroidt et al., 2014; Muller, Griffiths, & Hostert, 2016; Neill et al., 2013; Nepstad et al., 2014). Remotely sensed data, field surveys, and deforestation maps examined by Morton et al. (2006) indicated that in the southern Amazon portions of Mato Grosso during the early 2000s, soy cropland expansion had grown in importance to become a major cause of deforestation, accounting for 23 percent of forest loss in 2003. They found that new clearing for cropland was directly correlated to soybean prices. Macedo et al. (2012) also examined Mato Grosso, finding that in the latter part of that decade, southern Amazonian deforestation and soybean production "decoupled": deforestation dropped at a time when soybean production increased. Forest conversion to cropland in that part of the Southern Amazon fell to account for just 2 percent of deforestation by 2010. The study notes that Brazil's strong anti-deforestation measures, which coincided with a reduction in the profitability of soybean farming, as well as an intensification of farming could be responsible for breaking that link. Government initiatives included an increase in real-time monitoring via satellites and stepped up enforcement of anti-deforestation measures such as Brazil's Forest Code. The 2006 Soy Moratorium, a voluntary initiative by major soy buyers to exclude from their supply chains soybeans produced on Amazonian land cleared after the year 2006, also proved successful at limiting soy expansion into the Brazilian rainforest. The study did not find evidence of deforestation leakage to the *cerrado* within Mato Gross state, though it acknowledged that leakage was possible.

An analysis by Barona et al. (2010) largely agreed with the earlier studies, but found preliminary "support for the hypothesis that an increase of soy in Mato Grosso has displaced pasture further north, leading to deforestation elsewhere."

The data examined for this report indicate the possibility that agriculture and ranching in Paraguay are strongly coupled with deforestation. Additional research would be needed to determine causality rather than just correlation. In Paraguay's Eastern Region, as prime land to clear for soybeans became limited and land and commodity prices climbed, the deforestation dynamic began a transition from largely a direct relationship between deforestation and field crop expansion to one that is a combination of direct and indirect. Over time, the effects of soybeans on Paraguay's deforestation rates could become predominantly indirect, through the displacement of ranchers. Both soy and cattle production could be intensified, with multiple

cropping for soy and increased stocking densities for cattle, although the intensification of both commodities appears to be limited, particularly in the semi-arid and hotter Western Region. If soybean farming in the Chaco became more tenable through the development of heat- and drought-tolerant varieties of beans, the coupling of soybean expansion and deforestation would likely be restored. Stronger anti-deforestation policy and stepped up enforcement along with successful supply chain initiatives would likely be necessary to decouple soybean expansion and deforestation in Paraguay.

Future Expansion

Limiting the loss of valuable ecological landscapes while increasing food production is a challenge that will involve constraining demand growth while increasing agricultural productivity and limiting food waste. Conservation groups that throughout the twentieth century largely focused their efforts on protecting vulnerable land areas through parks, purchases, and government regulation have more recently begun to look to agricultural supply chains to find levers to limit deforestation. These levers include voluntary agreements among governments and businesses and corporate commitments to remove deforestation from supply chains.

For soybean production, efforts like the RTRS mapping for responsible soybeans are intended to facilitate the conservation of highly biodiverse ecosystems while allowing for commodity production, yet their effect of such efforts is limited by how they are implemented. The RTRS, which was created in 2006, has since 2011 offered voluntary certification for soy and soy products asserting that the soy "was originated from a process that is environmentally correct, socially adequate and economically viable" (RTRS, 2017). However interviews with representatives from major soybean buyers, including Bunge and Cargill, indicate that demand for "responsible" soybeans is lacking, and thus there was little incentive for soy producers to certify. As of 2017, the supply of RTRS certified soy exceeded demand (Searby, 2017). In 2016, RTRS certified soybeans occupied their largest area on record, yet this only amounted to 3.02 million tons of output from 956,515 hectares, or less than 1 percent of the global soybean harvest (RTRS, 2017). Just two companies—Desarrollo Agrícola del Paraguay (DAP) and Payco S.A.—produced RTRS certified soy in Paraguay, with certified holdings reaching 16,155 hectares, or 0.5 percent of Paraguay's total soybean harvested area (RTRS, 2017; USDA, 2017).

Furthermore, the current RTRS maps for potential responsible soy production in Paraguay potentially open up large areas of the country for land clearing, largely depending on

the results of HCVA analyses. Interviewees noted that the reliability of HCVA assessments varies widely among practitioners; in other words, an assessment may not be the best measure for determining which lands should be conserved for biodiversity protection. Comparing Paraguay's RTRS map to Brazil's (Appendix M) reveals a striking difference to the amount of land that is not considered appropriate for soybean production. With Paraguay's ecosystems generally less well-studied than Brazil's, truly responsible food production may need to leave additional Paraguayan land off-limits to large-scale production agriculture.

Interviews for this study indicate that efforts such as the RTRS mapping for sustainable production are being mirrored by some large soybean purchasers themselves, largely as a supply chain risk mitigating strategy. For instance, a representative from Bunge, one of the major soybean traders, indicated that the company is working with The Nature Conservancy to produce maps indicating which landscapes to avoid purchasing from. Cargill has recently developed a partnership with World Resources Institute to undertake a similar endeavor. Whether these efforts alter current practices or are largely an effort to mitigate reputational risk without much on the ground change remains to be seen. Representatives from environmental groups interviewed on background for this study conveyed a mix of perceptions on this point. It should be noted that some of them receive funding from agribusiness groups, potentially limiting their candidness and emphasizing the need for independent research detached from corporate funding.

Future Studies

This study is just a preliminary examination of land use change due to agriculture and ranching in Paraguay. Future studies could use commodity prices and broader economic indicators to more thoroughly explore the relationship between deforestation and food production in Paraguay. Parsing satellite imagery to examine the exact patterns of land use conversation nationally would help to tell the story of deforestation in Paraguay and hint at future production trajectories. Quantitative analysis of satellite imagery could complement the statistical analysis carried out here.

Additional research is needed to elucidate the effects of macroeconomic trends, agricultural commodity prices, and policies, laws, and voluntary agreements on land use and forests in Paraguay. This would involve analyzing land use changes associated with both domestic policies and policies outside the country, for example, leakage from stricter forest policies and enforcement in Brazil. A thorough review of anti-deforestation measures, including

governmental initiatives, voluntary commitments, and environmental campaigns associated with Brazil's Amazon rainforest could prove instructive for understanding levers to limit agriculturally driven deforestation in Paraguay's Chaco region and preserving the remaining fragments of Paraguay's portion of the Atlantic forest.

Furthermore, additional research is needed to shed light on the human side of this agricultural expansion. Paraguay is notable for some of the most unequal tenure of any country (Guereña, 2013). The consolidation of farm size and the movement from smaller-scale agriculture to industrial production, namely for soybean production, has led to the displacement of smallholders and disrupted traditional land use, resulting in conflict (Elgert, 2016; Guereña, 2013; Lovera, 2014). A more integrated assessment could review patterns of social disruption and identify models of development that carry less social risk.

Conclusion

This study lays the groundwork for future research on land use change in Paraguay. Compared to the Brazilian Amazon, or even the Brazilian *cerrado*, Paraguay's ecosystems are under-studied. The rapid rates of forest loss described in this paper indicate that valuable landscapes and biodiversity could be lost before they are well understood.

Expanding food production poses a threat to the remaining natural systems in Paraguay. The correlations between deforestation and both soybean expansion and cattle ranching since 2000 are high. Ultimately forest loss in Paraguay is tied to meat production, whether land is cleared for beef production or to grow soybeans that are processed and turned into animal feed rations. Global demand for soybeans and for beef is poised to grow as the human population expands and becomes more affluent.

Brazil may have decoupled agricultural expansion and deforestation, at least in the Amazon region. Whether Paraguay can follow a similar path and decouple agricultural expansion with deforestation within its borders remains to be seen. Much of the Atlantic forest in the Eastern Region has already been cleared or is fragmented to the point that it can no longer sustain previous levels of biodiversity. The Chaco in the Western Region still contains extensive uninterrupted habitat, but its longevity depends on national policies along with eating habits around the world and the actions of a relatively small group of players in commodity supply chains.

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Appendices

Appendix A. Highest Valued Global Agricultural Exports, 2013

	Item	Billion USD
1	**Soybeans**	**57.3**
2	Wheat	49.4
3	Maize	34.9
4	Palm Oil	33.8
5	**Soybean Meal**	**32.0**
6	**Beef and Veal**	**29.6**
7	Cheese	28.6
8	Chocolate	25.7
9	Rice	24.1
10	Chicken	23.0
11	Rubber	19.9
12	Coffee, green	19.0
13	Cotton lint	18.5
14	Sugar (Raw)	17.1
15	Pork	16.5
16	Sugar (Refined)	15.4
17	Fruit	14.0
18	Tobacco	12.7
19	Rapeseed	12.5
20	Milk (Whole dried)	12.2
	Source: FAO (2017)	

Table 4. Highest Valued Global Agricultural Exports, 2013. Source: FAO (2017).

Appendix B. Political Map of Paraguay

Figure 16. Political Map of Paraguay. Source: UN (2004).

Appendix C. Annual Precipitation in Paraguay

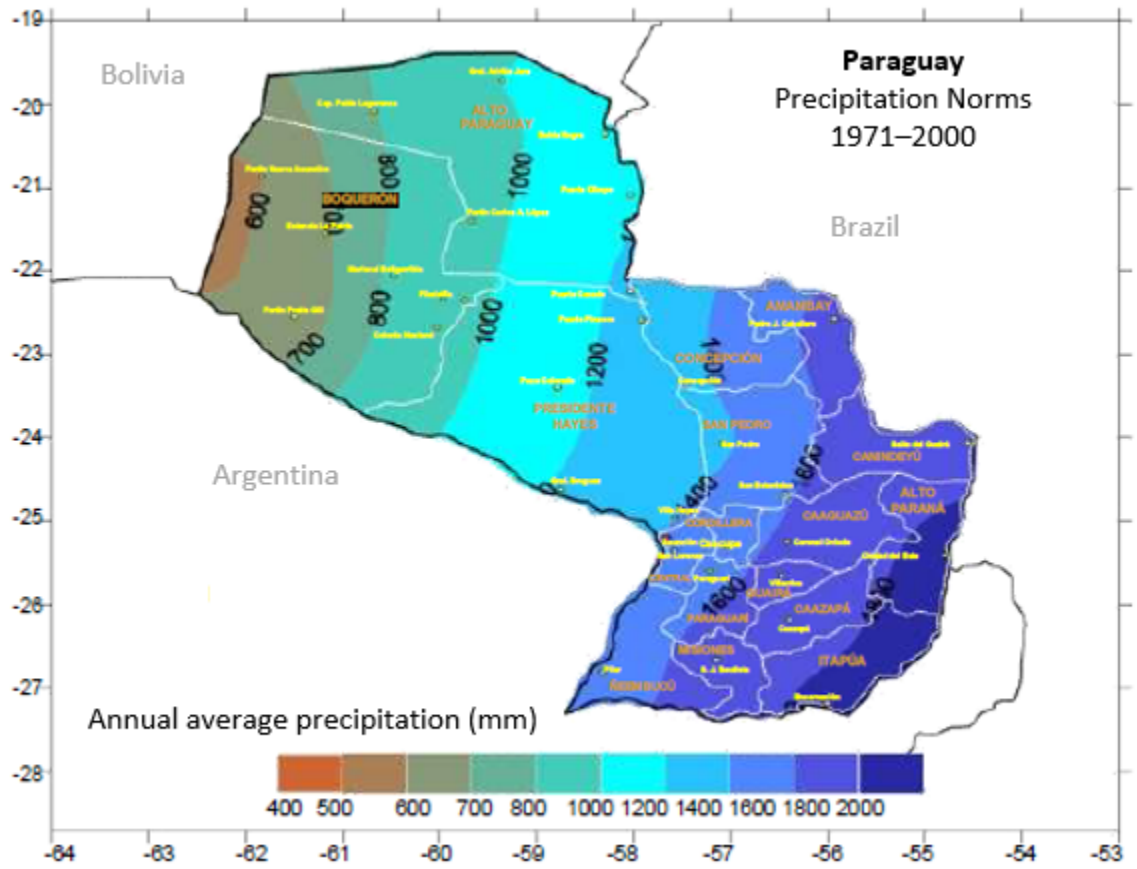


Figure 17. Annual Precipitation in Paraguay, Norms for 1971–2000. Source: MAG, 2017.

Appendix D. Top 10 Exporters of Soybeans and Beef and Share of Global Total, 2015/16

Country/Region	Soybean Exports	Share of Global Total
	Million Metric Tons	Percent
Brazil	54,383	41.12
United States	52,688	39.84
Argentina	9,920	7.50
Paraguay	**5,310**	**4.02**
Canada	4,258	3.22
Ukraine	2,369	1.79
Uruguay	2,100	1.59
Russia	456	0.34
European Union	144	0.11
India	134	0.10
Other	477	0.36
Total	**132,239**	**100.00**

Country/Region	Beef* Exports	Share of Global Total
	Million Metric Tons	Percent
India*	1,764	18.71
Brazil	1,698	18.01
Australia	1,480	15.70
United States	1,157	12.27
New Zealand	587	6.23
Canada	441	4.68
Uruguay	422	4.48
Paraguay	**389**	**4.13**
European Union	345	3.66
Mexico	258	2.74
Other	885	9.39
Total	**9,426**	**100.00**

** Note: includes buffalo and veal.*

Table 5.Top 10 Exporters of Soybeans (2015/16) and Beef (2016) and Share of Global Total. Source: USDA (2017).

Appendix E. Paraguay Agriculture Production by Top Crop, 1960–2016

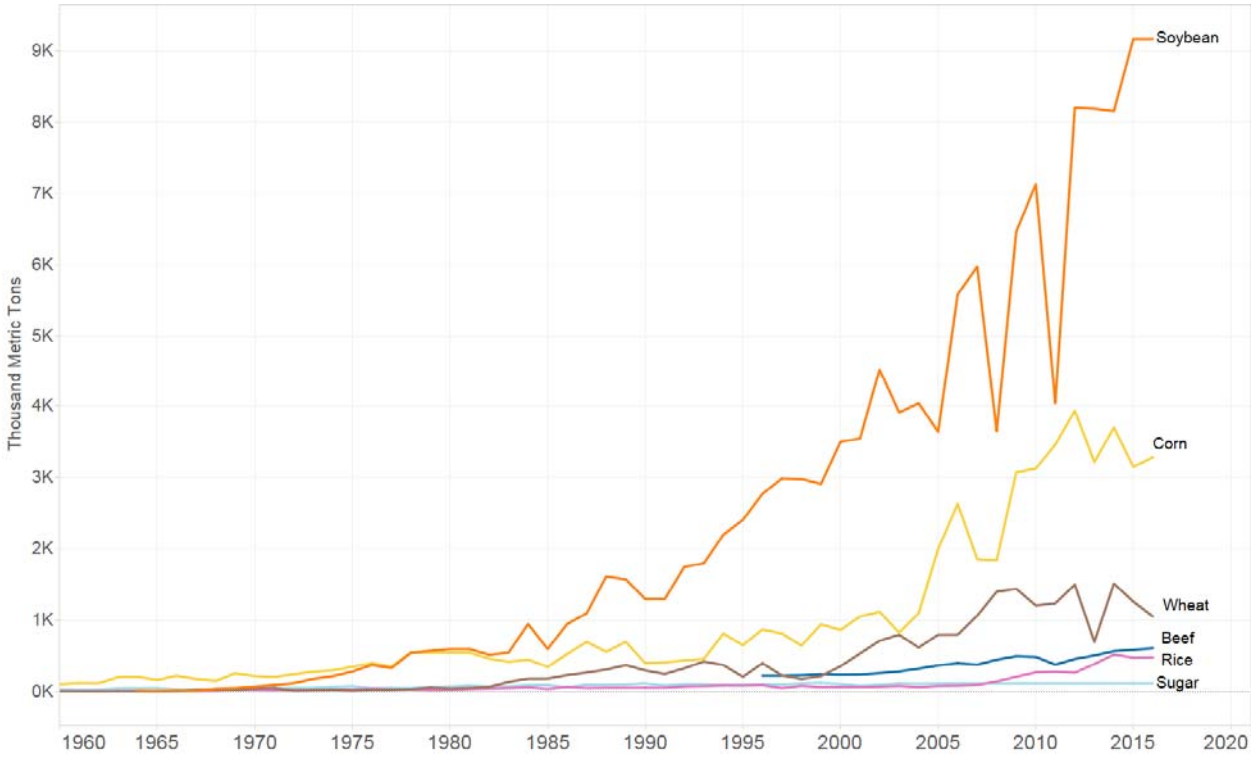
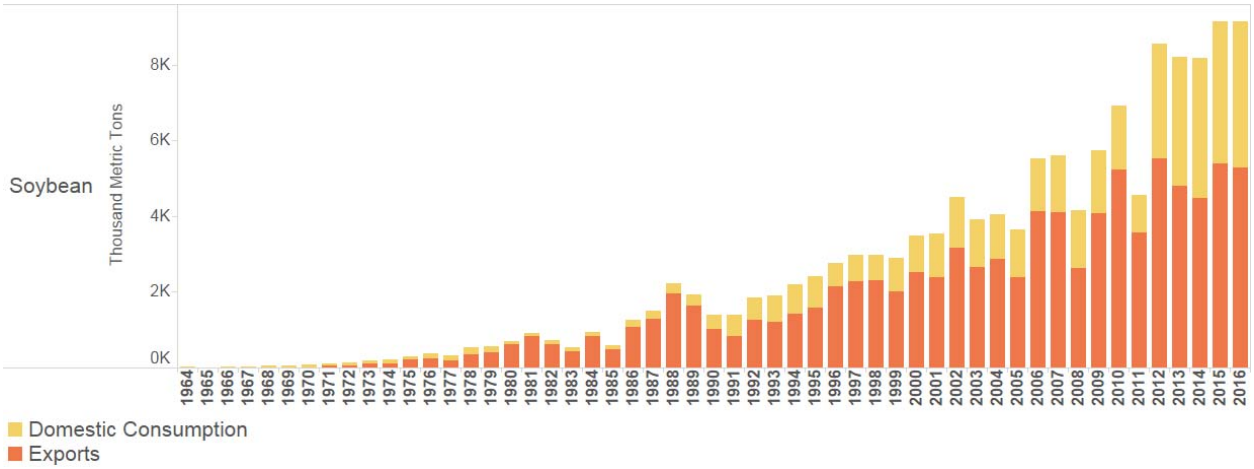


Figure 18. Paraguay Agriculture Production by Top Crop, Thousand Metric Tons, 1960–2016 (USDA, 2017).

Appendix F. Paraguay Soybean and Soybean Oil and Meal Production, Domestic Consumption, and Exports, 1964–2016



Note: full bars represent Production as Imports are negligible. Domestic Consumption is then processed into Soybean Oil and Meal in crushing facilities based in Paraguay, nearly all for export markets, as illustrated below:

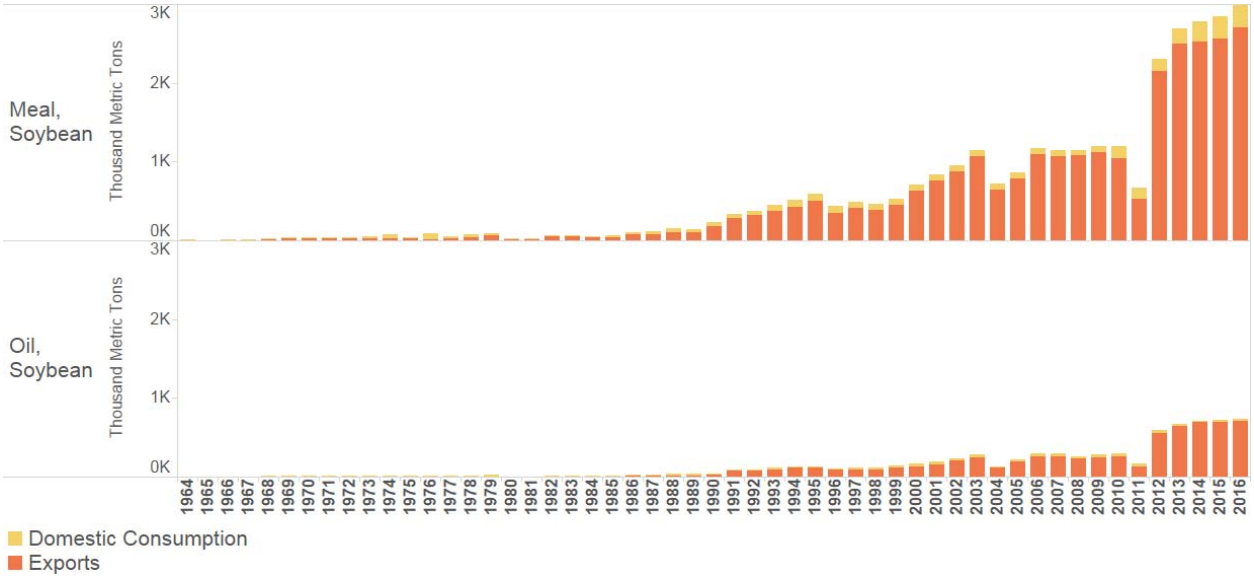


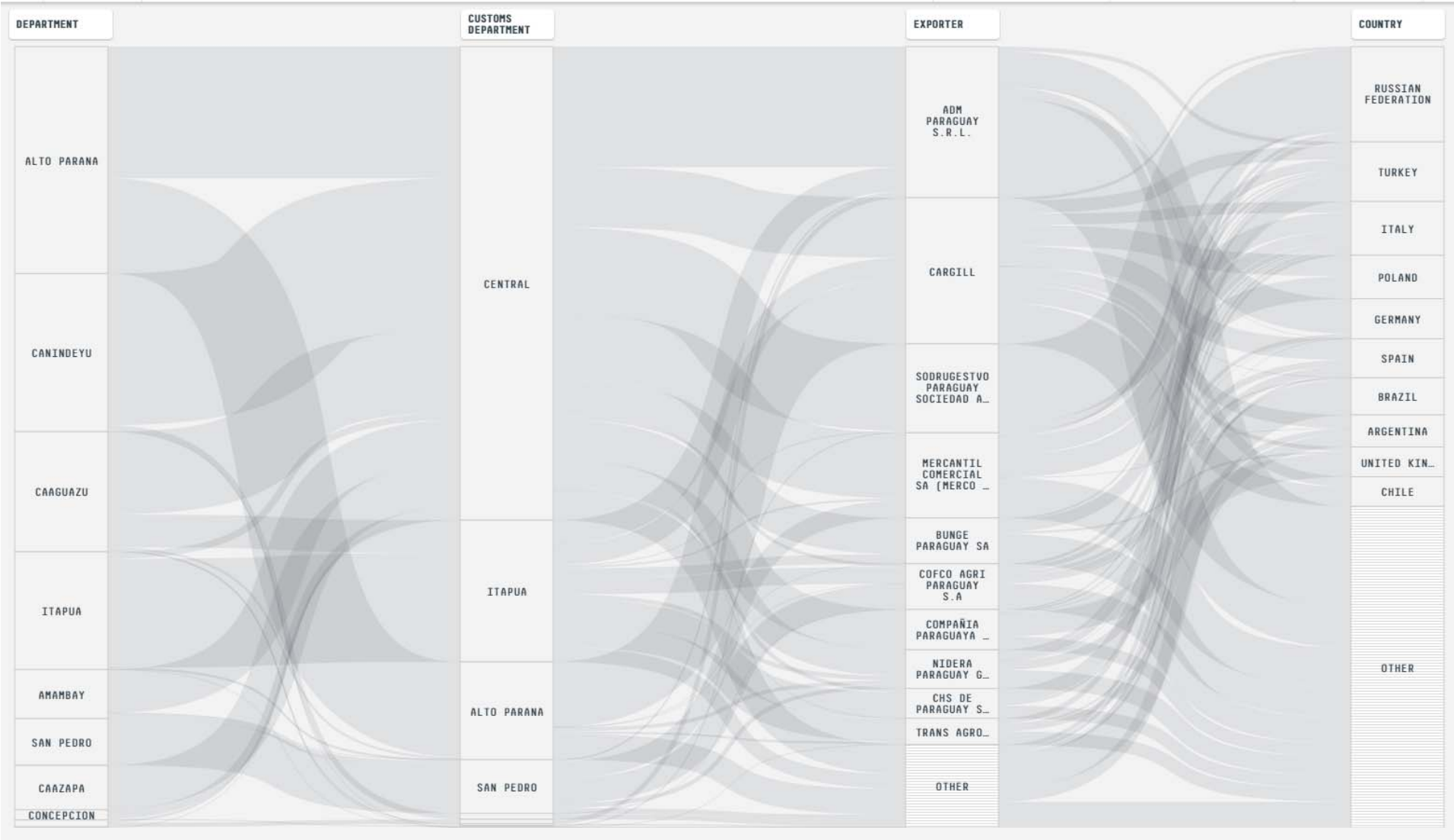
Figure 19. Paraguay Soybean and Soybean Oil and Meal Production, Domestic Consumption, and Exports, 1964–2016. Source: USDA (2017).

Appendix G. Paraguay Soybean Export Destinations, 2016

Trading Partner	Weight	Value
	Thousand Metric Tons	Million USD
Russian Federation	981	347
Argentina	654	234
Turkey	620	210
Germany	399	133
Spain	336	121
Brazil	375	116
Mexico	300	94
South Africa	265	83
Uruguay	204	72
Israel	216	69
Portugal	198	68
Italy	193	66
Rep. of Korea	163	55
Netherlands	101	33
Tunisia	101	29
Greece	90	28
Viet Nam	81	25
Peru	50	15
United Kingdom	37	13
Malaysia	7	3
India	6	3
Other	3	1
Total	**5,381**	**1,816**

Table 6. Paraguay Soybean Export Destinations, 2016. Source: UN Comtrade (2017).

Appendix G. Paraguay Soybean Export Destinations, 2016



Note: This Sankey diagram illustrating the movement of soy from producing department to customs department to exporting company to destination country was generated from the Trase platform (SEI & GCP, 2017). The width of the connections indicates relative volume of soybeans. Discerning the size and the role of the players throughout the soybean value chain is complex. The developers note that the data can be improved, but it is a useful starting point to understand the scale various institutional involvement.

Figure 20. Trade Flows of Soybeans from Paraguay by Volume, 2016. Source: SEI & GCP (2017).

Appendix H. Cattle and Soybeans in Paraguay

Figure 21. Cattle Stocks (Head) and Soybean Harvested Area (Hectares) in Paraguay by Department, 2007–2016. Source: MAG (various years).

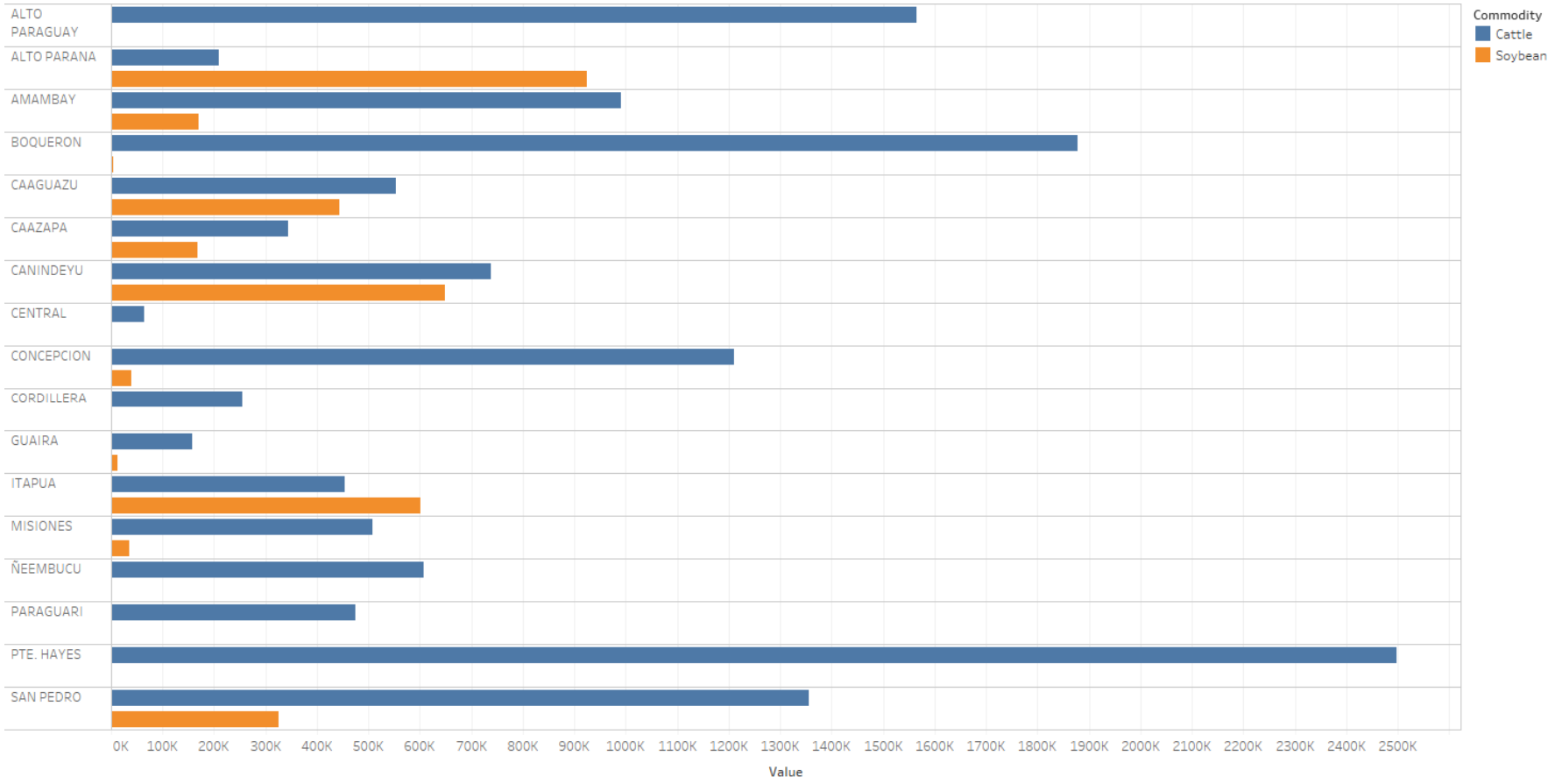
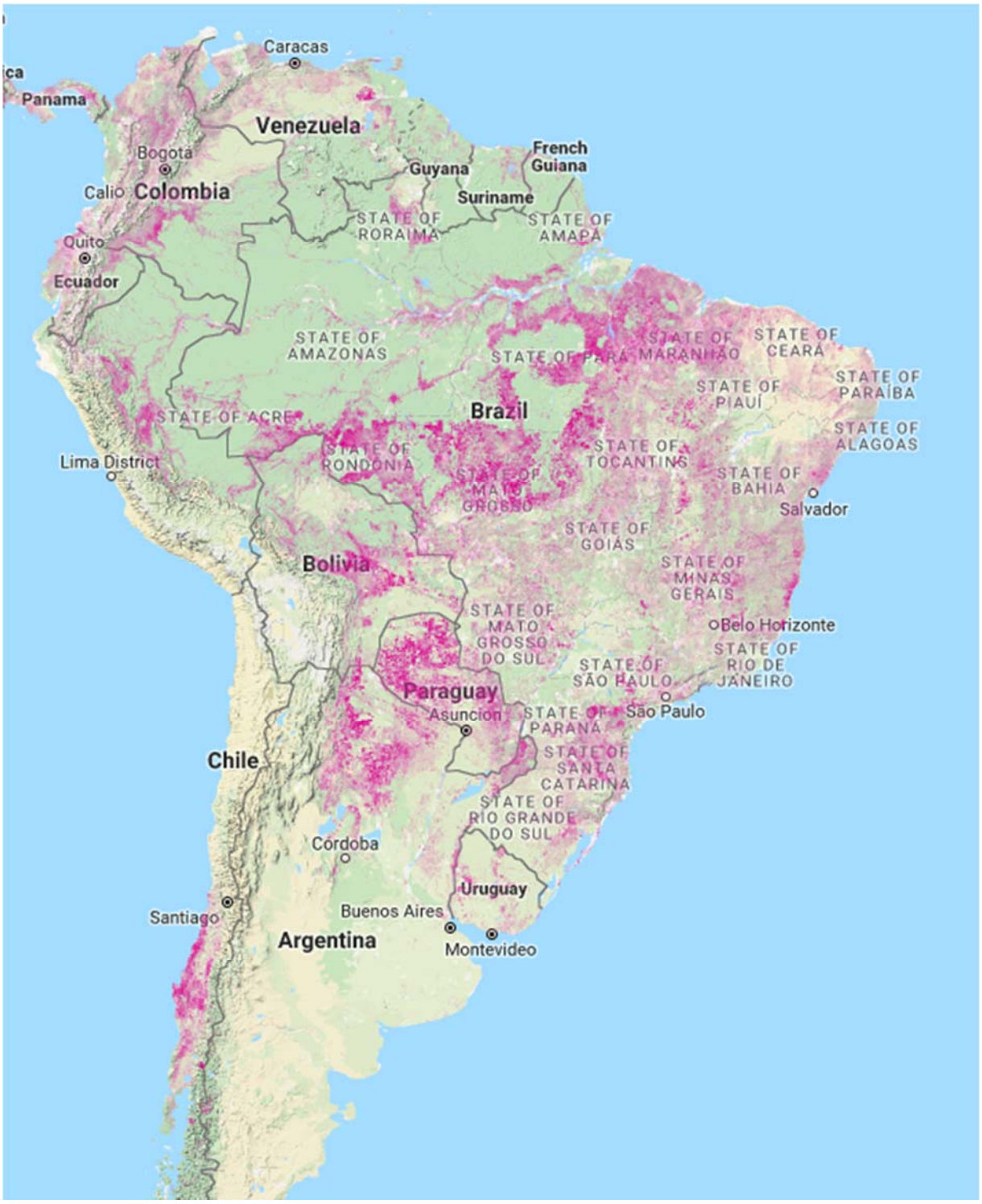


Figure 22. Cattle Stocks (Head) and Soybean Harvested Area (Hectares) in Paraguay by Department, 2016.
Source: MAG (various years).

Appendix I. Tree Cover Loss in South America, 2000–2015



Note: Each pink pixel is a 30 meter by 30 meter area that lost tree cover. Darker pink areas indicate high concentration of pixels with tree cover loss. Tree covered areas considered had 30 percent or higher canopy cover at the start of the period.

Figure 23. Tree Cover Loss in South America, 2000–2015. Source: Hansen et al. (2017), via Global Forest Watch.

Appendix J. Tree Covered Area in Paraguay by Department, 2000–2015

	Tree Covered Area in 2015	Change in Tree-Covered Area, 2000-2015	
	Hectares	Hectares	Percent
SAN PEDRO	716,562	-267,291	-27.2
CANINDEYU	534,381	-197,973	-27.0
BOQUERON	5,175,317	-1,886,294	-26.7
CAAGUAZU	457,319	-113,801	-19.9
ALTO PARAGUAY	5,467,795	-1,247,881	-18.6
AMAMBAY	475,091	-108,234	-18.6
ALTO PARANA	379,824	-83,712	-18.1
PTE. HAYES	3,430,227	-595,616	-14.8
CONCEPCION	894,211	-129,145	-12.6
CAAZAPA	423,476	-49,323	-10.4
GUAIRA	162,120	-17,959	-10.0
ITAPUA	543,489	-53,419	-8.9
CORDILLERA	194,981	-10,628	-5.2
CENTRAL	62,790	-2,912	-4.4
PARAGUARI	265,976	-11,609	-4.2
ASUNCION	1,740	-55	-3.1
MISIONES	153,461	-4,256	-2.7
ÑEEMBUCU	176,577	-1,402	-0.8
TOTAL	**19,515,336**	**-4,781,510**	**-19.7**

Table 7. Tree-covered Area in Paraguay by Department, 2015, and Change Since 2000. Source: Hansen et al. (2017).

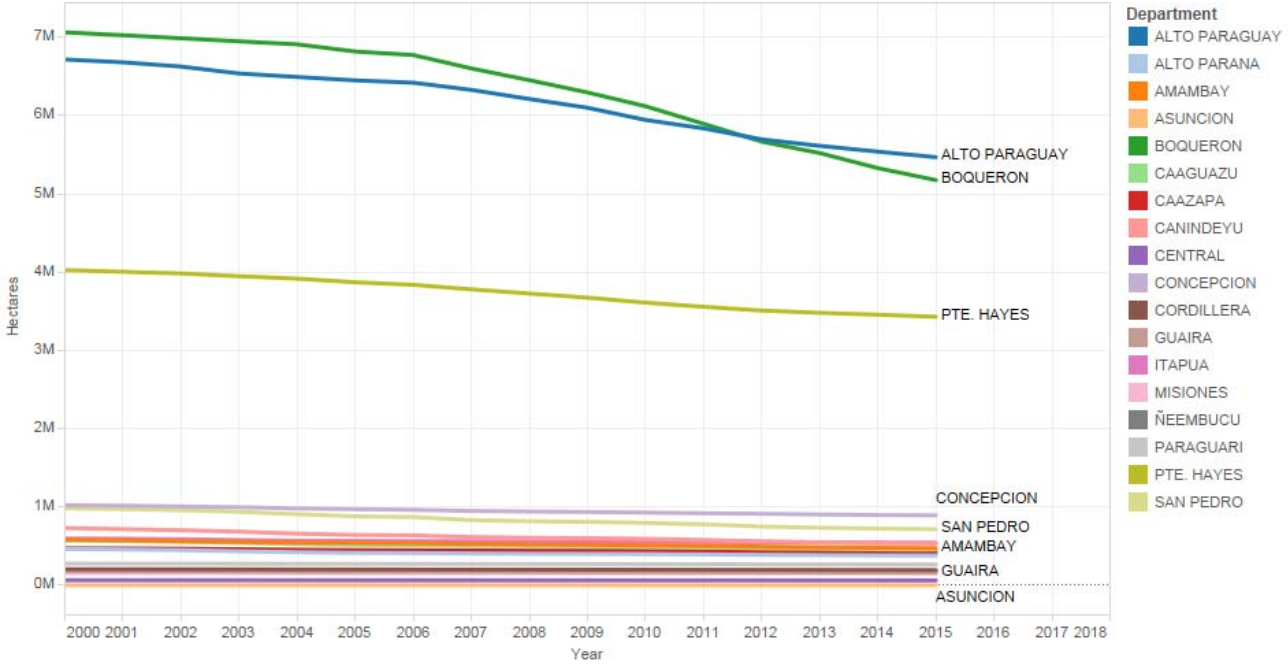
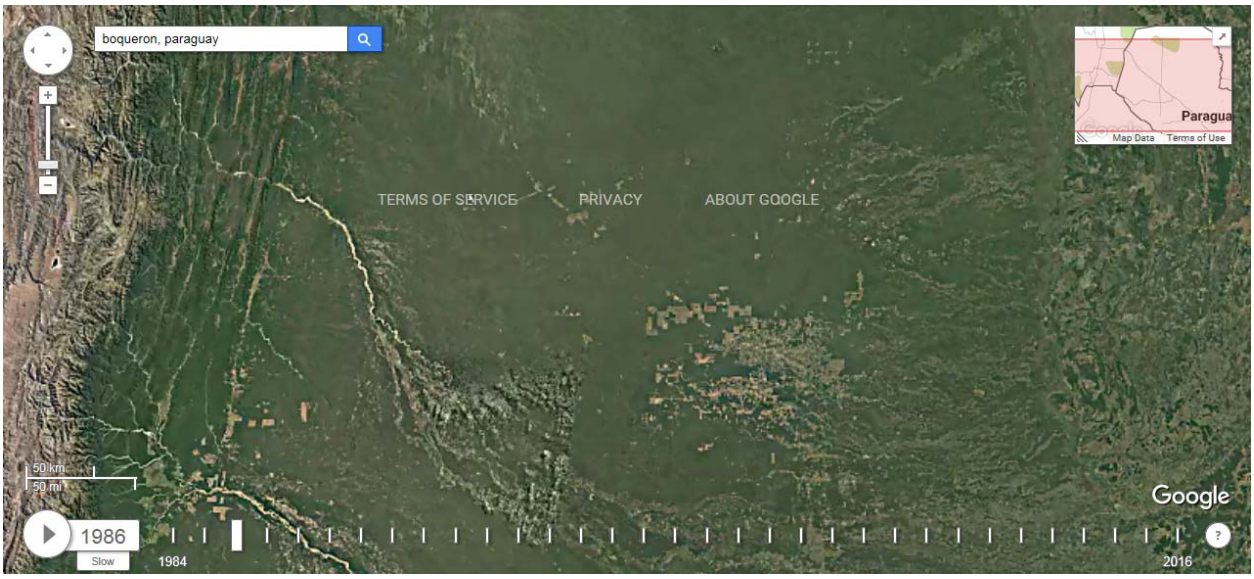
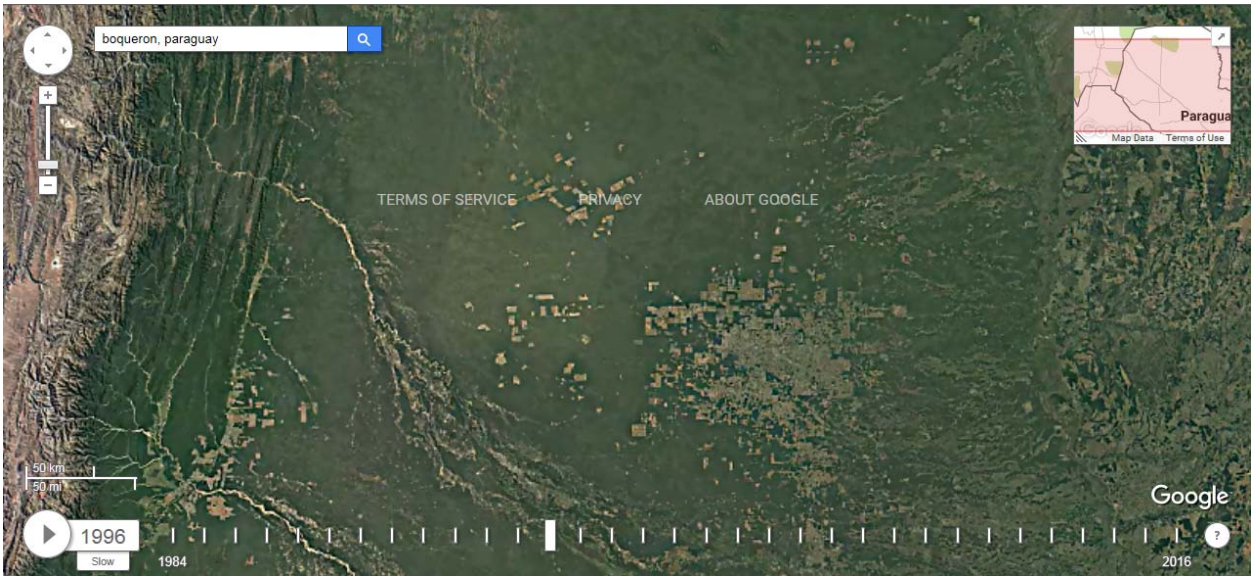


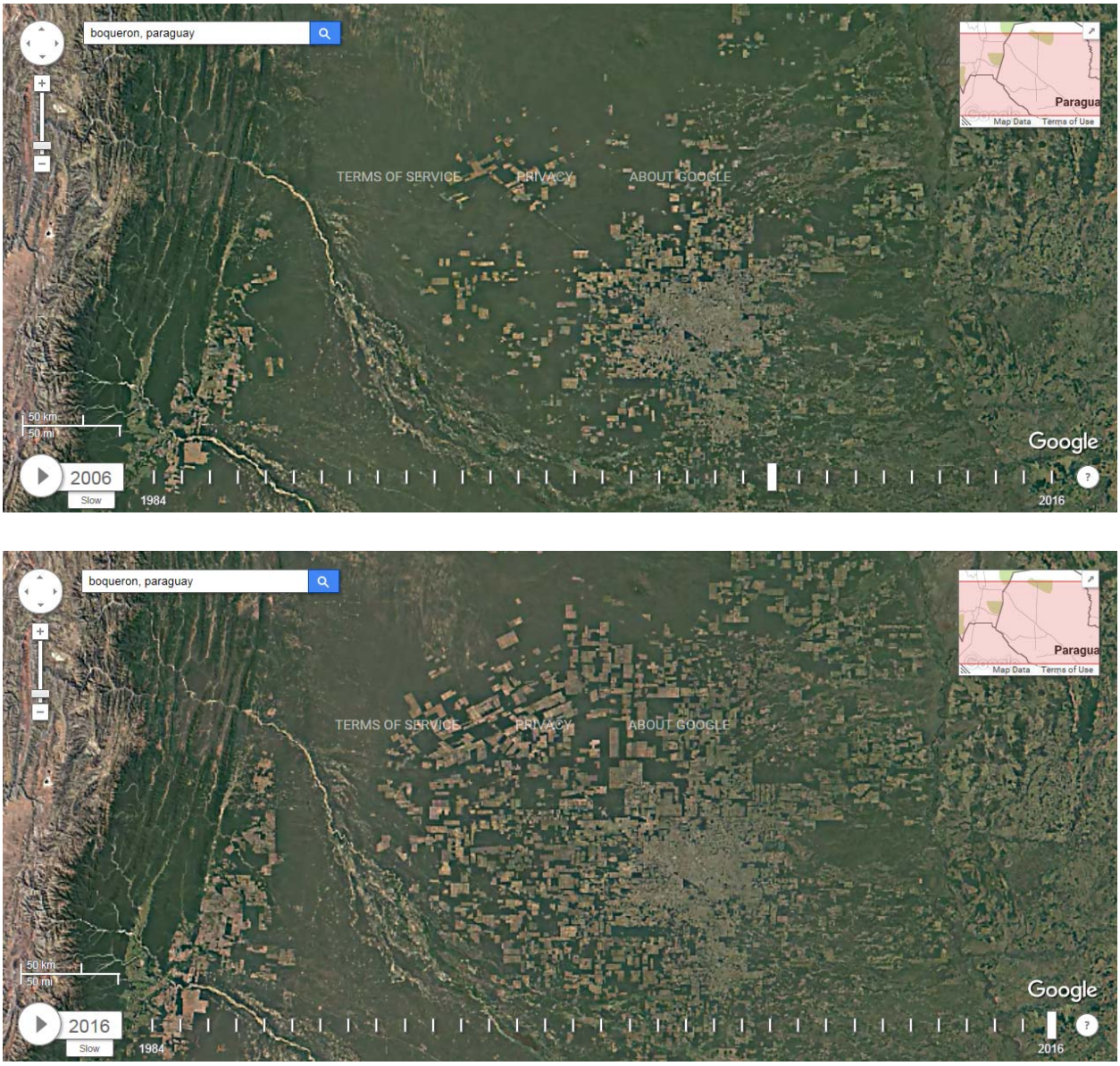
Figure 24. Tree-covered Area in Paraguay by Department, 2000–2015. Source: Hansen et al. (2017).

Appendix K. Satellite Imagery of Selected Locations in Paraguay

Boquerón Department, Paraguay

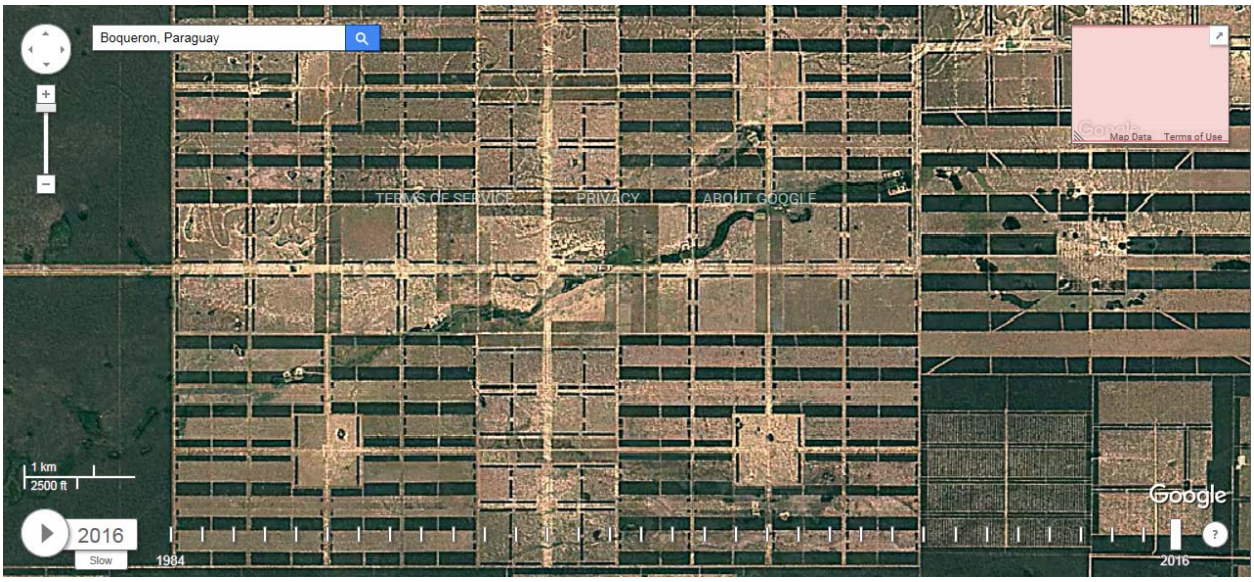






Note: Time lapse video is available at https://earthengine.google.com/timelapse/#v=-21.98125,-60.96502,6.292,latLng&t=3.23

Figure 25. Land Use Change Imagery for Boquerón, Paraguay by decade, 1986–2016. Source: Google Earth Engine (2017).



Note: Vegetative buffers are likely the legally mandated buffer strips, illustrating natural forest reserve requirements. Time lapse video is available at https://earthengine.google.com/timelapse/#v=-21.96342,-60.89759,11.973,latLng&t=3.23

Figure 26. Close View of Land Use Imagery in Boquerón, Paraguay, 2016. Source: Google Earth Engine (2017).

San Pedro Department, Paraguay

Note: Time lapse video is available at https://earthengine.google.com/timelapse/#v=-24.3351,-56.33665,7.855,latLng&t=0.23

Figure 27. Land Use Change Imagery for San Pedro, Paraguay by decade, 1986–2016. Source: Google Earth Engine (2017).

Note: Time lapse video is available at https://earthengine.google.com/timelapse/#v=-24.3351,-56.33665,7.855,latLng&t=0.23

Figure 28. Close View of Land Use Imagery in San Pedro, Paraguay, 2016. Source: Google Earth Engine (2017).

Appendix L. Correlations among Cattle Stocks, Soybean Area, and Forest Cover in Paraguay

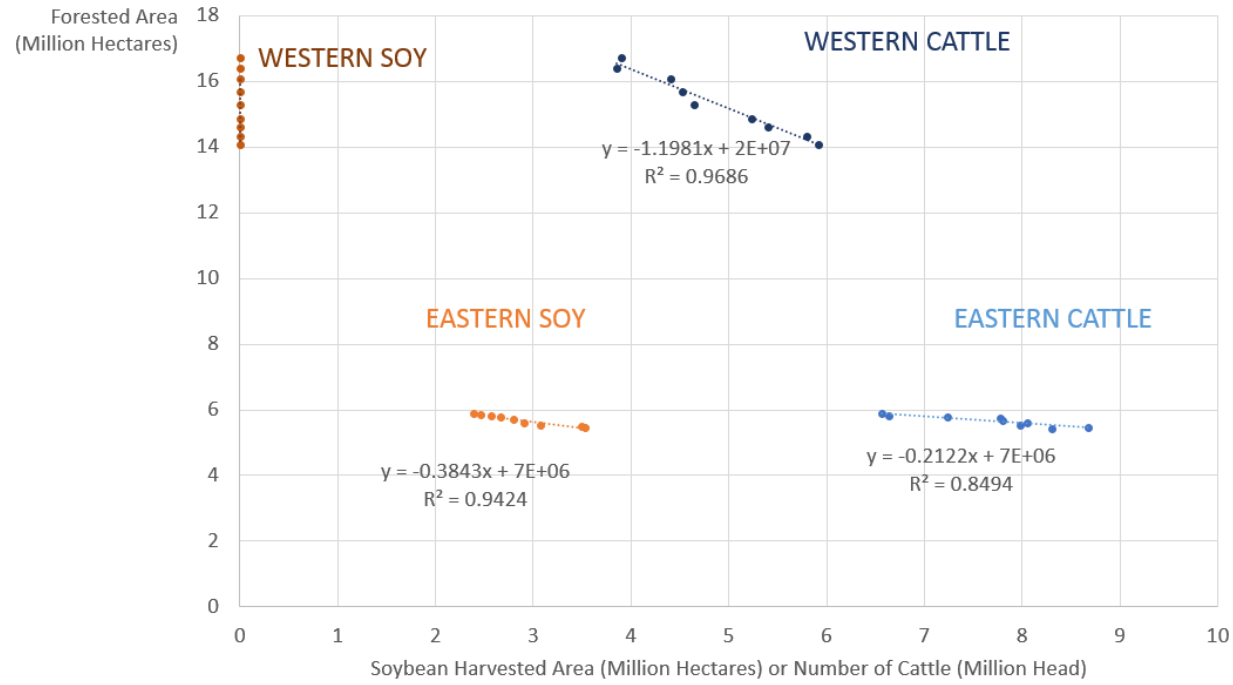


Figure 29. Regional Soybean Area and Cattle Stocks in Paraguay versus Regional Forested Area, 2007–2015. Source: Hansen (2017); USDA FAS (2017); FAO (2017); MAG (2016, 2017).

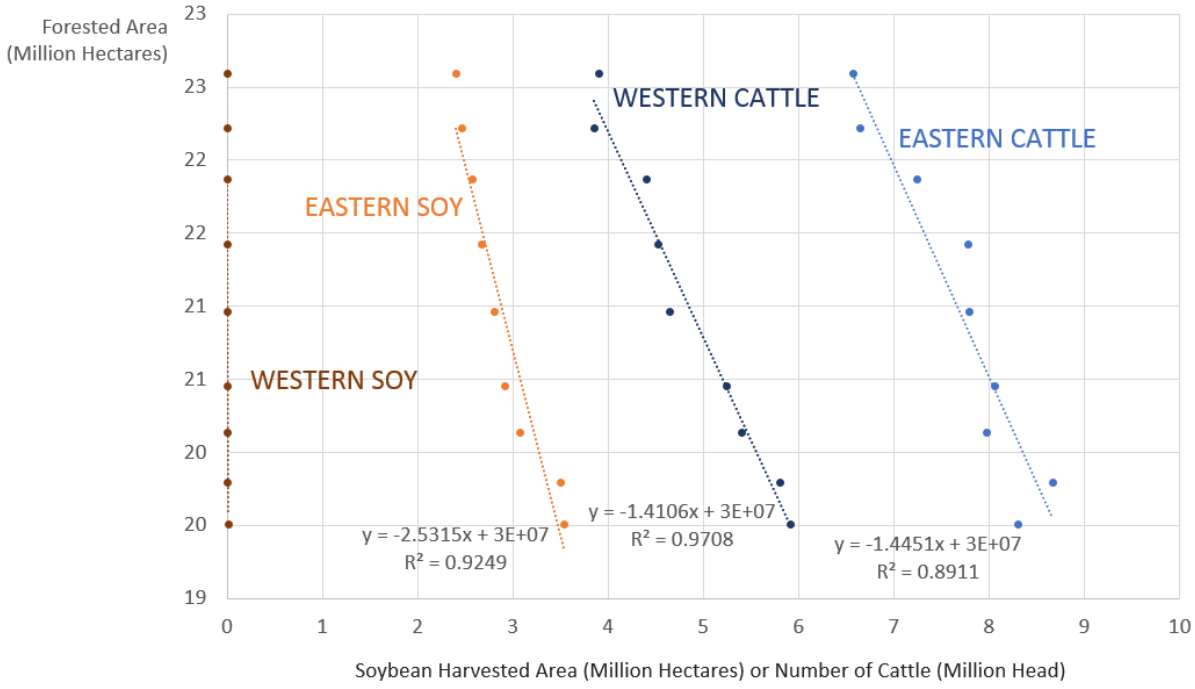


Figure 30. Regional Soybean Area and Cattle Stocks in Paraguay versus National Forested Area, 2007–2015. Source: Hansen (2017); USDA FAS (2017); FAO (2017); MAG (2016, 2017).

Appendix M. RTRS Classifications

Department	Hectares				
	Area deforested after 2009	Expansion potentially allowed after HCVA assessment	No expansion allowed	No land available for expansion	Responsible expansion as per legislation
ALTO PARAGUAY	967,383	1,573,136	5,988,880	3,789	350,424
ALTO PARANA	41,386	306,957	641,805	574,473	60,811
AMAMBAY	86,104	143,503	537,898	148,902	563,479
ASUNCION	0	576	881	0	1
BOQUERON	1,773,727	1,531,330	5,861,262	193	1,161,111
CAAGUAZU	33,381	362,922	535,079	265,845	337,860
CAAZAPA	23,685	398,066	404,863	94,177	266,779
CANINDEYU	78,408	250,569	804,977	433,075	226,877
CENTRAL	501	99,288	102,433	0	25,928
CONCEPCION	209,822	339,172	1,004,322	15,787	614,302
CORDILLERA	9,318	282,051	158,528	0	125,374
GUAIRA	10,142	155,673	185,408	6,015	111,740
ITAPUA	36,772	413,642	729,530	493,235	170,844
MISIONES	12,083	660,920	157,379	41,234	164,146
ÑEEMBUCU	431	1,229,984	109,458	0	0
PARAGUARI	6,448	390,834	354,383	0	320,150
PTE. HAYES	1,514,277	4,087,418	2,632,206	0	499,362
SAN PEDRO	192,878	942,670	704,950	142,014	502,359

Table 8. RTRS Classifications for Paraguay Departments. Source: RTRS (2015), via Global Forest Watch.

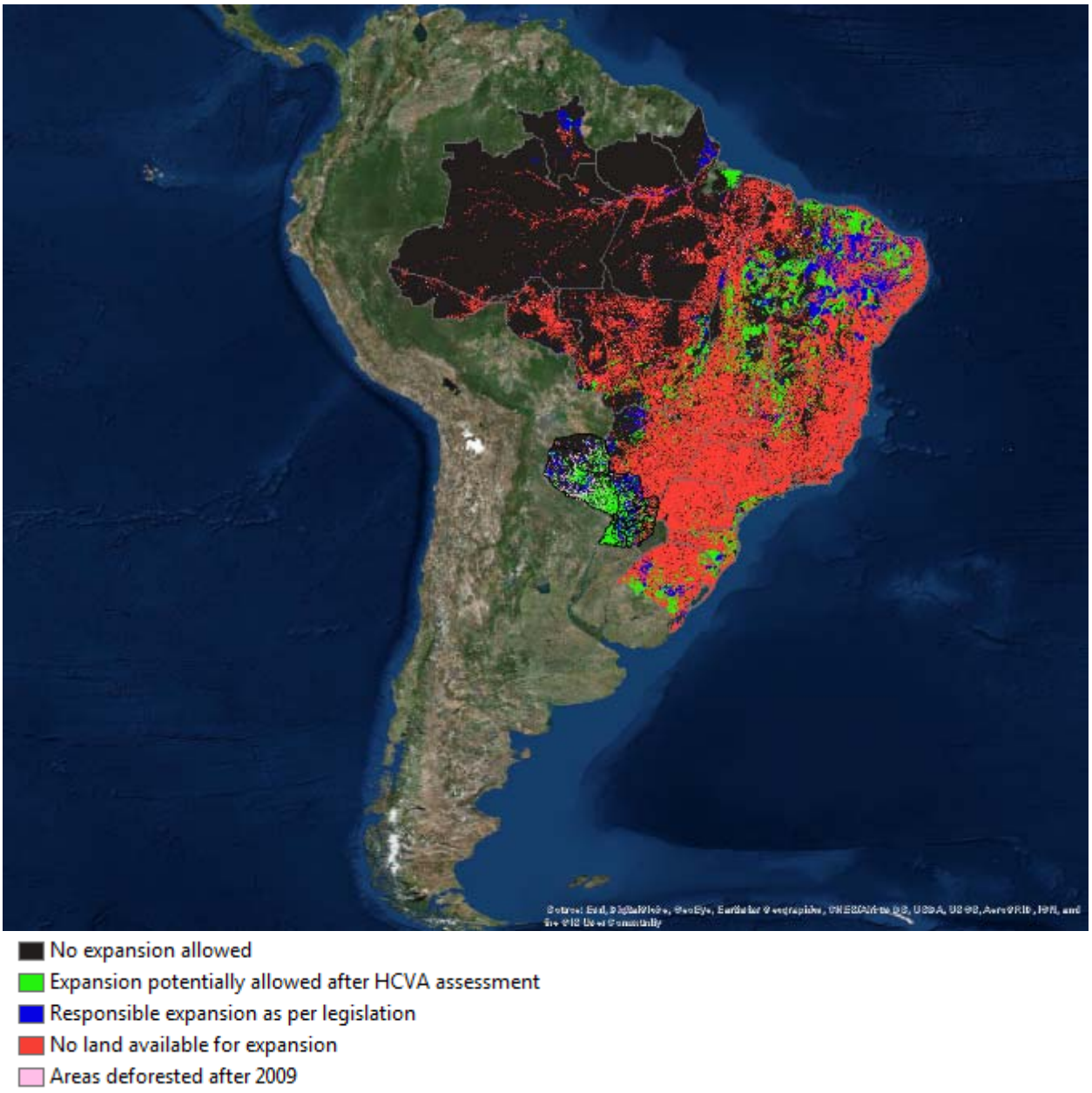


Figure 31. Map of RTRS Designations in Brazil and Paraguay. Source: RTRS (2015), via Global Forest Watch.