COMPLEX LAND USE AND COVER TRAJECTORIES IN THE NORTHERN CHOCO BIOREGION OF COLOMBIA

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ABSTRACT

COMPLEX LAND USE AND COVER TRAJECTORIES IN THE NORTHERN CHOCÓ BIOREGION OF COLOMBIA

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The Chocó bioregion in Northwestern Colombia is a lowland rain forest and hotspot of biodiversity. Significant land use and cover change (LUCC) is occurring throughout the region driven by global markets, illicit drug production, and civil unrest. The dominant land cover conversion is from primary forest to African Palm plantations, mediated and modified by complex combinations of social and biophysical drivers. This research combined a remote sensing based methodology to monitor LUCC in the region with an analytical approach for evaluating the possible trajectories of LUCC in a complex biological, socio-economical, and political environment. Synoptic LUCC models were developed using textural classification derived from Synthetic Aperture Radar (SAR) images for the period 1995 to 2010. LUCC models along with empirical social and spatial biophysical drivers were used to project historical land use trajectories. DINAMICA EGO a complex systems based spatial analytical framework was adopted as the platform to model land use change. The RADAR backscatter was able to capture areas were forest has been converted to African Oil Palm Plantations. However, an in depth characterization of the LUC dynamics was problematic given the spectral and spatial limitations of the sensor combined with the lack of ground data. The results of the LUC model suggest that under the current socio-political conditions African oil palm plantations will continue to expand toward forested areas into the territories traditionally

inhabited by Afro-Colombians and Indigenous populations. Insecure land tenure appears as a main driver of the transformation in close association with the conditions created by the armed conflict, and the drug traffic. The rate of the transformation appears to slow down in the period after 2007. However, according to the model by 2020 most of the area inhabited by ethnic groups will be transform to AOP. This study contributes towards the understanding of land use change in the context of social conflict. Although, it is recognized that conflicts impact the land–use and land-cover, few studies have address the linkages between particular circumstances and events in the conflict and the consequences for the land. As resource conflicts spread around the globe a better understanding of how it impacts the land and the people is paramount.

Dedicated to:
Isabel, my dear daughter.

ACKNOWLEDGMENTS

This dissertation topic started in a visit to the Institute Alexander von Humboldt in Colombia; the question at the time was whether African oil palm plantations were replacing the forest in the Northern Chocó. I knew little at the time about the underlying causes of the land change process or the magnitude of the events taking place in the country.

The escalation of the Colombian conflict and, in particular, the actions of paramilitary groups during the past 20 years have caused tremendous suffering to the Colombian rural inhabitants. Histories of violence, cruelty, and plain madness have plagued the Colombian landscape. The endurance of the human spirit in the face of such horrors is, however, extraordinary, as illustrated by Picasso's painting: the Guernika. This iconic painting depicts the horrors of war interwoven with hope and peace. Reconciliation and hope in Colombia comes through the stories of women, women that overcame violence and transform their sorrow into poetry, and in the construction of a better future for their children. My hope is that, together, we can all contribute to writing a more peaceful chapter in the history of Colombia. This work is my contribution to that endeavor.

I want to thank my family and husband for their unconditional support and my dear friends here and in Colombia; my advisor Dr. Joe Messina for his patience, support and incredible wisdom; my committee members Drs. Simmons, Lindell, Lusch, and Tucker for their support and willingness to be with me even after a long absence. I would also like to thank the following: the Center for Global Change, Dr. Qi and the staff members; Ashton Shortridge and Sharon Ruggles for their kind support; the graduate school for granting me the extensions to finish, and NASA and the NASA Earth and Space Fellowship program, grant number NNX08AV11H.

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CHAPTER 1

1.1 Introduction

Colombia is recognized as one of the five "megadiverse" nations in the world (Mittermeier, 1998), it ranks first in the number of species of amphibians and birds, and second in vascular plants. The country possesses 18 ecoregions, the second highest in any country in Latin America (Dinerstein et al., 1995). Two areas of the country have been identified as biodiversity hot spots: the northern Andes and the Chocó corridor (Myers et al., 2000). The Chocó region in Northwestern Colombia is a globally significant bioregion. Published data, based on species counts (Faberlangendoen and Gentry, 1991; Gentry, 1982), expert opinion (Myers et al., 2000), and molecular phylogeny (Jaramillo, 2006) identify this region as being one of the most diverse ecosystems in the world with about 80% of the biological resources of the region untouched (Gentry, 1986; Gentry, 1993; IIAP, 2001; Myers et al., 2000). Afro-Colombians, "mestizos," and indigenous groups of the Embera-Catios, Cunas, and Waunana ethnicities constitute the cultural diversity of the region (López, 1998). Recent (1997-present) and rapid Land Use Land Cover Change (LULCC) is taking place as a result of several competing forces: the ongoing armed conflict, the rise of ethnic movements, in particular among the Afro-Colombian communities; concern about biological biodiversity; and, most significantly, the rapid expansion of African Palm, *Elaeis guineensis,* plantations (Escobar, 2003, 2008; IIAP, 2001).

African palm oil is an edible vegetable oil produced from the fruit of the oil palm tree (*Elaeis guinensis)*, a species of West African origin. It has been under export production in West Africa from the mid-1800s and has emerged as one of the most significant globally distributed agricultural products (Corley and Tinker, 2003; Murphy, 2007). African Palm oil and its derivatives are used extensively in food, cosmetics, pharmaceuticals, detergents, and, in the emerging biodiesel industry (Anderson and Fegusson, 2006; Corley and Tinker, 2003). However, African Palm cultivation has been linked in Asia to biodiversity declines, deforestation, soil degradation, environmental pollution, and appropriation of indigenous lands, challenging the suitability of this non-native palm for Latin America (Aratrakorn et al., 2006; Linkie et al., 2003; Schroth et al., 2000, 2001; WRM, 2001;). Colombia is, the fifth largest producer of palm oil in the world, and is the largest producer in Latin America (Mesa, 2007; Leech, 2009). Global demand for vegetable oils is expected to double between 2012 and 2050 up to 240Mt (Corley, 2009) consequently, the palm industry in Colombia plans to expand African Palm agriculture from 147,000 ha in 1997 to 740,000 ha in 2020 (Fedepalma, 2000; Mielke, 2000). The crop is promoted by the Colombian government as a part of its "alternative development" plan and as a substitute for illegal coca cultivation (Moreno, 2000; Ramirez, 2003; Escobar, 2009).

African palm expansion in the last decade has occurred worldwide and throughout the tropical areas of South America (Garcia-Ulloa et al., 2012; Yui and Yeh, 2013;Hazlewood, 2012). Increasing interest in African palm oil cultivation has promoted remote sensing specifically tailored for the detection of African oil palm plantations: multi-sensor approaches were applied to identify AOP plantations in Peru and Ecuador (Santos and Messina, 2008; Gutierrez-Velez and Defries, 2013). Recent modeling efforts have been undertaken in Colombia to evaluate the environmental impacts of the projected AOP expansion, but these do not include the region (Garcia-Ulloa et. al, 2012; Castiblanco et al., 2013). The unique social, economic, and environmental factors of the region have not been taken into account in the modeling efforts.

Remote sensing, spatial analysis, and complex systems modeling provide tools to fill this information gap. Protecting the cultural and biological diversity of the Northern Chocó bioregion of Colombia is an explicit goal of Afro-Colombian and indigenous communities supported by the Inter-American Commission of Human Rights, and the Colombian Ombudsman Bureau (Escobar, 2003; Ombudsman, 2005). However, the development of any functional public policy requires a basic awareness of the site, the context, and the complex interactions of people and the environment.

1.2 Research Goals and Objectives

Land transformation in the Chocó region in Northwestern Colombia is occurring over a large and growing area. The dominant and continuing land transformation, from primary forest to African Palm, began in 1997 and is the result of endogenous and exogenous factors. AOP cultivation is part of development plans for the region and it is portrayed as an alternative to Coca cultivation (Flórez-López and Milán Echeverria, 2007, Escobar, 2008). This transformation is measurable via remotely sensed data and may be predictively modeled via a dynamic spatial simulation system. I will use a complex systems approach developed with DINAMICA- EGO a cellular automata (CA) type model that provides a platform for environmental modeling (Soares-Filho, et al., 2002), The main objective will be to characterize the land process that is driving the replacement of forest by AOP plantations.

In this system the forced displacement of ethnic communities is both cause and consequence in the land transformation process. This unexpected event shifted the status of the socio-ecological system from an isolated area with subsistence economic activities associated to the land to a system where land tenure is contested, large-scale agribusiness was introduced, and an egregious violent environment was established. The violent environment is caused by the presence of armed groups, elite economic interests and a forced demographic change. The future land trajectories and in particular AOP establishment is thus an emergent process driven by multi scale social and biophysical factors operating across both space and time. While the biophysical factors remain constant the socio-political and economic factors are very fluid.

In spite of the complexity, a few hypotheses regarding the land use trajectories in association to AOP establishment could be venture:

1. In the presence of financial and technical resources AOP expansion will continue regardless of who owns the land.

2. Alternatively, AOP will decrease in extent and will potentially disappear in the absence of the financial and technical means to handle the crop and its diseases.

3. In the absence of AOP the irreversible shift in the socio-ecological system will drive the land trajectories into the establishment of other agribusinesses (e.g. banana), cattle ranching, and gold mining with few areas transitioning back to forest.

1.3 Background

1.3.1 African Oil Palm

African oil palm, originally from the Guinea Gulf in western Africa, is a tall palm (8-20m) with a heavy, ringed trunk. It is monoecious with male and female flowers in separate clusters on the same tree. Natively, the palm is found in lowland or riverine forest, where it acts as a pioneer species in disturbed areas and is likely to be found in close relation with human settlements (Corley and Tinker, 2003). African palm growth is generally limited to altitudes below 500 meters and requires a wet tropical climate with mean low temperature of about 22^{o}C and mean high temperature of 33^{o}C and regular annual rainfall of 2000 mm or greater, although it can survive with as little as 1500 mm per year, if the rainfall is distributed throughout the year with a dry season of less than three months duration (Corley and Tinker, 2003). It requires adequate light and soil moisture, and can tolerate temporary flooding or a fluctuating water table (Corley and Tinker, 2003; Goh, 2000; Hartley, 1988). The optimal climatic conditions for African oil palm development are found in the countries located between 15^{o} north to 15^{o} south latitude.

The genus *Elaeis* is distributed in Africa and in tropical America, *Elaeis guianensis* is the true oil palm, *Elaeis oleifera* known as American palm or Noli occurs naturally in wet tropical ecosystems in central and Northern South America. *Elaeis guinen*sis is severely stressed in the neotropics by a wide range of diseases. The most significant one is known as oil palm bud rot or "pudrición del cogollo" responsible for the destruction of entire plantations in Colombia and neighboring countries (De Franqueville, 2003). In Colombia more than 60,000 Ha have been affected by the bud- rod (Phytophthota palmivora) in the southwest and central regions of the country (Martinez et al., 2013). As a result of the phytosanitary problems of the African palm, *Elaeis guinnesis*, efforts to hybridize the African palm with the native palm started early in 1960's; the resulting hybrids show some advantages compared with *Elaeis guinensis*: their annual height increment is lower, allowing for the plants to be harvested for a longer time span. The oil of the hybrids is richer in unsaturated fatty acids and more importantly they are more resistant to several of the most problematic pests (Pedersen and Balslev, 1990). In spite of the success with the hybrids, the plantations in the neotropics are still vulnerable to diseases calling into question the sustainability of the crop in the region (De Franqueville, 2003). In Colombia as in most of the commercial plantations in the world the recommended planted variety is tenera (DxP hybrid), which is a hybrid of dura and pisifera varieties of *E. guinensis*.

The slaves who used it as a primary food source first introduced African oil palm in South America in Brazil. In Colombia it was introduced in 1932 by Florentino Claes but the only trees that survived ended up as an ornamental garden in an experimental agriculture station in Palmira, Valle (Bozzi and Jaramillo, 2001). The United Fruit Company established the first plantation of African Palm in Colombia in 1945 in Tucurinca, Magdalena on the Caribbean coast. In 1957, the Colombian government started a program to promote African Palm cultivation; five years later the National Federation of African Palm Growers (Fedepalma) was founded (Bozzi and Jaramillo, 2001). In 2000 Fedepalma developed a plan for the industry that included the increase of African palm cultivation from 147,000 ha in 1997 to 740,000 ha in 2020, mostly for food production (Fedepalma, 2000). More recently, the Colombian government as a result of the emerging biofuel market has established a more ambitious plan. At present 470,000 Ha are under oil palm cultivation (Fedepalma, 2013a, 2015b).

1.3.1.1 Global Markets Expansion

African Palm grew mainly in Africa and in Brazil during the 19th century. In the 1830's, the British government deliberately encouraged the oil palm trade, and palm oil was exported from the Benin, the Bonny and, the Calabar rivers, in West Africa. During the 20th century, in the period between the two World Wars, Africa was the major producer of African oil palm followed by Malaysia and Indonesia. European countries and the United States acquired the oil for soap production. In Africa smallholders managed the crops whereas in Asia the production scheme was large-scale agribusiness (Corley and Thinker, 2003; Bozzi and Jaramillo, 2001). African oil palm has passed from being a minor crop as late as the 1960's to a crop that has steadily increased in annual production. The production has increased from 22 million tons in the year 2000 to 54 million tons in 2013 with Indonesia and Malaysia as the leader exporters and China, India and the EU as the principal importers. AOP production worldwide was 54 milliom tons in 2013 (Faostat http://faostat3.fao.org/browse/Q/QC/E; Corley, 2009). The main use for African palm oil, until recently, was for edible products. It is expected that the needs for edible African palm oil will increase as the Chinese and Indian economies continue to expand. However, the growing demand for biodiesel from European countries and the USA has changed the market perspectives. Since the beginning of 2006 the Malaysian government has approved 20 biodiesel projects with investments, usually with foreign capital, close to $515 million (Murphy, 2007).

A similar situation is taking place in Colombia where development plans aim to devote 6 million hectares to African oil palm cultivation; the plan includes infrastructure development, and institutional and policy changes (Uribe-Vélez, 2004; WOLA, 2008). In the period between 2007-2008 four biodiesel plants with the capability to produce 286 tons/year of biodiesel, the equivalent production of 63,256 ha of African palm crops, was approved. New national institutions such as the National Federation on Biofuels, funded in 2004 along with legislation that promotes the use of biofuels in Colombia are among the national initiatives. Expected sources of biofuel go beyond African Palm to include sugar cane and cassava (Arias, 2007).

The environmental consequences of replacing forest with African palm plantations have fostered an international debate; the main concerns are biodiversity losses, damage to the environment, and more recently food scarcity (Murphy, 2007). For some economic sectors the competition between food and fuel could be managed with an expansion in the areas devoted to agriculture. However, the goal of having food production, expansion of biofuel crops, and conservation of the forest at the same time appears to be incompatible. Additional factors need to be addressed to understand the drivers of LULCC and the impact of African oil palm cultivation in the context of Colombia: the internal conflict, drug trade, antidrug policies, counter insurgence policies, and national and international economic interests.

1.3.2 Internal Conflict

Colombia is one of the oldest democracies in the Americas, nevertheless it is a country with fifty years of internal conflict; one of the oldest conflicts in the Western hemisphere. Conflict has been a constant in the history of Colombia going back to the war of one thousand days in 1899 to La violencia in the late 1940's and early 50's to the ongoing conflict that is now more the 50 years old (Centro Nacional de Memoria Histórica, 2013). Exclusion and poverty in rural Colombia are considered to be the primary causes of the social unrest and armed conflict. The current armed conflict has never been treated as "civil war" nor has it escalated to encompass all of Colombia's territory (Perry Rubio, 1994; Rangel, 1998; Duncan, 2006; Centro Nacional de Memoria Histórica, 2013; Molano, 2013; Hataya et al., 2014).

The main armed insurgent groups (guerrillas) in Colombia that oppose the State are: the Revolutionary Armed Forces of Colombia (Fuerzas Armadas Revolucionarias de Colombia (FARC)), the National Liberation Army (Unión Camilista-Ejército de Liberación Nacional (UC- ELN)), and the People's Liberation Army (Ejército Popular de Liberación (EPL)). The FARC is a Marxist-Leninist Guerrilla group with origins traced to the peasant organizations of the 1960's. It is the oldest and best-trained group with 17,000 combatants and an unknown number of supporters (Duncan, 2006). Over time the political and social demands of guerrilla groups have lost popular support as a result of their use of terrorist tactics, human rights violations, kidnapping and extortion.

The strategies of the government to fight the insurgent groups have changed over time. As the guerrillas relied more and more on the money from the drug trade to support their activities, the Colombian government started referring to these groups as narcoguerrillas (Rangel, 1999; Duncan, 2009). The term was coined to denote a group involved in the production and trade of illegal drugs ignoring the social and political claims of the guerrillas. After September 11, and in the framework of the war on terror, these groups were listed as terrorist groups (Duncan, 2006).

The paramilitaries represent another major player in the Colombian Civil Conflict; they are believed to have about 20,000 militants. The main paramilitary organization is the AUC (*"Autodefensas" Unidas de Colombia; the united self-defense groups of Colombia), w*hich brings together most of the groups. However, these groups adopted a federal structure with a military commander in chief, Salvatore Mancuso, but each group has autonomy and independent regional dynamics (Duncan, 2006).

The paramilitary groups call themselves self-defence groups and claim to be purely counter-insurgent. However, they have been responsible for most of the killing and forced displacement of civilians. These groups were originally formed to combat leftist guerrillas and protect rural and urban neighborhoods and communities, but the main targets have been elements of the democratic left, labor leaders, candidates and elected officials belonging to the political party Union Patriotica, professionals, and student activists. Hundreds, have been killed at the hands of right-wing death squads, often in massacres, and hundreds more have been victims of anonymous death threats, and have been silenced or forced into exile (Rangel, 1998; Duncan, 2006).

On June 15th, 2003 the Colombian government signed an agreement in Santafe de Ralito, Córdoba (Northern part of Colombia) with some of the paramilitary groups. The agreement required the paramilitaries to stop the violence against civilians and to demobilize

(O'Shaughnessy and Brandford, 2005, Centro Nacional de Memoria Historica, 2013). In the aftermath of the demobilization process non-governmental organizations (NGO's), the Catholic Church, and some of the Afro-Colombian organizations in the Pacific region reported the presence of armed groups in their territories with the same characteristics as the Paramilitaries (Flórez-López and Millán-Echeverría, 2007). Colombian Government rapidly characterized the new groups as criminal bands not as paramilitary remnants. Further analysis has shown that these neo-paramilitary groups are diverse in origin, objectives and organization; they have in common its links with the narco-traffic, the lack of political discourse, and the use of violence (Granada et al., 2009; Prieto, 2013).

The paramilitary group that operated in the Curvaradó and Jiguamiandó watersheds arrived in 1997 and is known as the Elmer Cárdenas front. Since 1997, about 22,000 ha of land have been taken from the Afro-Colombian communities and later appropriated by commercial entities: Uraplama, Palmas de Urabá, and Palmado. The establishment of these plantations resulted in about 120 deaths and 1500 displaced people (Mingorance et al., 2004; Flórez-López and Millán-Echeverría, 2007, Molano, 2010; Centro de memoria historica, 2011). Logging activities along with coca cultivation are promoted by the paramilitaries as a strategy to control this region and appropriate the land. The cultivation of coca in communal territories violates the agreements about land tenure and the status of these territories. By planting coca the Afro-Colombian and indigenous communities are not fulfilling the social and ecological function entrusted to them; land expropriation, in this way, may be justified and legalized (Flórez- López and Millán-Echeverría, 2007).

1.3.2.1 The Drug Traffic and Antidrug Policies

According to UNODC the global cocaine retail value is estimated at US $ 80-$100 billions, equivalent to 0.15 % of the global GDP (UNODC, 2010). The market is supported by 243 million people (5.2% of world's population); 17.24 millions of whom correspond to cocaine consumers (UNODC, 2006b; UNODC, 2014). The production of coca leaves in the Andean countries provides the supply for cocaine production throughout the world. During the 1980's and 1990's Colombia became the country with the largest area under illegal coca production (UNODC, 2006b). The market for coca leaves and its derivatives at the farm level, amounted to a gross value of US$ 843 million, equivalent to 0.7% of the Colombian GDP in 2005 (UNODC, 2006a). In the 1990's, the U.S. changed its anti drug strategy from interdiction in the American borders to fighting the illicit drugs at the source. The strategy implemented was not new; however, it set the stage for the approval of Plan Colombia a U$1.3 billion plan to combat drugs within Colombian territory.

Andres Pastrana, the Colombian president at the time, proposed "Plan Colombia" in 1998. He described the plan "as a policy of investment for social development, reduction of violence and the construction of peace". The plan was presented in Washington for funding but the approval was subject to changes that reflected the counter drug goals and the broad framework of U.S. policy where the concepts of drug war, counterinsurgency and antiterrorism converge (Youngers and Rosin, 2005).

The plan comprised four components: (i) strengthening of the military, (ii) illicit crops eradication program, (iii) social development, and (iv) human rights. However, 80% of the resources have been spent in military and eradication programs. The eradication program has two components; aerial spraying of herbicides and manual eradication. Under the program different herbicides have been tested: tebuthirion, imazapan, and glyphosate based. Since 2000 glyphosate formulations have been widely adopted for use in coca and poppy eradication efforts (Ramirez -Lemus et al., 2005).

In spite of the efforts and after 172,026 ha sprayed with herbicides and 43,076 ha eradicated manually in 2006 alone; the area under Coca cultivation increased by 27% from 2006 to 2007 (UNODC, 2008). The persistence of the illegal crops and the spreading of the crop across Colombia have been described as a balloon effect (Buxton, 2006). The areas under eradication pressure are abandoned and the crop moves deeper into the forest or to completely new areas. Prior to 2002 no coca cultivation was reported for the Chocó bioregion (UNODC, 2002) and until the 1990's the presence of the illegal armed groups was transitory; the region was a model for non-violent resolution of conflicts (Escobar, 2003; Escobar, 2008; Flórez-López and Millán- Echeverría, 2007).

1.3.2.2 Violence and Displacement

The Pacific coast of Colombia has been a forgotten, neglected and isolated area since colonial times. The primary economic activities have been associated with extraction of natural resources and the exploitation of the indigenous and Afro-Colombian groups (IIAP, 2001, Escobar, 2008). This region presents the lowest indices of quality of life in the country; 60 percent of the population lives in extreme poverty, 70 percent of the population is illiterate, only 30 percent of the population has access to health services and child mortality is comparable with African countries with 110 deaths per 1000 born children (IDEAM, 2002, Sanchez, 2004).

The Pacific was fully incorporated into the Colombian civil conflict in the 1990's. Previous views held by the Colombian central government regarded the region as a swampy area of no economic potential; the new perception is focused on the richness of the natural resources and its geopolitically privileged location (Flórez-López and Millán-Echeverría, 2007). The arrival of the paramilitaries marked the start of a violent conflict that at the same time opened the space for development projects, one of which is the establishment of agro-plantations of African oil palm mainly in the territories owned by Afro-Colombian and Indigenous communities (Flórez-López and Millán-Echeverría, 2007).

The practices shaping the availability of any resource can create conflict with violence becoming the decisive means of arbitration (Le Billion, 2001). The violence and displacement of people in the Pacific is not random. The areas where violent conflict, massacres, and displacement are occurring are the same areas where mega projects of development overlap with black or indigenous territories (Escobar, 2003; Escobar 2008, Flórez-López and Millán-Echeverría, 2007). The Inter-American commission of human rights described the displacement of people in Colombia as a “humanitarian catastrophe”. According to the Centro de Investigación y Educación Popular (CINEP) by 1999 one and half million people were displaced in Colombia, the second largest displaced population in the world. Responsibility for the displacement in the country can be attributed 33% to the paramilitaries, 20% to various guerrilla groups, 16% to the armed forces and other state agents; the remaining percentage cannot be credited with certainty (Flórez-López and Millán-Echeverría, 2007).

Although, Colombia ratified in 1995 Protocol II of the Geneva Convention, which is intended to the protection of victims of non-international armed conflicts, forced displacement of civilians, a violation to the protocol, has occurred across the country. The Colombian government has failed either by action or inaction to protect its citizens and to comply with the Protocol (Flórez-López and Millán-Echeverría, 2007).

1.4 Theoretical Approach

The proposed research aims to link LULC science, political ecology, and complexity theories and methods to describe, understand and predict land cover trajectories, drivers, and processes in the Chocó bioregion. Land cover change is a process that takes place as a result of the interactions among several factors from the physical to the human dimensions (Geist and McConnell, 2006; Lambin, et al., 2001). Therefore, Land use change is a complex process which complexity arises in part from the many factors involved in the decision to transform the land.

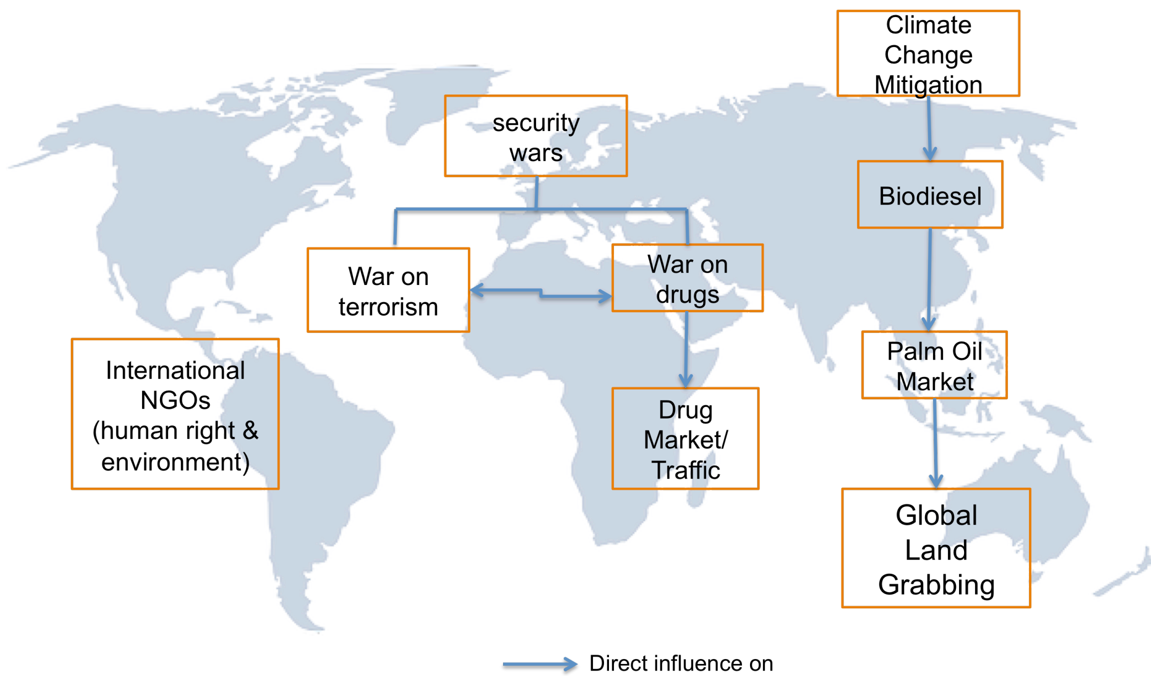
The land change in the Chocó region can be described as a socio-ecological complex system, as such it occurs in an environment or context that structures and influences its dynamics and interactions. The interactions in the system are often non-linear and regulated through positive and negative feedback loops. The resulting land cover trajectories are complex, encompassing processes and interactions that take place at different spatial-temporal scales.

The land use trajectories in this system imply an understanding of the endogenous and exogenous factors that constitute the context of the process. The endogenous factors consist of the biophysical characteristics of the area and its inhabitants. The exogenous factors include the underlying and proximate causes of change that operate at various scales. The emergent properties, the land transformation, as well as the endogenous factors manifest at a local scale and can be observed and measured through remote sensing observations or other data. However, the underlying and proximate causes range from local, national, to global and their influence and relationship to the land change process are not evident on the ground (Figures 1.1, 1.2, and 1.3).

The distribution of the drivers into scales is useful to describe and approach the analysis of the system yet the relationships are inter-scalar with elements moving across different scales.

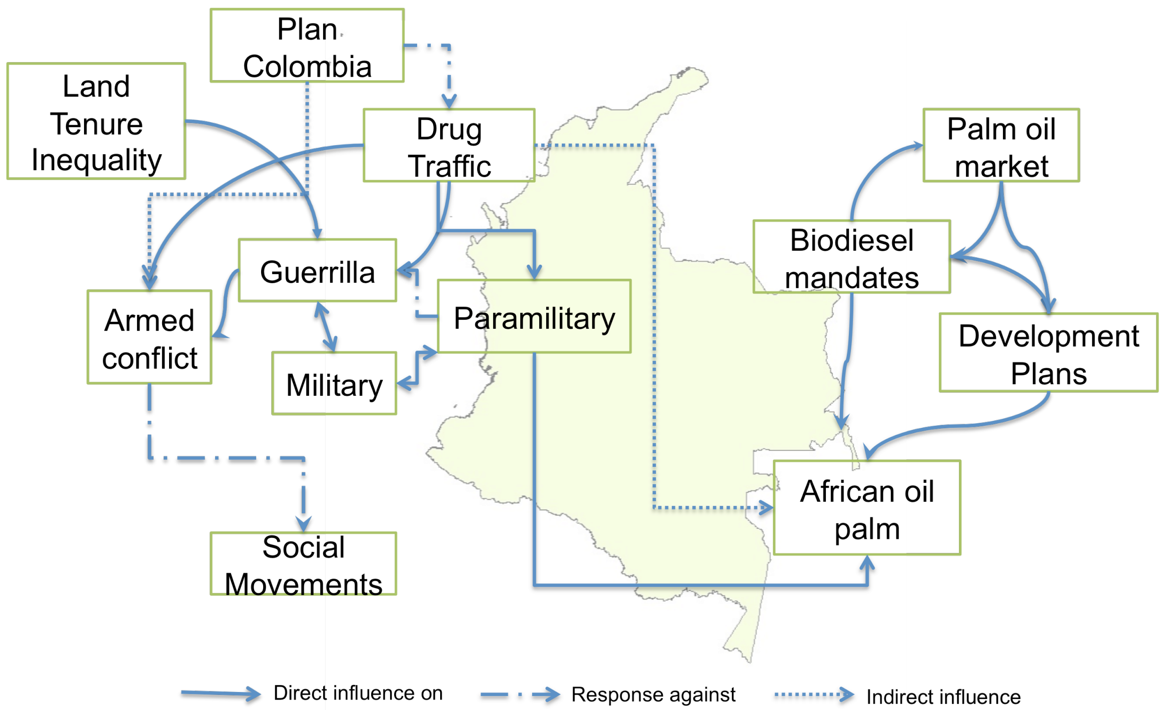
The proximate causes are defined as those human activities that directly affect the environment. The underlying causes aim to include broader economical, political, demographic, and cultural forces that are behind the biophysical changes (Geist and Lambin, 2002). For the Chocó region the obvious proximal change is agricultural expansion. However, the underlying causes are not as obvious.

Figure 1.1: International Scale. This Figure shows the underlying drivers of land use change at international/global scale in the Chocó socio-ecological complex system.



At a global/international scale policies related to climate change mitigation, the security and drug wars, and international NGOs are elements of the system that influence the land use trajectories (Figure 1.1). At a national scale (Figure 1.2) drug production and traffic, palm oil market, and the armed conflict constitute underlying causes of land use change. For the Chocó socio-ecosystem forced displacement and agricultural expansion represents the proximate causes of the transformation (Figure 1.3). The relationships between the process-taking place in the study area and the underlying and proximate causes are not evident and need to be established.

Figure 1.2: National Scale. This Figure shows the underlying drivers of land use change at national scale in the Chocó socio-ecological complex system.

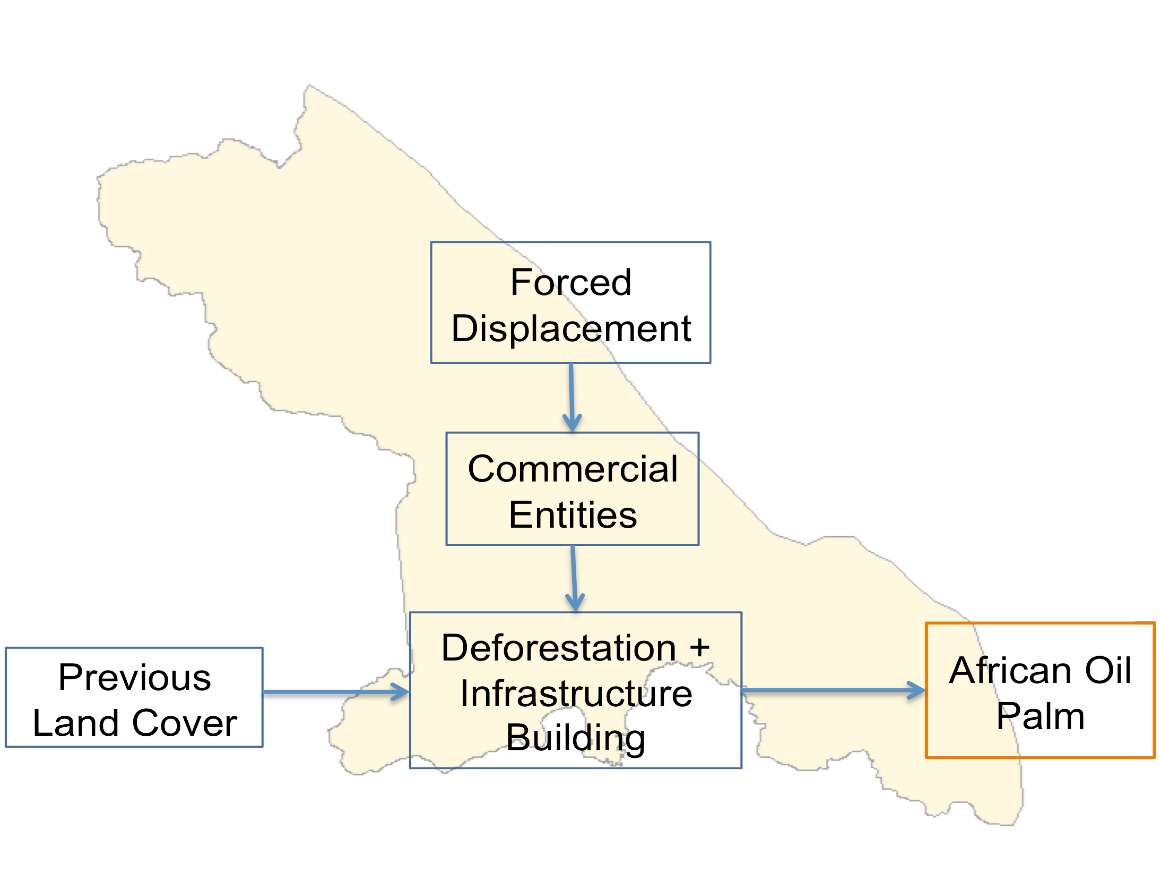


In the case of the Chocó socio-ecosystem, global influences (Figure 1.1) have shaped and engender the conditions for the change to take place. For instance, the policies adopted to mitigate climate change, that have been agree upon by several developed countries have resulted in the formation of a global biofuel market. Associated with the market " global land grabbing"[1], an unintended consequence has spread in tropical regions (Borras and Franco,

1 A general consensus about a definition of land grab has not been reached (Edelman et al., 2013). Divergences in the different land grab cases make it difficult to typify. However, "Global land Grab" has become a catch phrase to refer to the explosion of (trans) national commercial land transactions and land speculation in recent years in relation to large-scale production and export of food and biofuels (Borras and Franco, 2012). In the case of Choco land grab describes the process of land dispossession associated to the forced displacement of ethnic populations followed by the establishment of African oil palm plantations.

2012). At national scale, policies intended to boost biofuel production and consumption mirror the international adopted strategy. In Colombia the expression of this global, regional, national forces crystallized on biofuel mandates and economic incentives for the establishment of African oil palm plantations (Figure 1.2). The biophysical characteristics of Chocó along with these circumstances contributed to make land grabbing and AOP establishment a reality in the region.

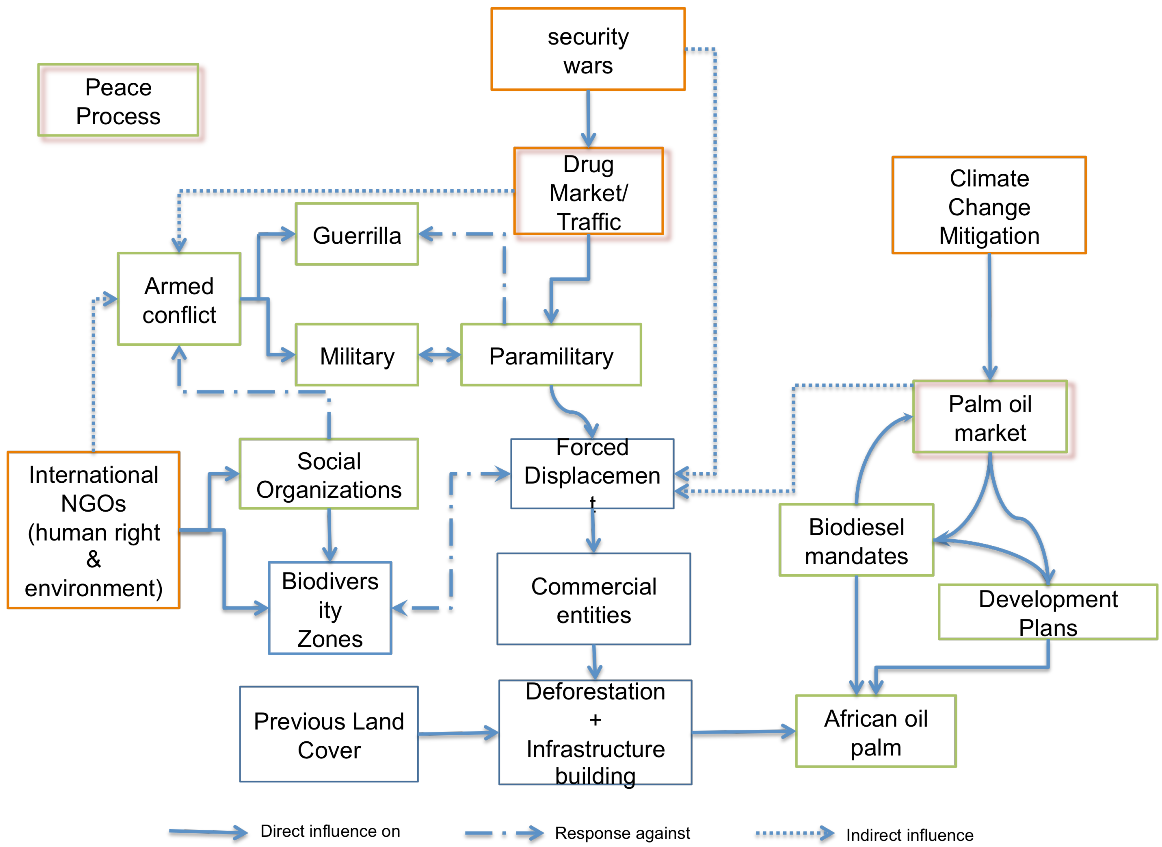
Figure 1.3: Local Scale. This Figure shows the underlying drivers of land use change at local scale in the Chocó socio-ecological complex system.



On the other hand the war on drugs (entangled with the security wars) has had a profound effect in Colombia. At the national level the war/security drugs is reflected in plan Colombia, a counternarcotics US military and diplomatic initiative (Figure 1.3). The consequences of plan Colombia in the country are manifold and an exhaustive explanation is beyond the intent of this research. The aspects that pertain to this research are related to the" balloon effect" and the vicious cycle of drug and war that has been established. The drug traffic has provided the financial means for the Colombian internal conflict to persist. As such the boundaries between guerrillas, paramilitaries and drug traffickers have become fuzzy over time. The war on drugs has kept the drug market alive and lucrative while it creates a "balloon effect". The balloon effect states that pressure in one location make the production and trafficking move to a new location with no more than a temporary inconvenience for the drug traffickers (LSE, 2014). In the case of Colombia drug production, trafficking and the armed actors are mobile and pressure in the traditional areas of coca production resulted in the spread of the problem throughout the Colombian territory (Ramirez-Lemus et al., 2005). The arrival of these mobile actors to the Choco region in the mid 1990's created the conditions for the violent actions that resulted in the forced displacement of people, in turn the proximate cause of land use change.

In addition, the presence of national and international environmental and human rights NGOs provides another element to the context (Figures, 1.1, 1.2 and 1.4). The presence of these organizations in the region is related to the concerns of the national and international communities for the conservation of biodiversity and the protection of ethnic minority groups. Although, their influence was subtler it has provided the opportunity to document the socio-political episode bringing it to the attention of the international community (including the inter-American commission for human rights). International pressure and the increasing visibility of the Colombian conflict brought the land issue to the forefront to became a national "public problem" (Grajales, 2015), in the Chocó region has provide the communities with legal elements to oppose the land grabbing.

Figure 1.4: Scales Integration. This Figure shows the integration of underlying and proximate drivers of land use change at international, national, and local scales in the Chocó socio-ecological complex system.



How can such a complex system be modeled? A reductionist approach will suggest the study of the different elements in isolation. However, studying the drug market does not provide any inside into the process of land use change. Neither will a study about the paramilitary groups or the Colombian armed conflict. The opposite approach will suggest the construction of a model including all the elements that constitute the environment of the system. Perhaps the ideal system to study this particular land cover transformation is three-dimensional: One dimension representing the endogenous elements a second dimension accounting for the exogenous processes occurring at different spatial scales, and a third-one that accounts for time. Inside this three-dimensional space, fuzzy agents moving according to a set of optimization rules will complete the model. Although such an approach will be closer to represent reality in practice it will render the model untreatable. For instance, attempts to model the drug market have described it as chaotic and unpredictable (Erdi, 2008).

In a different venue, complexity theory suggests that some understanding of the behavior of the system and simulation capabilities can be built by finding simplicity. That is to find the key elements that could better represent the emergent behavior in the system. In that pursue cellular automata provides a method by which a complex system could be constrain by using cells that are discrete in time, space and value making the exploration of the processes behind the change more amenable and providing an opportunity to identify key drivers[2].

The use of CA models requires the development of synoptic LUC models and a spatial representation of the key endogenous and exogenous elements of the system. Therefore, The first step towards understanding the system involves characterizing the geographic location, extent, rate of change, and the spatial pattern, all of which can be addressed using remote sensing and statistical methods. In addition, land use change science has been successful at identifying proximal and underlying drivers of change (Geist and Lambin, 2002).

Neither the LUC synoptic models nor the CA provide an analytical framework to understand the socio-political and economic relationships that reside at the core of the underlying causes of land use change. An awareness of how these relationships work and how they relate to the imbalances in access to resources, the distribution of power in social relationships, and the urges of capitalism (Walker and Richards, 2013) are needed to guide conservation and development policies.

[2] A more thorough description of CA can be found in section 3.3.1.

Political ecology provides the analytical framework to explore the causes behind the causes. Political ecology combines the concerns of ecology and political economy. A new element in political ecology is the consideration of ecosystems not only as social constructs but also as biophysical realities. Therefore a political ecology framework within the land cover and land use change discourse will be helpful to guide the integration of social, economic, historic, and political considerations at multiple scales. Struggles over natural resources and their relationship with conflicts have been a traditional area of study in political ecology (Robins, 2004; Simmons, 2004). However few studies have explored the linkages between resource scarcity and large-scale violence. The process in the Chocó region is more similar to the struggles for land associated with capital development in the Brazilian Amazon (Simmons et al., 2007) than the Diamond wars in Sierra Leone and Botswana (Le Billion, 2008) at the same time it is more complex and includes many other factors other than land tenure conflicts (e.g. drug traffic and armed conflict).

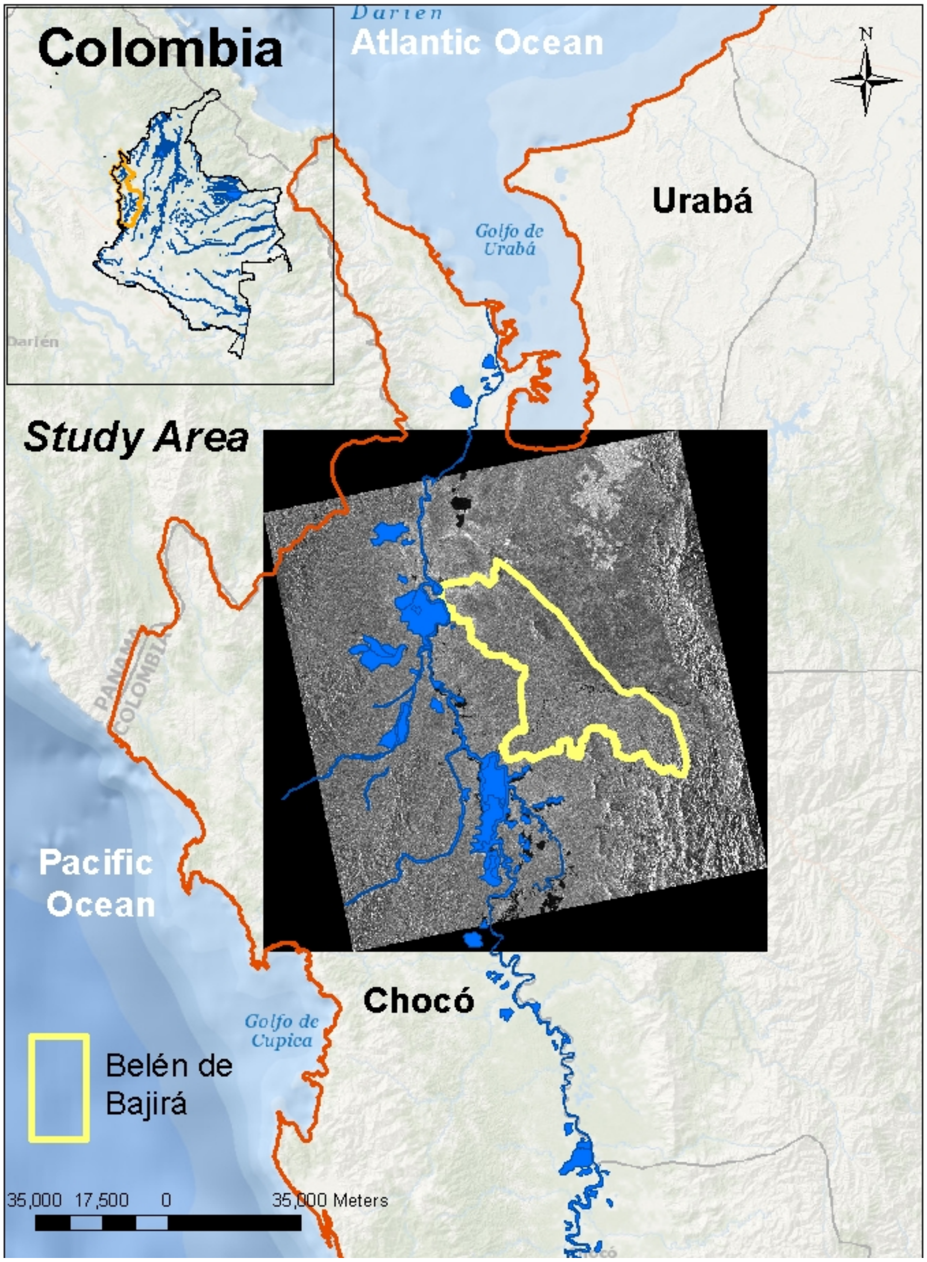
Political ecology along with LUC science provides a thorough description of the different elements and processes that are part of land cover transformations in the Chocó bioregion. The resulting land covers could then be considered emergent properties of the system amenable to be model through complexity theory and methods. Complexity theory and cellular automata have successfully been used as an analytical approach to examine couple human-natural systems in Ecuador in relation to land use dynamics (Walsh et al., 2008), to explore and model deforestation processes in Venezuela (Moreno et al., 2007) and to reconstruct landscape trajectories in the Peruvian Amazon (Arce-Nazario, 2007).

1.5 Research Design

1.5.1 Study Site

The specific section of the Northern bioregion to be studied (Figure 1.5) is located in the Jiguamiandó and Curvaradó watersheds, in the municipality of Belén de Bajirá, in the northern Chocó bioregion of Colombia. The area is encompassed in the Landsat image Path 10 Row 55. The area is bordered on the north with Turbo municipality (Antioquia), to the south and west with Riosucio municipality (Chocó), and to the east with Mutatá municipality (Antioquia). The climate is classified as tropical super humid with temperatures above 25°C. A high precipitation regime combined with a mild dry season make the region suitable for African palm cultivation.

Figure 1.5: Study Area.



1.5.2 Data

Land use and cover will be described using SAR data from RADARSAT, ERS, and PALSAR (Table 1.1). The region, a lowland rainforest, presents persistent cloud cover. A climatic feature known as the Chocó Jet that directs strong flow from the Pacific along and towards the western Andes near the Coast of Colombia causes the almost permanent cloud cover. The wide convective cores echoes coincide with the orographic forcing (Zuluaga and Houze, 2014). In other words the winds from the pacific collide with the western Andes causing clouds and rain to occur more frequently that they will do otherwise. Consequently, After an exhaustive search, both within the USA (EROS-USGS gateway) and in Colombia, no cloud free optical scenes were found, necessitating the primary use of synthetic aperture RADAR (SAR) data.

Synthetic Aperture RADAR SAR is an active sensor, collects information in longer wavelengths than passive optical sensors (Pohl and van Genderen, 1998; Qi et al., 2003). The basic quantity measured by a single-frequency single polarization SAR at each pixel is a pair of voltages that represent the effects of the scene on the transmitted wave. These measurements are determined by electromagnetic scattering processes (Oliver and Quegan, 1998), the backscatter signal is sensitive to the dielectric constant, related to moisture content. Because of this characteristic, SAR has been used primarily for applications that require an estimate of moisture status (Lillesand et al., 2004; Oliver and Quegan, 1998). However the backscatter signal is not only affected by the electrical characteristics of an object; it is also affected by object geometry (Lillesand et al., 2004). Therefore, SAR is sensitive to surface roughness, topography, and sensing system parameters such as depression or incident angles (Qi et al., 2003).

One major advantage of SAR over optical imagery is the ability to penetrate cloud cover (Lillesand et al., 2004). For African Palm remote sensing, this is particularly important since African Palm plantations are replacing the natural tropical forests in areas with high humidity and persistent cloud cover (Dennis and Colfer, 2006). Since signal response depends on structure, the electrical properties of the surface rather than on surface reflectance, it ought to be useful in the discrimination of African Palm.

Socio-historical and demographic data, dendrology, climatology, and basic geomorphology data are available at the following institutions in Colombia: IDEAM, DANE, IGAC, Code, Technologic University of Chocó, and the Ombudsman office. A previous survey, personally conducted, for data at the Instituto Geográfico Agustin Codazzi (IGAC), and at the Instituto de Hidrología, Meteorología y Estudios Ambientales de Colombia (IDEAM) confirmed the complete lack of information about the current state of land use or cover across the region.

Table 1.1: Data Sets. This table presents an overview of data sources and availability.

Dataset	Time Span	Resolution	Source	Archived at MSU
SRTM	2000	90 m	GLCF	Yes
LANDSAT	1991-2008	30 m	GLCF/EOS	Yes
RADARSAT	1995-2005	25 m	RADARSAT	Yes
PALSAR	2006-2010	10 − 30 m	ALOS	Yes
ERS	1995-2008	30 m	ESA	Yes
Cadastral Data	2005 2005	1:10,000 1:25,000	Code IGAC	Yes Yes
Demographic Data	Census 1993 Census 2005	Municipality	DANE	Yes

Socio-historical and demographic data from the 1993 and 2005 national census will be used. Available demographic data include gender, age, ethnicity, household income and economic activity, number of children, education level, and land ownership. The variables to be included in the model will be restricted to the variables and spatial scales, from the household to aggregate demographic data based on political units, available from the 1993 and 2005 census.

RADARSAT, ERS and PALSAR images are central to this project. The RADARSAT data to be used are standard beam 25m resolution C- band images with HH polarization corresponding to April 1997, 2000 and 2006. The three images have been purchased and one of them has been tested in a proof-of-concept model (Santos and Messina, 2008). The ERS data correspond to the C-band with VV polarization. The L- band PALSAR data used correspond to 4 images FBD (Fine Beam Double Polarization) from 2007 to 2010.

The combined effects of the different polarization characteristics and frequencies of the PALSAR and RADARSAT data are highly desirable in vegetation mapping (Kasischke et al.1997); the complementarity of L and C bands in land cover classification have been demonstrated for coastal areas (Simard et al., 2002). In addition, the use of multiple polarization images provides more structural information allowing for a better discrimination of targets with different geometric components. Broad leaf crops exhibit a high level of backscatter in C-band with less penetration, which will reduce soil backscatter and provide a better vegetation signal (Brisco and Brown, 1998).

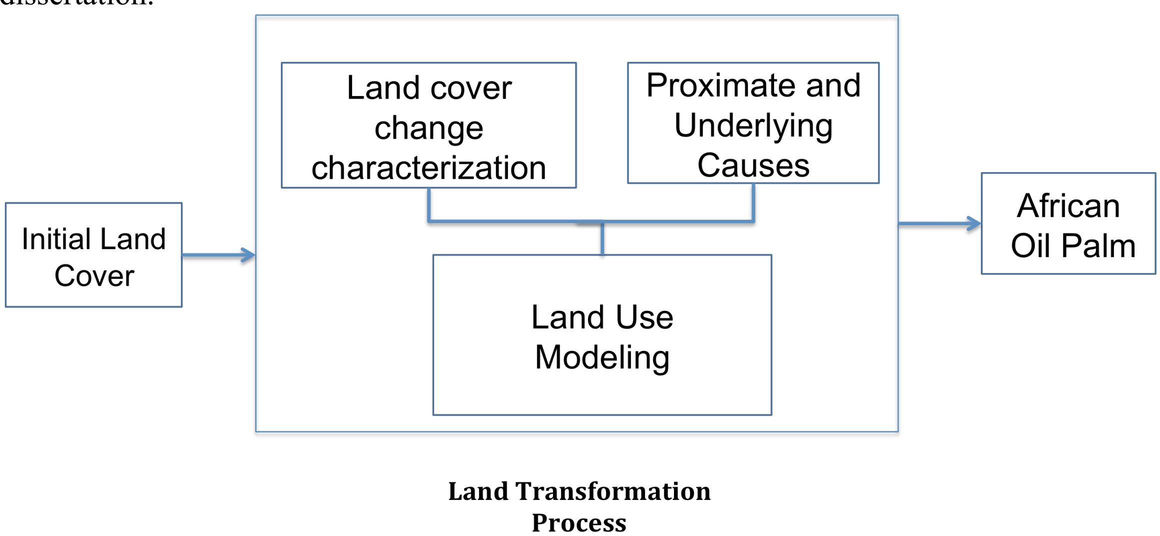
The L- band on the other hand is more sensitive to the presence of water on the ground allowing for the detection of hydrological changes that should have occurred as a result of the conversion from inundated forest to well drained African oil palm plantations.

The methods developed to identify African Palm will be transferred to the Alexander Von Humboldt Institute, Corpo, and the Ombudsman Office in Colombia. LANDSAT data from 1991 to 2005 have been acquired from the GLCF website LANDSAT of path 10 and row 55. The images will be preprocessed and corrected for topography using the SRTM data (Shepherd and Dymond, 2003). The area is included in the Panama - BCI Aeronet station, and MODIS products and atmospheric information were collected. Sample 8-day composite MODIS Level 3 products have been acquired.

1.5.3 Methods

The structure of this dissertation is illustrated in Figure 1.6. The process under investigation is the conversion of forest and other land covers to African oil palm plantations. The first step in the process is a spatial characterization of the change, in particular where the change has occurred if it has occurred. This step is accomplished through remote sensing methodologies. The second step is why, where and who took the decision for the land transformations and under what circumstances did it occur. That takes us to the underlying causes of the transformation. The underlying causes and the land cover characterization converge in the land use change-modeling framework.

Figure 1.6: Dissertation flow chart. This Figure shows the general framework of the dissertation.



1.5.3.1 Land Use Land Cover Classification

There are five specific LUC classes to be identified: lowland rainforest, flooded rainforest, African Palm, mixed agriculture, water and barren /sandy areas. While there are clearly many more potential LUC classes, it is unlikely that more classes will be discernable with the SAR data in this environment (Santos and Messina, 2008). With the exception of African Palm, each of these classes has been well identified in other Amazon based remote sensing literature

(Etter et al., 2006; Matricardi et al., 2005). Remote sensing of palm plantations has, to date, focused on management applications; palm age groups using Lansdsat TM (McMorrow, 2001) or biomass and carbon stocks from IKONOS data (Thenkabail et al., 2004). The complicated spectral mixed pixel relationship of palm plantations has frustrated many other research efforts (Messina and Walsh, 2001).

The use of SAR for land cover classification presents a challenge in terms of data processing and interpretation. Previous work has shown that RADAR backscatter intensity was correlated with leaf area index in African Palm (Rosenqvist, 1996). SAR texture information has been used successfully to develop land cover classifications in the primary forests of the Amazon (Oliver, 2000), wetland mapping (Arzandeh and Wang, 2002), land cover classification in mountainous areas (Peng et al., 2005). Recently, the fusion of RADARSAT derived texture measures, and Landsat data was successful in mapping African Palm in the Ecuadorian Amazon (Santos and Messina, 2008). One textural procedure that will be used is based on the grey-level co-occurrence matrix (GLCM), which provides the co-occurrence probability of pairs of grey- level pixels within a local window based on spatial arrangement (Pultz, et al., 1987; Herold et al., 2005). The use of different window sizes and fragmentation procedures will allow for "data mining" approaches that acknowledge the particular characteristics of each structural class (Henebry and Beurs, 2008).

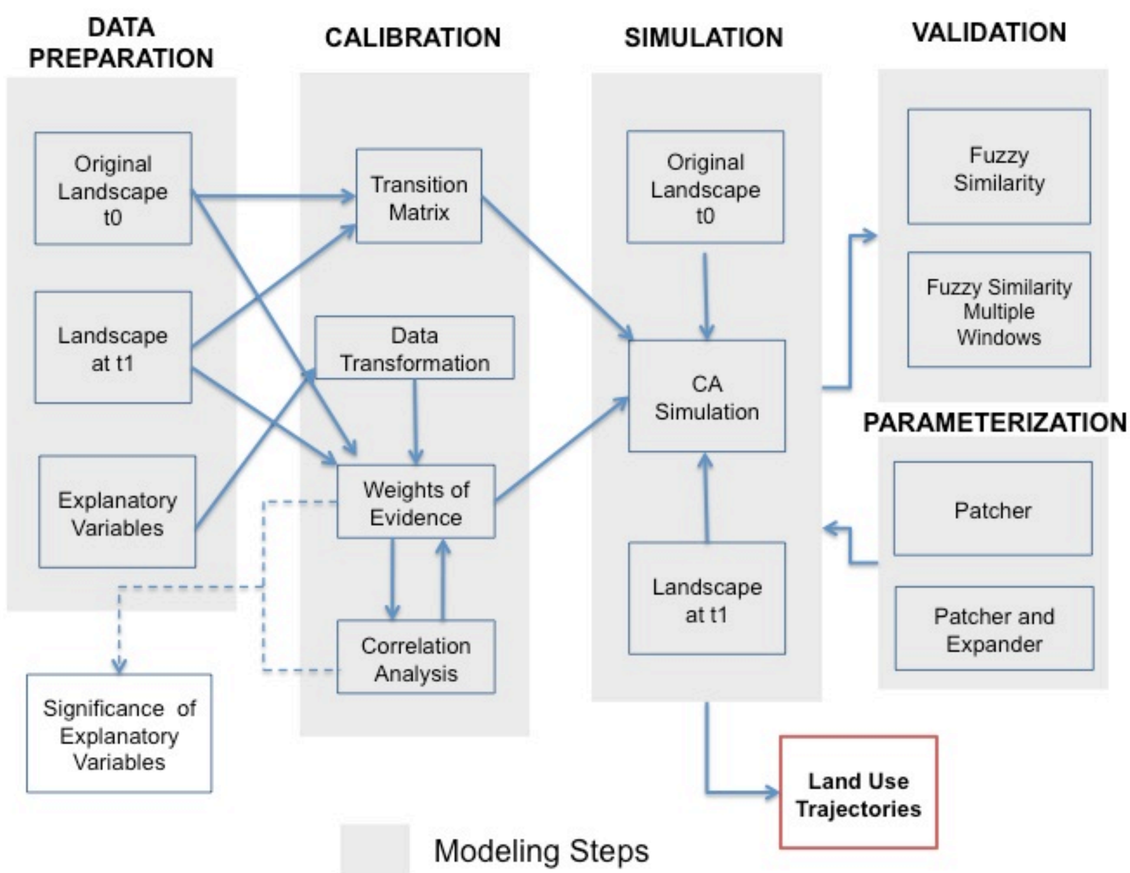
The effectiveness and potential of RADAR information to successfully monitor changes in land cover is yet to be explored (Almeida-Filho et al., 2005). To that purpose, the Advanced Land Observing Satellite (ALOS) launched in 2006 provides a unique opportunity for the development of monitoring methods based in SAR data. The mission contains a Phased Array L-band Synthetic Aperture RADAR (PALSAR) with variable resolution (Rosenqvist et al., 2007). In this proposal multitemporal SAR data and a combination of methods such as GLCM, the normalized difference index NDI, backscatter false-color composite BFCC (Almeida-Filho et al., 2005), amplitude decision trees (Simard et al., 2002), spatial extent data mining (Henebry, 2006) and SAR multiscale classifiers will be used with the aim to develop a system for the monitoring of African Palm expansion in the Chocó bioregion.

The ENVI software package and associated RADAR tools will be used for basic orthorectification and classification activities. Sample LULC classifications will be derived from SAR data. Large African Palm plantations in forested areas are easily identified by their spatial patterns (Trigg, Pers. Com., 2007). Since most images contain only small cloud free areas, these, arguably random, small area classifications will be used for a cross validation accuracy assessment (Congalton and Green, 1999). This approach is required as a substitute for validation fieldwork given the present dangers involved in traveling within the region.

1.5.3.2 Modeling

The modeling approach is illustrated in Figure 1.3 DINAMICA EGO will be used as the platform for the land use change simulations. The proposed approach uses empirical analyses to establish the manner in which population characteristics and behavior outcomes are associated with LUCC and then use CA (and the associated links between complexity theory and political ecology) to spatially and temporally model processes. The historical scenario will be examined based on empirical relationships, ranging from the history of regional settlement, to accessibility, to demographic and land use allocation resulting from exogenous policy decisions (e.g. Plan Colombia). Results of the historical scenario simulation will be used to examine the spatial distribution as well as the composition of LUCC, LUCC trajectories at the pixel and other levels, and temporal and spatial scale dependencies. The validation of the model will be performed following the criteria establish by Santner et al. (2003); comparisons of simulated patterns with empirical data derived from the satellite information in a maximum likelihood approach. It should be noted that this coupling of the simulation power of CA modeling (with its ability to allow for non-linearities and feedbacks) with a rich set of empirical relationships is a major advantage of the proposed research.

Figure 1.7: Model Flowchart. The Figure shows the steps followed to develop the land change model for the Chocó region. Data preparation, calibration, simulation validation, parameterization and land use projection. An in depth explanation of each step will be provided in the methods section.



1.5.3.2.1 General description of CA in relation to the land use-land cover change process

Several approaches have being use recently to model human-environment interactions. Among them the integration of multi-agent and cellular automata models, in the BIOCAPARO model in Venezuela (Moreno et al., 2007), and the SYPRIA (Southern Yucatán Peninsular Region Integrated Assessment) that combines Geographic Information Systems (GIS), agent- based modeling (ABM), cellular modeling, and genetic programming (Manson, 2006). These previous works do not attempt to identify the major drivers in the process, and furthermore lack a thorough incorporation of population dynamics and socio-economic considerations.

The proposed approach is to use empirical analyses to establish the manner, in which population is associated with LUCC, and then use CA (and the associated complexity theory) to spatially and temporally model the process. Various scenarios will be examined based on empirical relationships between biophysical factors, socio-economic factors, distance factors and external factors.

The transformation from Forest to African palm in the Chocó region is a complex process. The change involves environmental, human and structural processes occurring at different scales. The human interactions are stochastic and range from individual decisions, national institutions management to international policies. Environmental systems can be categorized and modeled in a deterministic manner. Human behavior on the other hand requires a stochastic approach (Messina and Walsh, 2005).

In the context of Colombia, agent categorization is difficult since for instance a paramilitary could be a legal or illegal driver and decisions are taken at the intersection of many circumstances. Therefore there are multiple routes an individual might take in making land use decisions (Boserup, 1965).

The dependent variable for the CA is the pixel transition from any cover type to African Palm. Quantitative and qualitative factors (independent variables) will be divided in biophysical factors (land cover type, elevation, slope, moisture), socio-economic factors (gender, anthropic pressure, economic activity), and geographic factors (accessibility distance). External factors that are not intrinsic characteristics of the cells will be included in the model as events. Events are external factors caused by human decisions (i.e administrative decisions such as development plans) that are stochastic and cannot be derived from the predictive evolution of the Cellular Automata. These external factors will allow for the evaluation of the effect of external factors that are not considered or modeled by the transition rules. Instead they will be modeled as underlying probabilities.

1.5.3.2.2 Calibration

For the model to be useful for policy decisions it will be useful to discriminate among the different drivers in the LULCC process. The goal of the sensitivity analysis will be to determine the degree to which factors, if any, are responsible for change. The sensitivity analysis that I will use is based on weights of evidence (Bonham-Carter, 1994). This approach aims not only to test the robustness of the model predictions but also to explore the relationship between the inputs and outputs of the model. For the implementation of the sensitivity analysis a scatterplot of each input in the model versus the output is created; from these plots it is possible to discriminate the inputs that seem to generate larger variation from the ones that produce a smaller variation. The correlation coefficients calculated between each input and the output would indicate the extent of whether or not there is a linear association between the inputs and the output (Bonham-Carter, 1994; Santner et al., 2003).

1.5.3.2.3 Validation

The LULC trajectories derived from the model will be compared and validated using by 1) Comparisons of the patterns obtained in the simulations with empirical data derived from the satellite information 2) Fuzzy similarity 3) Decay functions a with different window sizes.

The CA will be then applied for the historical land cover scenario. The initial socio-economic factors for future scenarios will be obtained from the 2005 census. The land cover for the future historical scenario modeling will be the 2000 land cover derived from SAR data.

The developed LUCC spatial simulation model will be an important tool in the evaluation of policies and in the identification of primary drivers of the LUCC in the Chocó bioregion. The use of political ecology linked to complexity theory and methods under a LULCC discourse explores how social and physical theories; concepts, frameworks and method can be used together to contribute to a better understanding of human-environment interactions.

Products from this research will be published in peer-reviewed journals and presented at national and international meetings. Methods developed will be publicly available and posted to the project web site hosted by www.globalchange.msu.edu. Results will be provided to the research partners including the Alexander Von Humboldt Institute, Code Chocó, and the Ombudsman Office in Colombia. The results will empower the local communities, NGOs, and international organizations to enforce regulations in place for the study area.

The rest of the dissertation is organized in 4 more chapters. The first part of chapter 2 describes the physical, biological and social characteristics of the region. The second part looks into the historical and political conditions that allowed the irruption of violence before the land cover transformation. Chapter 3 presents and overview of the national and international context for oil palm development. The second part of chapter three gives a brief overview of the state of the art in land use change science and land change modeling. Chapter 4 describes the data, remote sensing and modeling methods that were chosen to characterize and analyze future trajectories of land use in the region. The final chapter presents results, discussion and future research.

CHAPTER 2

The violence, land grabbing, and further establishment of AOP plantations in the lower Atrato river basin appeared at first as a single isolated event in the Colombian landscape. However, further research shows that that is not the case. In Colombian recent history land grabbing associated with the Colombian conflict and the war on drugs has caused a "the facto" agrarian counter-reform (Escobar, 2008; Reyes-Posada, 2009; Molano, 2013).

In the last 20 years and, in particular, in the period between 2000 and 2009 about 7 million Ha of land was taken from its original owners. Although Colombia had already one of the highest indices of land concentration in the world (see table 2.1) during the period between 2000 and 2009, the National GINI[3] land index increased 2.5% (Ibañez and Muñoz, 2009). As explored by Reyes-Posada in his book "Guerreros y Campesinos: El despojo de la tierra en Colombia" (Warriors and Farmers; The stripping of the land in Colombia), land grabbing has changed the Colombian rural landscape; small farms with temporary crops have become large cattle ranching and agro-industrial projects. The ubiquitous process has been more extense in 11 of the 32 Colombian departments. Although it looks systematic, the process has had different outcomes in different regions as a result of complex social, economic, and political local forces.

[3] The GINI coefficient is a common measure of inequality. The coefficient varies between 0 and 1 (or 100). A coefficient of 0 reflects perfect equality where as 1 reflects perfect inequality, meaning one person has all the income and others have none.

Table 2.1: Land Ownership in Colombia. Source: IGAC- Uniandes 2012.

Size of Property (hectares)	% Of Land Owners	Total %
Smaller than 3	57.3	1.7
Between 3 and 100	39.7	22.5
Between 100 and 500	2.6	14.6
Larger than 500	0.4	61.2
Total %	100	100

In recent years, the search for explanations to the Colombian conflict and in particular the violence and land grabbing has resulted in the emergence of a considerable body of literature to document and explain these socio-political phenomena. Several explanations and interpretations have been offered: for some it belongs under the sphere of the new wave of neoliberal capitalism associated with land grabbing elsewhere. Others typify it as a step in the formation of the state (Grajales, 2013); for others, it is a collateral damage associated to the Colombian armed conflict and the drug-traffic; still others described it as the continuation of the struggle for the land that appears more and more often as the root cause of the civil unrest in Colombia since the 19th century (Reyes-Posada, 2009; Molano, 2013).

The case of the Curvaradó and Jiguamiandó community councils in the lower Atrato River is emblematic. It is perhaps the best-documented episode of land grabbing, and cooperation between the paramilitary and military (Mingorance et al., 2004, CNMH, 2012). The biological and cultural diversity of the region along with the social organizations and processes make it distinctive from other land grabbing episodes. In addition it is one of the few cases that has attracted international attention from environmental and human rights organizations alike.

Whatever explanations one may accept for the events in the Pacific a proper understanding of the drivers of land use change in this region needs to look at different spatial and temporal dimensions (see Figures 1.1-1.4). This chapter aims to present a comprehensive historical description of the endogenous elements and the underlying drivers of land use change that constitute the context of the processes taking place in this socio-ecological complex system. The first part describes its rich natural endowment and its geostrategic location. The second part looks at the cultural diversity and construction of social movements that are unique in the Colombian cultural landscape. The third part looks briefly to the Colombian conflict, its history, actors, and how they came to play a key role in the land grabbing, and AOP establishment. The role of the Colombian government, military and institutions in the region is also explored. The last part focuses in the events as they unfolded in the municipalities of Belén the Bajirá and Carmen del Darién from the initial violence to the struggle of the communities to recover the land.

2.1 The Chocó Region

The study region is located in the northwest corner of Colombia (Figure 1.5). It is part of a broader geographical region the "Chocó-Bioregion" or the - Darien - Western Ecuador Hotspot. The extent of the broader area reaches from the Southeastern portion of Panama, along the pacific coasts of Colombia and Ecuador, as far as northwestern Peru. The exact limits of the region vary according with researchers interest and methodologies (Poveda-M et al., 2004). Within this area the Colombian Chocó biogeographic region (The Chocó) is a strip of 130,000 Square kilometers (105,000 on Colombian territory) along the Pacific coast (Sánchez, 2004). The region is globally recognized as one of the world's most biologically and culturally diverse. The Colombian Chocó provides habitat to an extraordinary wealth of animal and plants. It supports an estimate 9,000 vascular species, approximately 25% (2,250) of them endemic. It is believe to be the most floristically diverse site in the Neotropics (Gentry, 1993).

The Colombian Chocó biogeographic region administrative jurisdiction resides in the Nariño, Valle del Cauca, Chocó, and Antioquia Department's of Colombia. The Chocó department holds about 53,6 % of the total area (Galindo et al., 2009). The Chocó department is one of the poorest departments in Colombia; it is divided into 30 municipalities. The study area is located in the municipalities of Belén de Bajirá (Riosucio) and Carmen del Darién.

Belén de Bajirá was once a town from the Riosucio municipality in; in 2001 a departmental law elevated it to a Municipality. Following this decision, the neighboring Antioquia department enacted a boundary dispute (Mosquera, 2006), Antioquia states that Belén de Bajirá is under the jurisdiction of Mutatá, an Antioquia municipality. The Colombian court gave the rights to the town to Antioquia in 2007 but the situation, as of today, remains unclear.

2.1.1 Physical Environment

The region has a strategic geographic location at the western tip of South America. It constitutes a corridor to both the Pacific and the Atlantic Ocean and is the only land route into Central America. Geographically the study area is locked between the Western Andean Mountain range and the Serranía del Baudó in the Atrato River basin south of the Darién and Urabá regions. The Darién and Baudó mountain ranges originated in a volcanic island arc that emerged in the Middle Eocene whereas the Atrato river basin emerged in the late Pliocene through tectonic activity (Martinez, 1993).

2.1.1.1 The Atrato River

The Atrato River rises in the slopes of the Cordillera Occidental in the Andes. It flows northward through a flat marshy floodplain flanked by the Andes to the East and the Darien and Baudó ranges to the west, before emptying into the Gulf of Urabá (Lobo-Guerrero, 1993). The basin has an approximate surface of 40,000 Km2. The river has an extension of 700 Km (420 miles) a relatively short river with a large discharge 4,000 − 5,000 cubic meters of water per second (175,000 cubic feet) transports a very large quantity of sediments. Platinum and gold mines are found in some of its tributaries and the river sands are auriferous. In a region with very poor infrastructure the river has become the main transportation route with 500 Km of it navigable by small boats (IIAP, 2001). The Atrato River was one of the three aquatic open channels (portals) during the Tertiary. The other two being: the actual Panama Canal and the Lago Gatún in Nicaragua. There is evidence that the volcanic activity caused the Colombian portal to close for short periods during the Eocene, allowing the entrance of rodents and primates into South America (Sympson 1950, Duque-Caro 1990).

The region's soils have been poorly studied. The predominant soil is a marshy soil of the alluvial plain that is present only in this area of the Chocó biogeoregion (Poveda-M, et al., 2004). The recent alluvial plain was formed by the accumulation of deposits from the Atrato River (Lobo-Guerrero, 1993); while the more hilly areas resulted from the dissection of tertiary sediments (González and Marin, 1989). The soils of the alluvial plain have poor drainage (Tropaquents, Tropaquepts, Fluvaquents), with the exception of the soils in terraces and natural docks where the soils are relatively well drained (Tropofluvens, Dystropepts, Eutropepts) (Cortes, 1993). The drainage in the hilly areas depends on the topography with soils ranging from well drained (Dystropepts, Troporthents, Tropudults) to poor drained (Tropaquepts) in concave areas between hills (Cortes, 1993; Poveda-M et al., 2004). In the slopes, soils tend to leach the nutrients due to high rainfall (F. Golley, et al., 1975).

2.1.2 Climate

Located in the Inter-tropical Convergence zone close to the terrestrial equator, the whole region was classified by Thornthwait in a unique climatic classification as a super humid A zone without any water deficiency (Thornthwaite 1948, Eslava, 1993). High precipitation rates, the highest in the Americas constitute a distinctive feature of the Chocó-bioregion. The pacific region is the most humid area in Colombia, in particular in sections of the Chocó Department and in the coastal areas of Valle and Cauca departments. The precipitation records reported for Tunendo with 11394 mm, Lloro with 12717 mm and the extreme values registered in Vigia de Curvaradó – Chocó of 26303 mm in 1974 and Tunendo – 19443 mm in 1981, confirmed the central part of the Chocó-bioregion as one of the rainiest places in the world (Eslava, 1993, 1994; Rangel-Ch and Arellano, 2004). In the North the influence of orographic factors due to the presence of the Serranía del Baudó and the foothills of the Western mountain range and the closeness in the South to the Pacific Ocean influence the high rainfall regime (IDEAM, 2005).

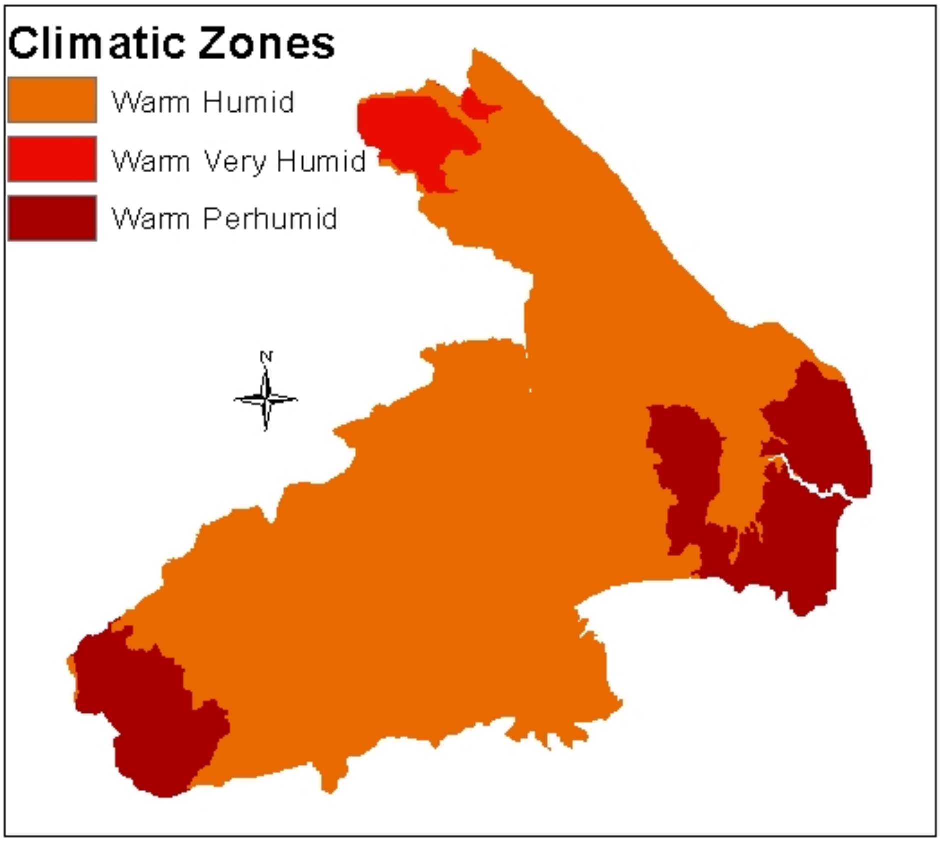
Relative Humidity is almost constant throughout the region with minimum values between February and March with maximum values in May for the South and October and December for the rest of the region. The rain frequency is consistent with the high precipitation values with 200 to 300 hundred or more rain days in a year (IDEAM, 2005).

Along the Pacific there is an almost constant cloud cover for most of the year (40% to 90% of Cloud cover) (IDEAM, 2001). It is the area in Colombia with less solar radiation intensity with values bellow 4,0 KWh/m2 a day. The lowest solar radiation values are reported during November 3,2 hours/day and the highest occur during the less rainy season in July with 4 hour/day (IDEAM, 2001, 2005).

The rain distribution presents a clear pattern that varies along with the altitude and latitude. A summary of the altitudinal variations in rain patterns is presented in table 2.2 (Rangel-Ch and Arellano, 2004). The precipitation and temperature variations related to altitude are described only for the Northern section of the Chocó-bioregion where the study area is located.

Three types of climates are found in the study area: Warm humid, warm very humid and warm perhumid, Figure 2.1 (IDEAM, 2005). The warm humid and very humid correspond with temperatures above 24 ^{o}C and precipitations between 2,000 and 4,000 mm and between 4,000 and 8,000 mm respectively. The perhumid climate is defined as a climate where the evapotranspiration is only 0.25 to 0.5 of the mean annual precipitation. This classification is important from the agroclimatic stand point of view. It takes into account the water balance of the soil defined as the water availability in the soil and its distribution over time (IDEAM, 2005). According to this classification the region presents water in excess requiring drainage instead of irrigation for agricultural use. Crop production, although difficult, is possible in particular for annual crops with high water requirements (IDEAM, 2005).

Figure 2.1: Climates. It shows the three climatic zones present in the study area.



The climatic conditions of the study area make the establishment and development of large-scale agriculture challenging. In the past, agricultural production has been curtailed by phytosanitary problems (Castaño-Uribe, et al., 2001). For instance, banana (Musa spp.) plantations in the region are affected by a fungus *Mycosphaerella fijiensis* (Morelet) that causes black Sigatoka[4] (Etebu and Young-Harry, 2011); the AOP plantations in the study area were affected in 2007 by a pest (presumably bud root) that destroyed them; currently the area is being replanted with a palm hybrid resistant to the illness (Colombia Land, 2013).

[4] Black Sigatoka Disease (BSD) is a leaf spot disease of plantains and banana caused by a wind-borne fungus. It has been the most important threat for banana production worldwide. BSD attacks plant leaves producing small spots of dead material reducing photosynthetic area; without treatment the fungus will eventually cause the dead of the plant (Etebu and Young-Harry, 2011).

Table 2.2: Climate. The table shows the altitudinal variation in precipitation and temperature in the North part of the Chocó-bioregion (Rangel-Ch. and Arellano, 2004).

Altitude	Regime	Annual Precipitation (mm)	Monthly average	Drier month (mm)	Rainy Season (Months)	Mean Temperature (oC)
0 − 4	Unimodal	2,882.3	240.2	February (88.83)	April - Nov	26.94
4 − 10	Unimodal	2,603.5	217	March (77.85)	April - Nov	26
10 − 50	Unimodal	3,280.6	273.38	February (97.1)	April - Nov	26.56
50 − 100	Unimodal	6,532.75	544.4	February (383.24)	April - Nov	26.54
150 − 500	Bimodal	2,423.24	201.9	July (121.84)	April - May and Oct - Nov	27.33
500 − 850	Bimodal	2,261.18	188.62	February (122.76)	April- May and Sept -Nov	26.32

2.1.3 Biodiversity

Every narrative about the Chocó since colonial times starts with a description of its almost mythical biological diversity "Chocó's fauna is abundant, almost all the species from the humid tropical regions can be found in its territory. Ophidia and wild animals are bountiful as the land is covered by dense forests and swampy areas " (Contraloria General de la Republica, 1948).

In recent times 's biodiversity has been widely highlighted in terms of species richness (Gentry, 1986, Rangel-Ch and Lowy, 1993; Galeano, et al., 1998; Rangel-Ch, 2004), diversity of landscapes, and climatic variations (Rangel et al., 2000). Several factors attempt to explain the high levels of biodiversity and endemism: a strategic geographic location, a complex evolutive history, high precipitation rates and an extensive and intricate hydrological network (Rangel and Lowy, 1993).

2.1.3.1 Vegetation

The tropical forests in this region are among the richest in the planet with a high degree of endemism. (Cuatrecasas 1958; Acosta-Solís 1968; von Prahl et al. 1979; Gentry 1982; Zuluaga-R., 1987; Aguirre-C and Rangel-Ch.,1990; Rangel-Ch. and Lowy 1993). The forest structure is characterized by a high density of small and medium trees (510 individuals/ 0.1 Ha), low densities of emergent trees, low presence of lianas and abundant climbing plants (Gentry 1993). Gentry reported that the Colombian Chocó has the world record in plant richness with 262 species in 0.1 Ha (individuals with DBH > 2.5 cm).

The Chocó supports an estimated 9,000 vascular plant species, from the 45,000 registered for Colombia (15% of the plant species described for the world) (Forero 1982, 1985, Gentry 1982, 1993, Forero y Gentry 1989). One fourth of the species found in the area are endemic (2,250 species) mostly belonging to the “anthuriums” and the like (Araceae), “Orchids” (Orchidaceae), “palmiches” (Cyclanthaceae) and “bromelias” (Bromeliaceae) families (García-Kirkbribe, 1986; Andrade G., 1993).

For the Chocó department Murillo and Lozano (1989) reported 4,638 species of vascular plants belonging to 201 Families and 1376 genus. The families with higher genus diversity are Orchidaceae, Leguminosae, Asteraceae, and Rubiaceae (Forero and Gentry, 1989; Rangel-Ch and Lowry, 1993).

2.1.3.1.1 Vegetation of the Study Area

The Atrato River and its tributaries form an extensive floodplain, with predominance of marshes and flood-prone valleys. Vegetation varies with the altitudinal gradient, edaphic conditions and the water balance. Defined by the altitude distinctive environments can be described: fluvial lacustrine (0- 10 m.a.s.l.), alluvial plain (10 to 50 m.a.s.l), low terraces (50 to 100 m.a.s.l); small hills (> 100-250 m.a.s.l), medium hills (>250 – 500 m.a.s.l) and high hills (mountains > 500 -1000 m.a.s.l) (Rangel-Ch, 2004).

In the fluvio-lacustrine environment diverse communities of floating vegetation (camalotes) forming dense tapestries are found along with swampy vegetation and grasslands (Zuluaga, 1987; Schmidt-Mumm, 1988). In sandy riverbanks along the shore a palm association "the panganal" with a strata of 12 m is dominated by *Raphia taedigera* (pangana) (Zuluaga, 1987). In the mid-Atrato watershed it is common to find vegetation associations dominated by few species in particular palm species such as *Euterpe*, *Mauritiella,* and *Oenocarpus*

In the alluvial plain, three main plant communities are found: 1. Shrublands and pastures intermixed and dominated by *Montrichardia arborescens,* 2. A palm forest dominated by *Mauritiella macroclad, 3* the "catival" forest dominated by *Prioria copaifera* (Rangel-CH., 2004).

The catival forest is a dominant forest formation along the Atrato River and its tributaries. It is found in the alluvial plain, low terraces and small to medium hill environments. The cativo tree up to 40 m tall, commonly forms monodominant stands along rivers and flooded habitats, but can be abundant in flood-free sites as well forming mixed forests (Condit et al. 1993; Lopez and Kursar, 1999). Timber exploitation in the last 40 years has drastically reduced the areas covered by the catival. From the original extension estimated in 360,000 Ha only 70,000

Ha are left (Rangel-Ch., 2004). In the study area timber extraction has become one of the drivers of land use change.

The fertile soils of the alluvial fan where the cativo tree grows allow for their use for temporary agriculture and cattle ranching (Code, 1996). However, in areas subject to timber exploitation, the construction of drainage channels to extract and transport the wood allow for the establishment of more permanent agriculture and cattle ranching.

The hills around the Atrato alluvial plain support tropical rain forest formations: Forests with a discontinuous canopy and two strata dominated by Cavanillesia platanifolia (Zuluaga 1987) and associated species such as *Anacardium excelsum, Brosimum utile, Castilla elastica* y *Ceiba pentandra,* and forests with a continuous canopy and emergent species of *Anacardium excelsum* (aspavé) and *Castilla elastica (caucho negro)* (Zuluaga, 1987) up to 40-45 m tall (Rangel-Ch, 2004).

2.1.3.2 Fauna

The diversity of fauna follows a similar pattern than the vegetation. The biological diversity and in particular the degree of endemism are considered to be the highest in the Neotropic. (Haffer, 1969; Haffer and Prance, 2001; Burham and Graham, 1999). Although a thorough inventory of the fauna of the region has not been performed, the available records by animal group highlight its unique biological richness.

Colombia and Ecuador are the countries with the highest amphibian biodiversity in the world. For Colombia a total of 733 species have been reported representing 13% of the world's reported species (Rueda- Almonacid et al., 2004). For the Colombian Chocó 139 species have been reported, 100 of them restricted to the wide Chocó-bioregion (Nicargua to Ecuador). The highest species richness is found in the low Atrato and San Juan rivers basins (Lynch and

Mayorga, 2004). An estimated of 1,450 species of butterflies (41% of what it is reported for the whole country) are found in the Colombian Chocó (Constantino et al., 1993).

Colombia is recognized as the country with the most diverse avifauna with more than 1,760 species (Renjifo et al. 2002). The Chocó hosts about 44% of the Colombian birds with 793 species (Rangle-ch, 2004). The highest number of species (686) is reported for aquatic and marshy environments (between 0-250 m.a.s.l). Haffler (1975) reported 247 species for the Northern Chocó, south of Uraba with 112 endemic species. In spite of the immense network of rivers; the rivers in the region are poor in fisheries with a predominance of species of small size more characteristic of mountain streams (Mojica et al., 2004). The biodiversity decreases from North to South with the Atrato River a natural border for many families shared with other Atlantic basins. A total of 196 species belonging to 78 genera have been reported. The low biodiversity reported for this group of vertebrates may reflect the lack of studies rather than a lack in species richness (Mojica et al., 2004). Colombia is, after Brazil and Mexico, the third country in mammal diversity in the Americas (Alberico, 2000). Forty-one percent (180 species) of the 471 species reported for Colombia are found in Chocó; from those 0.9% are endemic and 8% have a restricted distribution to this region inside Colombia. The most diverse family is *Phyllostomidae* (Chiroptera), followed by *Murida*e (Rodentia) (Muñoz-Saba and Alberico, 2004).

The Colombian Chocó holds 188 species of reptiles about 4.5% of the total number of species described for the world. Although, this group diversity is lower as compared with Amphibians it shows a high degree of endemism. In Colombia 123 species of reptiles are endemic of which 28 (23%) are reported for the region. The genus *Anolis* (Iguanidae) is the richest in total number of species (31) with 14 endemic (Castaño-M et al., 2004).

2.1.4 Cultural Diversity

The Colombian 1991 constitution, which replaced the one from 1886, recognized the country as a pluri-ethnic, multicultural State. A set of articles developed specific spaces for indigenous communities and for the first time for black communities (IAP, 2001, Hoffman, 2007).

The Chocó Biogeographic is characterized for heterogeneity in the biological and cultural diversity that became an integral part of the territorial identity. The territory is shared by Colombian Afro-descendents (more than 90% of the population). Ethnic indigenous groups: Embera, Katio, Chami, Wounaan, Esperara-Siapidara, tule and Awa, which constitute 4% of the population and the other 6% represented by mestizo settlers and recent immigrants (chilapos, Serranos and Paisas) (Antón-Sánchez, 2004).

The ethnic populations that inhabited the region for centuries established a close relationship with the environment to the point that nature and culture are interwoven (Escobar, 1998). In this relationship the black communities are intimately linked to the rivers and the "aquatic space" (Oslender, 2002).

2.1.4.1 Black Communities

After Brazil, Colombia has the largest black population in Latin America (Asher, 2009). Afro-Colombians are the descendants of enslaved Africans who were brought into the country from the 16th century onwards. An estimated 89,000 slaves, from the 1.5 million introduced in Hispanic-America, were brought to Cartagena (IIAP, 2001). The slaves replaced indigenous labor in agriculture, urban services and in the gold mines in Zaragoza, Antioquia, and later on in the Pacific region (Colmenares, 1976; del Castillo, 1982; Maya, 1998; Sharp 1976).

In the Pacific they worked in the Nóvita and Barbacoas gold mines (IIAP, 2001). Among the African ethnicities that came to the Pacific Velazquez reported: the Aguamú, Anda, Arará, Attié, Alanta, Bato, Betes, Biáfaras o Biafras, Bram, Briche, Cana, Ctangara, Casanga, Congo, Coto, Cuambú, Cuca, Culango, Chalá, Chamba, Chato, Egba, Fanti, Guaguí, Guancheras, Havi, Luango, Mandinga, Malinke, Matamba, Mago, Popo, Sanga, Taba, Tabí, Tembo and Viví groups (Velasquez, 1962).

Several attempts have been made to find ways to generalize the culture, ways of production and social structures of the Black Communities of the Pacific (Asher, 2009; Restrepo, 2007, Hoffman, 2007). However, the rich and distinctive ethnic heritages along with the particular processes (migration waves, relationships with nature and between rural and urban areas) in each community defy such an effort (IIAP 2001; Antón-Sánchez, 2004; Asher, 2009).

The story of the settlement of the Chocó area has followed a pattern of colonialism since the arrival of Spain in the Neo-tropic (Oslender, 2004). The original indigenous inhabitants were displaced and pushed away from the low lands of the main rivers by Spaniards and later on by free Afro-Colombians (Hoffman, 2007, Antón-Sánchez, 2004)

The model of slavery in the Chocó was also different from the one established in sugar cane plantations (Hoffman, 2007). The white owners of the mines did not live in the area. Furthermore in some cases gold extraction was done in the tierras baldias “Empty lands” without property titles. Around the mines a population of “free slaves”, indigenous, and few mestizo settlers established themselves. The economic activities of these groups were: subsistence agriculture, fishing, small-scale mining and gathering resources from the forests (Hoffman, 20007).

During this period slaves could buy their freedom with the gold they collected on Sundays. These “free slaves” established themselves along the shores of the rivers usually in riverbanks an alluvial terraces. The settlement of the rivers by the Afro-Colombians has historically been a source of tension between the Indigenous Ethnic groups, which inhabited them, and the new settlers (Tamayo, 1993).

Over time the black communities appropriated the lowlands, in particular after the abolition of slavery in Colombia in 1851 (Tamayo, 1993). In some areas a new wave of colonization happened during the most violent of the civil wars of the 19th century and beginning of the 20th century (la Guerra de los mil dias). Poor peasants from the interior came looking for land and to flee the violence (Hoffman, 2007). The migration in the area has not been unidirectional as migration out of the Pacific has been a constant due to the poor economic conditions (Antón-Sánchez, 2004).

Afro-Colombian's communities, land management and production systems are built around family and "compadrazgo" ties (extended family and close friendships). The difficulty of the environment creates mobility conditions where men or whole families move in search of better opportunities. Women are often the focus of the family and the ones to stay while men go about the different economic activities: wood extraction, hunting, fishing, etc (Hoffmann, 2007).

In spite of their isolation and neglect from the central government, during the 80's and 90's the communities organized. In different areas of the pacific peasant and grassroots organizations emerged often times with the help of the Church (Restrepo, 2004; Escobar, 2008). The Asociacion campesina Integral del Atrato (ACIA) (Integral peasant association of the Atrato) was the first organization in Colombia to define itself as a Black community with a distinct ethnicity (Restrepo, 2004).

A convergence of factors instigated and allowed the formation of ACIA in the 1980's. The large concessions to the timber industry by the Colombian Government in the tierras baldias "empty lands" of the Atrato River were the communities were settled created a powerful motive. DIAR a Colombo-Dutch cooperative agreement that validated for the first time the ways of production and the relationship of the black communities with the ecosystems as valuable, and the support of the Church with is previous experience in the formation of the Indigenous organizations provided the elements needed for the organization (Restrepo, 2004, Escobar, 2008). Hence, the organization emerged as a strategy of defense by the large black peasant communities of the middle Atrato River against the predatory interests of the timber industry (Escobar, 2008). The experiences with the church and DIAR provided the black communities with the building blocks to articulate their discourse around their ethnicity, their right to the territory, and the right for their culture and ancestral ways of production (Restrepo, 2004).

During the 1990's several Afro-Colombian groups and organizations came together in order to fight for the recognition to their rights. The result of that process was the PCN Proceso de Comunidades Negras (Black Communities Process). This organization gathered 120 smaller grassroots organization from the Pacific, Andean and Atlantic regions (Asher, 2009; Escobar, 2008), PCN participation was critical in the formulation of the "Ley 70 of 1993" or law of black communities (see section 2.3.3. for an explanation of the law).

The PCN guiding principles are:

- The right to be black, the right to be different
- The right to the territory
- The right for autonomy and
- The support for the black struggles in the world.

2.1.4.2 Indigenous Communities

The population census of 2005 reported that 1,392,623 or about 3.4% of the Colombian population is indigenous. In the Chocó Department there are 41,214 indigenous people (DANE, 2005). The present indigenous inhabitants of the Pacific region belong to three big linguistic families: The Tules of Chibcha origins, the Awa belonging to the Barbacoa family and the Chocó integrated by the Emberá, Eperara, Katíos, Chamí and Wounann. The Chocó are located in the North part of the Pacific and are the groups found in the Atrato River Basin (Antón-Sánchez, 2004).

The organization and identity of indigenous groups revolves around the land, the forests, the animals and plants present in their territories. They are usually organized around the nuclear family and the elder men and shaman (the traditional authorities) make decisions about where to build the houses, where to cultivate among other things. The Colombian government recognizes the authority of indigenous councils (cabildos), established according to the law 89 of 1890, inside the communities (Antón-Sánchez, 2004).

Unlike the situation for Afro-Colombians, Colombia has a long history of viewing indigenous communities as culturally distinct and recognizing— at least legally— their special rights (Gros 1991). For example, Law 89 of 1890 granted Colombian Indigenous people the collective title to their lands and recognized the traditional authority of cabildos to govern and manage affairs within such territories (Asher, 2009).

In spite of the laws in place, the indigenous people have long suffered from discrimination, neglect and marginalization. During the 60's and 70's, with the help of the Catholic Church, the Embera and Wounann created the regional Embera-Wounann organization (OREWA) (Antón-Sánchez, 2004). This organization was fundamental during the national constituency in 1991 and before that to secure the lands from the attempts to dissolve the "resguardos"[5] under the framework of the agrarian reforms in 1950's and 1960's (Asher, 2009, Escobar, 2008).

According to INCORA[6] the Indigenous groups are the legal owners of 18.64% of the Pacific territory about 1,858,606 Ha (INCORA, 2002). In the Chocó Department there are 106 legally constituted indigenous resguardos corresponding to 1,234,670 Ha (INCORA, 2002). However, indigenous people have been subject to forced displacement and high degrees of human rights violations (IIAP, 2001). This situation is the product of economic forces related to the extraction of wood and minerals, agribusiness, cattle ranching and the construction of infrastructure megaprojects (Antón-Sánchez, 2004).

The Pacific lowlands and the black and indigenous movements have attracted the attention of many scholars. Asher, (2009); Escobar, (2008) and Oslender, (2007, 2008) among others. Their works follow black social movements and organizations from the beginning of the 1990s. They have documented their struggles for the land, for the acknowledgment of their identity and their particular ways of knowledge. Asher (2009) focuses on the women and black organizations as they interact with the state in the process of "state formation". Escobar offers an exploration of many aspects of the "neoliberal colonization" in the Tumaco area of the Pacific. While Oslender (2002, 2004, 2008) focuses in the violence in the production of what he calls "geographies of terror" and spaces of resistance and its relationship with the state and rural development policies.

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[5] An Indigenous reservation of colonial origin created by Spain with the purpose to tie Indian labor to the land. Colombia recognized the rights of the resguardos in the 19th century. The land in the resguardos belongs to the Indigenous community and is inalienable.

[6] INCORA instituto Colombiano de reforma agraria (Colombian institute of agrarian reform) this institute was abolished in 2003. It was replaced by INCODER Colombian Institute for rural development. (Resolution No 1292 of 2003)

2.1.5 Socio-Economic Factors

2.1.5.1 Poverty and Inequality

According to OECD (Organization for Economic Co-operation and Development) Colombia is a very unequal country by international standards with relative poverty being extremely high (OECD, 2013). For 2011 poverty was 64% and extreme poverty 34.3 % with an increase of 0.8 % between 2010 and 2011 in the later one. The country income GINI index was 0.567 for 2011 (DANE 2013).

This situation is reflected to the extreme in Chocó. The department in spite of its rich natural endowment represented in the gold and timber resources has historically maintain high percentages of poverty; its situation mirrors the poverty experienced in Colombia 20 or 25 years ago (Antón-Sánchez, 2004, Bonet, 2007). Well being indices in the region are the lowest in the country. 80% of the population has it basic needs not satisfied and 60% lives in extreme poverty. Illiteracy goes 37% and only 30% of the population has access to health services (IIAP, 2001).

2.1.5.2 Migration and Forced Displacement

The population density in the region is low with 18 Hab/Km2. Migration to urban areas inside Chocó but also to cities outside the area such as Cali and Medellin is frequent due to the social and economic conditions and the lack of opportunities (Antón-Sánchez, 2004). However, since the mid 90's, the rate of out migration has increased as a consequence of the escalation of the armed conflict linked to economic interest. The violence against the population has forced displacements (Escobar, 2008, 2004, Oslender, 2004, CNMH, 2012; Grajales, 2013).

Colombia is second in the world after Syria in the number of displaced people. The government's official registry put the number of victims of forced displacement in Colombia at 5,185,405 since 1985 to December 2013 (IDMC, 2014a). The Consultancy for Human Rights and Displacement (CODHES), a national NGO, puts the figure at 5,701,996 (CODHES, 2013). Both sets of data indicate that there have been an average of around 300,000 new IDPs (internally displaced people) each year for the last 15 years; they also agree that the peak year for internal displacement was 2002 (IDMC, 2014b).

In the Atrato River, 17,000 to 20,000 people were displaced between 1996 and 1997 (Oslender, 2004, Grajales, 2013, Escobar, 2008). The areas targeted for displacement were not selected at random rather they were chosen with economic pursues in mind (Escobar, 2004,2008; Grajales, 2013, Oslender, 2004, CNMH, 2012). According to the reports by the Centro Nacional de Memoria Historica, (2011, 2012) the violent displacement and further establishment of AOP in the Jiguamiandó and Curvaradó watersheds was part of a criminal plan forged by the members of, what is now known as, the "quintuple alianza" (quintuple alliance) an alliance among paramilitaries, politicians and public servants, local economic elites and narco-trafickers.

The criminal entity had as objective "refundar la patria" (re-found the homeland) their idea was to impose a model were they could exert their influence in a territory, elect public servants aligned with their interest and defeat the guerrilla. The model designed by Fidel Castaño[7] and carried out in other regions of Colombia included: 1) military operations and forced displacement 2) Appropriation of the land by legal, illegal and/or forceful means 3) Implementation of economic projects 4) Money laundering 5) repopulation of the area to exert social control (CNMH, 2011, 2012,2013). In the case of Jiguamiandó and Curvaradóó councils the consolidation of the development projects, timber and African oil palm, was

[7] Fidel Castaño Gil was a right-wing drug lord and paramilitary leader of the united self-defense Forces of Colombia (AUC).

followed by new settlements. These planned settlements introduced peasants, from Sucre and Antioquia, who became the work force for plantations and timber operations and the social force of the paramilitary (Escobar, 2004).

The UN Human Rights High Commissioner and the civil society warned about the humanitarian crisis that Chocó is facing. At present the index of extreme poverty has increased to 48.7. In the first part of the year 2014, 4,000 people have been displaced and 25 human rights activists have been threatened (Semana, July 2014; El espectador, July, 2014).

2.2 Colombian Conflict

At present Colombia is the country with the oldest conflict without negotiation in the world (CNMH, 2013). The 50 years old armed conflict is complex, it has evolved and adjusted according to changing times at national and international scales. An in depth analysis of the conflict is beyond the scope of this dissertation nevertheless some aspect of it are relevant to understand the underlying causes of the land transformation in the study area. The Colombian conflict has been heterogeneous over time and space changing in extension, location, armed actors, forms of violence, political discourse throughout the Colombian territory.

2.2.1 Colombian 50 Years Conflict

The Grupo de Memoria Histórica GMH (history memory group) has identified 4 different periods of the Colombian conflict. The first period (1958-1982) was the transition between the bi-partisan violence that occurred in the 1940's to the subversive violence. This period was marked by the formation of several guerrilla groups, social mobilization and marginal (low levels and usually in the agricultural frontier) violence (GMH, 2013). The next period (1982-1996) was characterized by the consolidation of a political platform, the territorial expansion, and the military growth of the guerrillas (GMH, 2013). The paramilitary militias activity increased associated with the drug cartels, the expansion of the drug traffic and a partial collapse of the state (Acemoglu et al., 2012). In this period the Fuerzas armadas revolucionias de Colombia FARC and ELN (National Liberation Army) were joined by other guerrilla movements such as the movimiento 19 de abril M-19 (movement of April 19) and the Quintin Lame (Acemoglu et al.., 2012). The third period (1996 − 2005) witnessed the expansion and worsening of the armed conflict. This time is marked by a simultaneous expansion of guerrillas and paramilitaries, a crisis and recovery of the state, and a polarization in the society towards a military solution to the armed conflict. The interweaving of the drug traffic with terrorist organizations increased international pressure that led to the participation of the Colombian state in the "security war" that in-turn fed the internal conflict (GMH, 2013). In the same period a further expansion of the drug trade that involved changes in the organization and the start of trans-national drug mafias materialized (GMH, 2013; ELS, 2014). The fourth period (2005-2012) identifies a sort of "reengineering" of the armed conflict. It is distinguished by a dramatic increase in counterinsurgent actions carried out by the Colombian army. These military actions were able to weaken the Guerrilla groups but did not defeat them. This period also witnessed the failure of the paramilitary demobilization that has resulted in the emergence of highly fragmented armed groups that are volatile, changeable, very pragmatic in their criminal actions, with strong links with the narco-traffic and more defiant in front of the estate (GMH, 2013; Prieto, 2013).

2.2.1.1 Guerrilla Groups

During the 1960's several guerrilla groups formed as a result of the policies adapted during the National Front, a coalition of the two traditional parties aimed at ending bi-partisan violence. During the National Front the two parties shared power to the exclusion of any other form of political participation. At the same time the Colombian Army was engaged in the repression of subversive groups in the framework of the United States ALASO plan (Latin American Security Operation) which intended to put and end to subversive left wing groups in Latin America (Osterling, 1989; Rangel, 1998).

The rise of the Fuerzas Armadas Revolucionarias de Colombia FARC (Revolutionary Armed Forces of Colombia), the main guerrilla group, has been linked to the military offensive (Marquetalia) against a group of self-defense organized peasants (Pizarro LeonGómez, 2004). The Marquetalia operation was not followed by structural economic and political reforms, which promoted the transition of peasant groups into Guerrillas. The FARC was formally constituted in 1965 and was able to spread in part due to the political vacuum created by the National Front (GNMH, 2013). Other groups that rose parallel to the FARC are the Ejercito de Liberación Nacional ELN (National liberation army), in 1962 and The Ejército Popular de Liberación EPL (Popular Liberation Army) in 1967. Several other groups such as the M-19 and the Quintin Lame appeared later on (GHM, 2013). In the 1990s they increasingly turned to drug trafficking, extortion, and kidnapping to fund their operations losing legitimacy among many Colombian sectors (Kiran, 2009)

2.2.1.1.1 Guerrillas in Chocó

The area located in the southwestern Urabá, outside the banana axis, had been relatively sheltered from the intense violence. The west bank of the Atrato River, as well as the Pacific coast and its hinterland, had been a refuge for the FARC since the early 1980s. The tropical forest of the Darién (Panamanian border) and the Western Andean mountain chain constituted natural shelters for the rebels. Sporadic military actions against the FARC did not affect guerrilla control; even if the locals had to endure FARC racketeering, they were not living in a war zone. (Flórez- López and Millán-Echeverría, 2007; Grajales, 2013).

In the banana axes the guerrillas were involved either with the banana industries or with the labor unions in the region. The spread of the Colombian conflict to the South of the Banana axis was the result of several national and local circumstances. The specific regional factors that contribute and ultimately trigger the incorporation of the region into the conflict are as follow (Flórez- López and Millán-Echeverría, 2007):

- The expansion of the paramilitaries
- The conflict between the ELN and the FARC for the control of the area, and
- The interest of banana companies to diversify given the bad moment of the banana market

2.2.1.2 Paramilitaries

Colombia's paramilitaries are thought to have originated from 1960s counterinsurgency measures and Law 48 of 1968 which allowed the creation of self-defense militias by private citizens for the purposes of protecting their properties and lives (Romero 2002; Duncan 2007). However, the escalation of paramilitary activity in the early 1980s is associated with the rise of the large drug cartels in Medellin and Cali. Many of the armies at the service of the drug cartels transmuted into paramilitaries in charge at the beginning to protect drug lords from the threats of kidnapping and extortion from left-wing groups. As the wealth of the drug cartels grew, many of their members began to buy up land and ranches in rural areas. Here their interests began to fuse with those of traditional rural elites who also wished to protect themselves from extortion and kidnappers (Gutiérrez et al., 2005)

This led to collaboration in the formation of paramilitary groups. One area of rapid expansion was the Magdalena Medio at the eastern periphery of the department of Antioquia which saw the emergence of groups such as Los Tangueros formed by the Castaño brothers (Carlos, Fidel, and Vicente) whose father had been killed by the FARC in 1981. In 1994 the Castaño brothers formed the "Autodefensas Campesinas de Córdoba y Urabá" (ACCU—Peasant Self-Defense force of Córdoba and Urabá). This further expansion was facilitated in the same year by a law promoted by President Samper to allow the creation of CONVIVIR, a national program of neighborhood watch groups. An important supporter of this program was Colombian ex-president Alvaro Uribe, then Governor of Antioquia, whose father was killed by the FARC in 1983 (Acemoglu et al., 2012). Carlos Castaño formed the AUC (Colombian Peasant self-defence force) in April 1997 and it included possibly 90% of the existing paramilitary forces. The creation of the AUC occurred right after the Medellin and Cali drug cartels collapse and at the beginning of the Pastrana's administration peace process with the FARC. The creation of this national organization increased the effectiveness of the paramilitaries considerably; as a result, the FARC and ELN were thrown out of large areas of the country (Restrepo, et al., 2004).

In 2002 after coming to power, Uribe began to negotiate with the paramilitaries. In January 2003 the president issued decree number 128 that gave de-facto amnesty for paramilitaries not under investigation for human rights violations and this has been applied to a vast number of demobilizations (around 92%). Later, in 2005, president Uribe, signed the controversial Justice and Peace Law. In article 29 the law limits the sentences of those found guilty of human rights violations to between five and eight years. Article 30 allows the government to determine the place of detention, which need not be a prison. In May 2006 the Colombian constitutional court altered many aspects of the law on constitutional grounds. Among the changes introduced by the court was the requirement for the paramilitaries to confess to their crimes.

In spite of the changes the Justice and peace law has been widely criticized by human right organization (Grajales, 2013, Escobar, 2008). Furthermore, there is a controversy about whether the demobilization was real or simply the institutionalization/legitimating of the power of the AUC (Pardo, 2007; International Crisis Group, 2007; Zuckerman, 2009). After the demobilization the structure and presence of illegal armed groups has continued in many regions without many changes. The “new” groups are known by the acronym “Bacrim” (Bandas Criminales—Criminal Bands). The connection between the paramilitaries and Bacrim is also under debate (Prieto, 2013).

The influence and alliances of the paramilitaries with politicians was made evident in the Colombian parapolitics scandal in 2006. Mancuso and Castaño, two top paramilitary leaders, were linked to 35% of members of the congress (Valencia, 2007). The political influence of the paramilitaries has slowly been discovered and several analyses have shown the influence that they have exerted in political elections (Valencia, 2007; Rangel et al., 2005). In a few years they change the composition of congress where the two traditional parties have been ruling since the beginning of the Republic (Acemouglu et al., 2013).

In summary the paramilitary are not a unified group guided by a particular ideology instead they were independent armed groups with different interests merged in order to gain political legitimacy (Reyes-Posada, 2009; Salazar, 2005). In some areas like in the Antioquia- border and in relation with the establishment of African palm plantations and other businesses they have establish alliances with political and economic elites (CNMH, 2012).

At present different neo -paramilitary groups, guerrilla, and the Colombian Navy and military are present in Chocó. The strategic location of the region makes it a battle ground for economic interests linked to drug trafficking, mining, agribusiness, and mega-projects (e.g. The Pan-American road, the inter-oceanic canal, seaports). The presence of these armed forces along with the drug traffic constitutes a powerful driving force for land use change and the conservation of the biological and cultural endowments of the Chocó and Urabá regions. Although, the Colombian armed forces are present, they are unable to exert the monopoly of the force hence their role as a regulatory agent in the conflict is difficult to fulfill.

2.2.1.2.1 Paramilitaries in Chocó

The Paramilitary group in Uraba and Northern Chocó was the Elmer Cardenas block of the AUC. The group was commanded by Fredy Rendón Herrera, alias "El Alemán" (The German) and formed in 1995. "El Alemán" is accused of land grabbing, massive displacements and human rights violations. He has presented the land grabbing as a social project called PASO that was aimed to the generation of productive enterprises in marginal areas. In reality, it was part of a strategy of repopulation and land control for the development of timber and AOP industries, a strategy designed by Vicente and Fidel Castaño (Verdad Abierta http://www.verdadabierta.com/victimarios/328-habla-vicente-castano).

The Elmer Cardenas Block was one of the last groups demobilized. A total of 1538 men and women were demobilized in 2006. The group is responsible of 110 crimes against humanity among them 23 forced displacements. Many of the crimes were committed with the participation or knowledge of the XVII brigade of the Colombian Army based in Carepa, Antioquia. The retired general Rito Alejo del Rio "the Urabá Peace-maker" was condemned to 25 years of prison for the assassination of a peasant as a result of paramilitary actions

(Verdad Abierta http://www.verdadabierta.com/la-historia/416-bloque-elmer-cardenas-de-uraba-,[8] Semana, 2012)

At present Belén de Bajirá is still a strong hold of the paramilitaries or Bacrim, (Colombia Land, 2013). The FARC has returned to the region, drug traffic along with the illegal occupation of the lands, timber extraction and agribusiness establishment continue (Comision Intereclesial de Justicia y paz, 2005).

2.2.2 Illegal Crops in the Region

Since 1999 coca cultivation has spread throughout the Colombian territory (Ramirez-Lemus et al., 2005). In 1999 when the plan Colombia started, three areas where considered to be traditional coca growing areas: the Amazon basin, Putumayo - Caqueta, and Meta-Guaviare-Vaupés. In 2012 coca was grown in 23 out of the 32 departments with the Cesar department registering coca for the first time (UNODC, 2002. 2013). Since 2007 with the shift to more interdiction and less eradication in Colombia, coca crops started to move back to Peru and Bolivia; cocaine processing facilities moved to Venezuela and Ecuador (where lower prices for some of the chemical precursors used in the production of cocaine such as gasoline and cement make this activity more lucrative); and the bases of operation of the main trafficking organizations were displaced to Mexico and Central America (Mejia and Restrepo, 2014). Although the total area under coca cultivation has decreased from 144,807 ha in 2001 to 48,000 Ha in 2012, the cumulative sprayed area was 100,549 for the year 2012 (UNODC, 2002, 2013)

An analysis of the physical environment of the Chocó department carried out by SIMCI in 2002, concluded that the biophysical conditions of the area hindered illicit crops cultivation

[8] As part of the Justice and peace process the web portal verdadabierta.com was created in 2008. The portal publishes and keeps the information related to the armed conflict with a section devoted to the paramilitary's crimes, victims, legal processes and reparation of the victims.

(UNODC - SIMCI, 2002). However by 2013 coca cultivation covered 3,429 Ha and the cumulative aerial spraying reported was 13,259 Ha (Table 2.3 and Figure 2.1). Between 2011 and 2012 there was an increase of 37% in the area affected by the crop (UNODC, 2001, 2005, 2013). Coca cultivation has come into the region along side with the armed actors, migration of coca farmers, aerial spraying, deforestation and a deterioration of the traditional economy (IDEAM, 2005). Aerial spraying of coca fields started in the Chocó department in 2005 with 425 Ha sprayed that year (UNODC-SIMCI, 2005).

Table 2.3: Coca Fields 1999 to 2012. The table summarizes the extent of the area under coca cultivation and the aerial spraying for the Department from 1999 to 2012.

Year	Coca Fields in Ha	Aerial Spraying Ha
1999	0	0
2000	168	
2001	354	
2002	ND	
2003	453	
2004	323	
2005	1025	425
2006	816	
2007	1080	
2008	2794	
2009	1789	
2010	3158	
2011	2511	4287
2012	3429	3259
% Change 2011/2012	37%	

2.2.2.1 Collateral Damage of the War on Drugs: Internal displacement IDP's and humanitarian crisis

Colombia is the country in the word with the highest number of internal displaced people. The civil society and the IDCM calculated that 4.9 to 5.9 million people have been displaced as a result of violence in the Colombian territory (IDMC, 2014; ELS, 2014). Although analysts concluded that internal displacement is associated with the internal armed political conflict it is also a collateral effect of the war on drugs. (Mexico has 160,000 IDPs as a result of the drug wars) (Atuesta, 2014). However forced displacement in Colombia has become the primary way to seize agricultural land from peasants and small farmers (Escobar, 2008; Grajales, 2013; Molano, 2005). The deliberate violence against civilians is aimed at land grabbing (Grajales, 2013, CNMH, 2012,2011, Reyes-Posada, 2009). As Escobar has pointed out we are witnessing a counter agrarian reform that is concentrating the already concentrated land in fewer hands (Escobar, 2011).

2.2.2.2. Collateral Damage of the War on Drugs: Glyphosate spraying

The history of aerial spraying in Colombia goes back to the 1970's when the US government strongly pursued the use of herbicides in exchange for economic and military aid. The Turbay's administration, Colombia's president at the time, refused to use herbicides in particular paraquat that was already forbidden to be used in the U.S. Instead he started the involvement of the Colombian military in the eradication and interdiction of Marijuana production (Ramirez-Lemus et al., 2005).

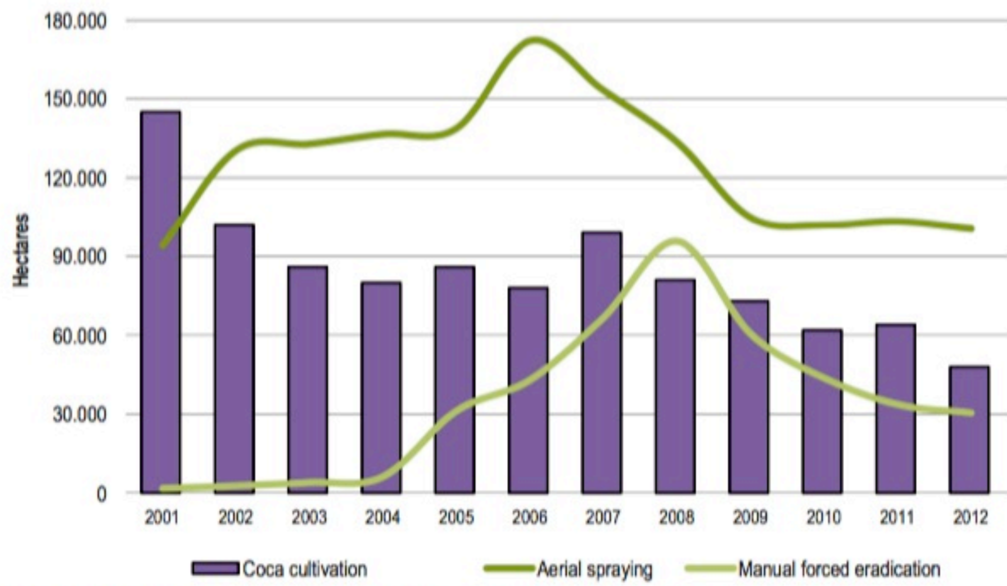
In 1984 due to the growing power of the drug dealers and the assassination of Rodrigo Lara Bonilla (who was serving as Minister of Justice) by the drug mafias, the Betancur's administration agreed to use herbicides. This decision however was a tacit acceptance that the problem of narcotics existed primarily in the place where drugs were being produced contradicting Colombia's official notion that drug dealing was a multilateral and international problem where the existence of markets is part of the equation. In the matter of drugs, Washington's pressure on Bogotá became more evident and difficult to counter through autonomous strategies.

Fumigation was used intermittently during the 1980's with or without Washington pressure. The situation changed during the President Ernesto Samper's administration (1994 − 1998). His political campaign was accused of being financed by drug money, this increased diplomatic tensions with Washington to the point that the president's visa to visit the U.S. was revoked. The president's struggle for political survival led him to "North Americanize" the fight against drug trafficking in Colombia; that is to say, the president accepted and implemented a strategy virtually imposed by the United States. Between the years 1995 and 1996, *glyphosate* was used on a massive scale to destroy illegal crops (Isaacson, 2005; Ramirez-Lemus et al., 2005).

During the Pastrana administration the "Plan colombia", originally drafted in Colombia, was substantially changed in Washington. The original plan had an emphasis in alternative development whereas the new one, approved in Washington without being consulted in the Colombian congress, had interdiction and especially crop eradication as main components (Isaacson, 2005). In 2002 the second phase of plan Colombia was changed again according to the new security interest with a focus on fighting terrorist groups (Ramirez-Lemus et al., 2005).

Since 2000 Colombia has increased the area sprayed with Glyphosate from 60,703 in 1999 to 172,024 in 2006. A total of 866,840 Ha were fumigated in the 2000 to 2006 period (Figure 2.2). The effort is futile as coca production simply shifted from one place to another in "a balloon effect" (Ramirez-Lemus et al., 2005). In 2006, the United Nations detected coca cultivation in 23 of Colombia's 34 departments, up from 12 in 1999 (UNODC, 2000, 2007). Mounting evidence suggested the failure of the drug war and the need for a change in strategy that minimize the collateral damage caused by the policies (LSE, 2014, Rincon-ruiz and Kallis, 2013, Isaacson, 2005).

Figure 2.2: Glyphosate spraying. The Figure shows hectares under coca cultivation, sprayed with glyphosate, and subject to manual eradication.



Source: PCI and UACT for eradication DIRAN for aerial spraying and SIMCI for coca cultivation.

Until recently, the link between environmental and health damage caused by glyphosate was difficult to demonstrate[9]. The Glyphosate environmental risk assessment study endorsed by the Colombian Government and funded by Monsanto concluded that environmental effects were negligible and human risks were greatest during the planting and harvesting of coca fields (Solomon et al., 2007). On the other hand independent research related to the

[9] In March of 2015, the IARC (Intenational Agency on Cancer Reseearch) – WHO included gjyphosate in the list of probable carcinogen pesticides (Guyton et al, 2015).

environmental effects of glyphosate were often disqualified and neglected (Relyea et al., 2011). Nevertheless, environmental and human health concerns were the cited reasons in the case Ecuador interposed against Colombia at the international Hague tribunal in 2008 (El Pais, 2008, ICJ, 2008[10]). The Ecuadorian government seized the court about the alleged spraying of Glyphosate at locations near, at and across the border with Ecuador. The Santos's administration went into negotiations with the Correa's administration in 2013; the result was the removal of the case from the international tribunal in September of 2013. The agreement included U$ 15 millions economic compensation from the Colombian state to Ecuadorian citizens (Semana, 2013, IJC, 2013[11]). For many groups it was a sad outcome since it did not allow for the investigation of the effects of the herbicide by the court.

In the study region the policies created during the drug and security wars are in part responsible for the environmental damage and humanitarian crisis (LSE, 2014; Ramirez-Lemus et al., 2005). African oil palm cultivation was proposed as an alternative to drug cultivation. The area was considered to be in need of "securing" so illicit drug cultivation would not occur. The financial incentives to grow African oil palm were one of the motivations for the criminal alliances to move into the region (CNMH, 2012). The companies that moved in got money from the USAID MIDAS program as well as from Finagro (Flórez-López and Millán-Echeverría, 2007).

There is no doubt that land grabbing and property concentration in rural Colombia is an indirect result of the drug trade. It financed the narco-terrorism of the 80's and 90's and currently is a main source of funds for left-wing guerrillas and right wing paramilitary groups (Thoumi, 2005,2007). The land grabbing and the establishment of agribusiness are a money

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[10] http://www.icj-cij.org/docket/files/138/14470.pdf accessed January, 2015.
[11] http://www.icj-cij.org/docket/files/138/17526.pdf accessed January, 2015.

laundry strategy as well as a way to control regions that are needed for illicit crop cultivation and the smuggling of drugs and arms (Escobar, 2008).

2.2.3 Antioquia and Chocó

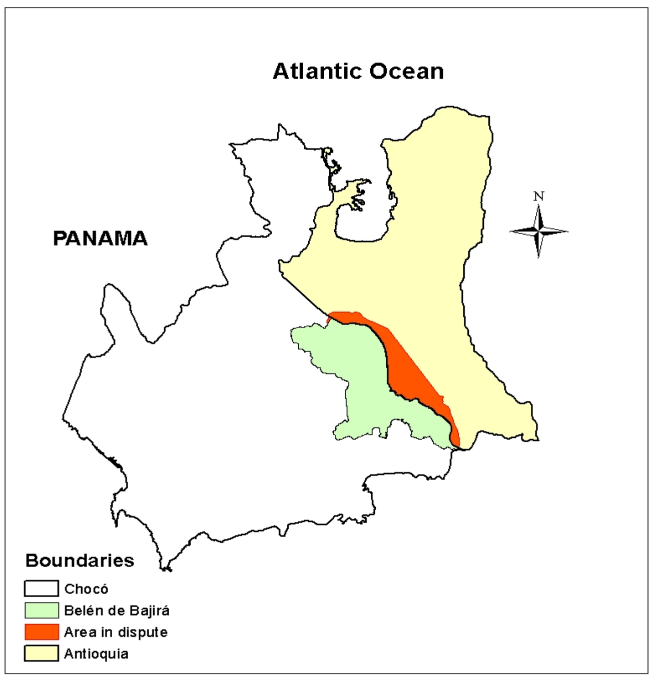
Violence associated with land grabbing is not a unique occurrence in the Mid-Low Atrato watershed. In the case of the region the violent "Pacification" and land grabbing in the region was framed under a "development opportunity" (Grajales, 2013, Escobar, 2004). Some argued that crime and violence are constitutive of political competition, accumulation and economic development (Bayart, 2004; Briquet and Favarel-Garrigues, 2010). In this sense two different aspects could be considered: the relationship between Antioquia (from where the development discourse arises) and Chocó (an entity to be developed) and the economic policies that have been applied in rural Colombia.

The relationship between Antioquia and Chocó has been well described by Escobar and Wade (Escobar, 2008, Wade, 1993,1983). Escobar talks about the "Euro-Antioqueño" vision whereas Wade suggests the term "internal colonialism" (Escobar, 2008, 2011; Wade 1993,1983). The internal colonialism refers to a situation where an ethnic group, usually spatially segregated, is in a subordinate relationship with another ethnic group. Several aspects define such a relationship: 1) Antioquia and Chocó have different racial identities 2) The Chocó Department is located in a marginal area of Colombia with difficult access to the center of the country 3) A region with an ideology an ethnic composition that is look down upon by the dominant class (Wade, 1993). In the Paisa imaginary the region is an empty area in need to be civilized and developed and idea that has being carried out since colonial times (Escobar, 2008).

2.2.3.1 Boundary Dispute

The Chocó department was created in 1947 at the time the boundaries were defined using the rivers to delimit the border between the Antioquia and Chocó, however the area around Belén de Bajirá was loosely defined (Figure 2.3) (Mosquera, 2006). The dispute between the two departments became serious in 2000 after Chocó department declared the municipality of Belén de Bajirá.[12] Antioquia sued Chocó at the administrative contentious court in 2001, it further demanded to the ministry of justice and interior to clarify the limits between the two departments (Mosquera, 2006).

Figure 2.3: Boundary Conflict. The Figure shows in light pink the area under dispute between Antioquia and Chocó.



[12] The cartography used in my analysis corresponds with the cartography established by Corporación Autónoma Regional para el Desarrollo Sostenible del Chocó CODEChoco in 2005. This cartography considers Belén de Bajirá as an independent municipality and does not reflect the boundary dispute between the departments of Antioquia and Chocó. To my knowledge no new official cartography has been produced at a national level since the dispute is still ongoing (see Governación de Antioquia, junio 2014).

A commission was created with the Instituto Geografico Agustin Codazzi IGAC (Agustin Codazzi's geographic institute) to review and delimit the border. A technical report was produced, however, the river network in the area has changed due to the construction of drainage channels making it impossible to corroborate without any doubt the exact borders between the two (Mosquera, 2006).

The decision as to which department the town of Belén de Bajirá and its surrounding areas belong to remains in the hands of the congress but a definite decision accepted by both parties has not been produced (Mosquera, 2006).[13] This dispute is important in the future of the land use trajectories of the area since Chocó and Antioquia hold different visions with respect to development and ethnic rights. The main reason behind the dispute is the jurisdiction of the law 70 of 1993. If the land belongs to the Chocó department the legal ownership of the land correspond to the Afro-Colombian communities and any mining or agribusiness development at least in paper is not possible. If the land belongs to Antioquia then the legal ownership of the land could be disputed since the law 70 of 1993 specifically talks about the tierras baldias "empty lands" in the Chocó Department.

2.2.4 Economic Policies in Rural Colombia

Displacement of peasants and land grabbing is not a new phenomenon in Colombia. Analysis of the violence occurred during the 1940's and 1950's shows a lot of resemblance with the violence and dispossession that Afro-colombians, indigenous and poor peasants are suffering today. It also confirms the persistence of the use of violence with politic and economic objectives (GMH, 2013). During the analysis of the violence of the 40's and 50's shows that 2 million hectares of land were stripped from the peasants in the agricultural frontier of the time (Offtein, 2005).

[13] As far as December 31 of 2014. The situation of the town remained unclear (El Colombiano, 2014).

Although, the Colombian state has not openly adopted war and violence as means for development, accumulation and state construction; the practice has had some leverage as the economic discourse has at least theoretically endorsed war and violence as steps or opportunities for development.

Some of the policies applied in the rural areas of Colombia have been influenced by the economic theories of Launchlin Currie, a Canadian economist. Currie identified that poverty in the agricultural sector was the result of insufficient employment with very low yields in rural areas with excess of population. He argued that a massive displacement of people from rural to urban areas "a redistribution of human resources" was needed in order to overcome the obstacles to mechanical agriculture and economic development. War could be then a way to promote such a displacement; the population will arrive to urban areas where appropriate employment could be found. He was not in favor of land redistribution as a way to overcome poverty in rural areas. In his view the division of land will result on small size parcels that will not be efficient and will not provide the much needed economic development (Zuluaga, 2003). As a result of this vision large agribusiness has been favored by different administrations (Hataya et al., 2014). Public policies were designed to favor big landowners, securing their property rights and protecting them against external competition (GMG, 2013). During the 20th century three attempts at an agrarian reform failed, the opposition of the landowners and their power at local and regional levels did not allow for the re-distribution of land (Asher, 2009; GMG, 2013). The local and national, and international visions of the Chocó as an entity in need of development manifest in in the formulation of development policies (Escobar, 2005).

2.2.4.1 From Exclusion to Development

The processes taking place in the Pacific are not happening in a vacuum. The region as a result of its rich natural endowment and strategic geopolitical location went from been a "worthless swamp" to be crucial in the development of megaprojects and a good place for investment. The development of the Colombian pacific is at the center of continental iniciatives such as the Puebla-Panama Plan (PPP), the Atrato-Truandó canal and the Regional Infrastructure Integration of South America (Flórez-López and Millán- Echeverría, 2007). These development plans aim at the integration of the Pacific watershed with the world to facilitate commercial exchanges.

2.2.4.1.1 Palm Sector Incentives

The economic models adopted by the Uribe and Santos administrations aim to attract national and international investors to agribusiness projects of large scale. The development plans are described in the projections for Colombia in 2019 and in the development plans documents "2019 Vision Colombia Centenario" Uribe and in "Proyectos de Ley del Plan Nacional de Desarrollo –2010– 2014 Prosperidad para Todos " Santos.At a local level Antioquia included the palm as part of its development plan in "Una Antioquia Nueva: un hogar para la vida " (2001-2003) were it set the goal to have 6.000 Ha of AOP in Urabá and the Magdalena Medio in the next 5 years. In the development plan "Plan Pacífico" AOP is included as well.

Economic incentives have been designed since the mid 90's and included the creation of *Fondo de Fomento Palmero* (Law 138 of 1994), the *Fondo de Estabilización de Precios* (Law 101 of 1993, Decree 2354 of 1996, and Decree 130 of 1998), and financial resources for investment from *Fondo para el Financiamiento del Sector Agropecuario* (FINAGRO). Subsidies for irrigation and drainage channels, technical assistance, tax free zones, tax exemptions schemes are in place along with biodiesel mandates designed to create a national market for biofuels.

2.2.4.2 Development Plans

In 1983, the first Plan for the Integral Development of the Pacific Coast (Plan de Desarrollo Integral de la Costa Pacífica, PLADEICOP), stated its call for development in the following way: "This vast region harbors enormous forests, fishing, and mining resources that are required immediately by the nation; the region constitutes an area of fundamental geopolitical interest for the country" (Mosquera Murillo, 2012). Some interpretations of the plan indicated that the plan was conceived under the pressure of economic groups and had as main goal the rapid exploitation of the natural resources to alleviate Colombian external debt (Barnes, 1993). Ten years later, the much more ambitious "Plan Pacífico: Una Estrategia para el Desarrollo Sostenible para la Costa Pacífica Colombiana" (DNP and CORPES, 1992), funded by the World Bank and the Inter-American Development Bank, elevated PLADEICOPS's goal to new levels by focusing chiefly on large-scale infrastructural investment (hydroelectrics, the pan- American highway and sea ports) (Escobar, 2008; Mosquera Murillo, 2012). Hence, the development plans have favored economic growth over poverty alleviation and inequality reduction (Mosquera Murillo, 2012).

African oil palm was proposed as a suitable economic activity for the region. However, it was conceived as a megaproject more in the line of a large-scale agribusiness than in tune with the needs and realities of the inhabitants of the region. National and International policies about bio-combustibles attracted local and foreign capital. As a large agribusiness AOP cultivation requires a transformation of the Bio-physic structure of the environment, which in turn transforms the social and cultural landscape of the region (Vélez, 2007). Other development plans for the region include timber extraction, mining, tourism and infrastructure. An ambitions plan to integrated the Country to the Pacific watershed has at its for front large infrastructure projects such as the development of roads and bridges, the construction of the interoceanic canal Atrato-Truando, hydroelectrics, and telecommunication (IIAP, 2001; Flórez-López and Milán-Echeverría, 2007).

2.3 Belén de Bajirá and AOP

The Pacific region was considered at the beginning of the 1990 as a "peace refuge" (Arocha 1999) now it is an integral part of the Colombian plans for the development of the Pacific watershed (Oslender, 2001).

2.3.1 Violence and Land Grabbing

The interest of Colombian political and economic elites, narco-trafickers and their links with illegal armed groups crystallized in the mid and low Atrato Basins in two armed operations in 1996 and 1997. One carried out by the Colombian Army "operacion Genesis" (involving paramilitary forces) and the other one "Operacion Cacarica" by the paramilitary militias alone. The operation resulted in the massive displacement of people (17,000 to 20,000 depending on the source) (Grajales, 2013, Gomez, 2007) and widespread violence.

The territories of the Jiguamiandó and Curvaradó were titled to the Afro-colombian communities in November of 2000, four years after the continuous human rights violations and the forced displacement. At the time of the titling many of the inhabitants were displaced making a return to their lands difficult. African oil palm companies, banana plantations, cattle ranching and beneficiaries of the paramilitary occupy the lands.

The events in Belén de Bajirá and Carmen del Darien are multifold in particular the ones related to human rights violations. The following is a list of the main events that have taken place (excluding the many particular violent events), which are of relevance to the clarification of property rights and the future of the people and the land:

Table 2.4: AOP Establishment. This table summarizes the main events that have taken place in the community councils of Jiguamiandó and Curvardó in the struggle for the land.

Date	Event
1996 – 1997	"Genesis" and "Cacarica" military/paramilitary operations Massive displacement of people, human rights violations.
1997 – 2005	Timber, African oil palm, banana, and cattle ranching enterprises move in.
2000	INCORA gives the titles to the land to the Afro-Colombian communities 46.084 Ha were given to the Curvaradó Community council and 54.973 Ha to the Jiguamiandó community council.
2002	Attempts from the Afro-Colombians to return to their land.
2003	The inter-American commission for human rights requested the Colombia State to adopt precautionary measures to protect the rights and lives of the Afro-communities in Curvaradó and Jiguamiandó. Similar requests were issued in 2004, 2005, 2006 and 2010
2004	Ruling T- 025 of 2004 from the Colombian constitutional court. Declares the situation of forced displaced people as unconstitutional and orders the Colombian State to adopt measures that guarantee the rights of the displaced population.
2005	INCODER Reports on the Demarcation and Use of Land in Curvaradó and Jiguamiandó (March 14)[14]
2005	Human Rights Ombudsman's Office report on Curvaradó and Jiguamiandó.
2006	Creation of the first humanitarian and biodiversity areas
2007	Attorney general's office opened the case against 23 palm oil companies

[14] The Ministry of Agriculture blocked the diffusion of the report by order of the Uribe administration (El Tiempo, 23 de octubre de 2005). The ministry at the time Andres Felipe Arias was sentence in June of this year by the constitutional court and it is seek by the Colombian Justice for other criminal actions (Semana, july 2014). This illustrates the powerful forces behind the establishment of African oil palm in the region.

Table 2.4 (cont'd)

	and other businesses involved in the forced displacement
2010	Invasion of the land by peasants foreign to the region.
2010	Ruling of the Constitutional court in which it orders the estate to adopt precautionary measures to protect the communities and measures to guarantee the transparency of the land restitution.
2011	President Santos signs the victims and Land Restitution Law (Law 1448). Although the law does not apply to the Curvaradó and Jiguamiandó communities, their case is emblematic and constitutes a pilot case to land restitution in Colombia.
2012	Constitutional court orders 045, 112 and 299. These orders are related to the census of the two communities, the protection of their rights and the expulsion of the bad-faith occupants.
2013	The inter-American commission for human rights removed the precautionary measures on the grounds that the Colombian government efforts were sufficient to guarantee the protection of the communities.
2013	Some palm entrepreneurs condemned for the forced displacement and land grabbing in the region.

The violence and human rights violations at the hands of different armed actors are ongoing (Ombudsman office, 2011). In response the communities of Curbaradó and Jiguamiandó have created 8 humanitarian zones and 50 biodiversity zones. These zones were created in an attempt to protect the families that are returning from the illegal actors (Colombian Land, 2013).

In spite of the laws protecting the rights of the communities, the constitutional orders, and the prosecution of some entrepreneurs the land has not been restituted to the communities. At present the Colombian government does not exert the monopoly of the force in the area and the local institutions are weak, corrupt and linked to armed groups (ie. CODECHOCO) (Orjuela-Escobar, 2000; el tiempo, 2015)

According to an analysis conducted by Afrodes (Association of Displaced Afro-colombians) and the PCN in 2001, the main causes of displacement are (Escobar, 2008):

- Infrastructure megaprojects such as construction of roads, ports, dams, a planned interoceanic canal, and expansion of the African oil palm frontier
- The spread of illicit crops
- The armed conflict
- The existence of natural resources, from gold to timber to tourism.

The PCN makes further observations (Escobar, 2008):

- Displacement became accentuated after the titling of collective territories
- Displacement is selective and planned; the largest displacement has occurred in zones suitable for macro-development projects
- The aim of terror is to break down the resistance of the communities and against their identities as ethnic communities.
- Displacement has altered the patterns of in- an outmigration that have characterized the Pacific since the 1950s and 1960s, making impossible a return to the home river communities; this ends up modifying the use of land, the traditional production systems, the spatial distribution of population and resources.
- The armed actors, particularly the paramilitary groups, have fostered a selective and directed resettlement of river territories, displacing some groups and bringing in others— mostly whites from the interior— who obey the new rules of cultural, economic, and ecological behavior.

2.3.2 African Oil Palm in Curvaradó and Jiguamiandó

The establishment of AOP plantations was first reported in 2001 when the people displaced by the violent events of the previous years came back to recover their land and found it covered by AOP plantations. After the forced displacement of Afro-Colombian and indigenous communities in 1997 AOP companies move in (Mingorance, 2004; Flórez-López and Millán-Echeverría, 2007). The AOP plantations were initially established between 1997 and 2000 and further expanded in the 2001- 2005 period right after property rights were granted to the Afro-Colombians.

The AOP plantations in Chocó are not accounted for in the official statistics of Fedepalma and were not included at a national level until 2006. However, a report from the Colombian Institute for rural development INCODER found that 93 % of AOP plantations in the region are located in lands that belong to the Afro-Colombian communities (INCODER, 2005). A total of 26,135 Ha is the extension that entrepreneurs foresee as part of AOP, banana, and cattle ranching development projects (INCODER, 2005). At present 13 AOP, banana and cattle ranching enterprises are present in the region: Urapalma S.A, Palmas de Curvaradó, Palmas S.A., Promotora palmera del Curvaradó "Palmadó", Inversiones Fregni Ochoa, Empresa La Tukeka, Sociedad Asi- bicon, Empresa Selva Húmeda, Empresa Palmas del Atrato5, Palmas de Urabá "Pal- mura", Inversiones Agropalma y Cia Ltada, Asociación de Pequeños Cultivadores de Palma de Aceite en el Urabá and Unidad Productiva Afrocolombiana de Palma (Colombia land, 2013; Semana, 2005 http://www.semana.com//nacion/articulo/palma-adentro/74291-3).

The linkages between AOP establishment and paramilitaries have been stated by the paramilitaries themselves in interviews and testimonies render as part of the "justice and peace law" in the framework of the demobilization process (CNMH, 2012). In different parts of Colombia AOP plantations became an opportunity for money laundry, land grabbing, and territory control (Romero, et al., 2007; CNMH, 2012; Reyes-Posada, 2009). The establishment of AOP has followed similar violent patterns in other regions of Colombia and Ecuador (i.e. AOP plantations in the Catatumbo region, NorthEast of Colombia and in Esmeraldas, Ecuador) (Hazlewood, 2012; Reyes-Posada, 2009; Romero, et al., 2007).

In relation to the AOP agribusiness in Urabá Vicente Castaño, leader of the AUC, said in an interview: " we have AOP plantations in Urabá. I myself found the businessmen to invest in those projects that are productive and long-lasting" (Semana, 2005). Urapalma S.A. a company with 3,636 Ha of AOP is suspected to be own by the paramilitary leader (Mingorance, 2004; Flórez-López and Millán- Echeverría, 2007).

In 2007 la Fiscalia, the prosecutor's general office, initiated an investigation of the 13 companies located in the Curvaradó and Jiguamiandó watersheds. In three cases it was possible to probe the linkages of the companies and their responsibility in the violence, land grabbing, and forced displacement. More recently, 16 palm entrepreneurs were prosecuted and sentenced for their links with the paramilitary and subsequent responsibility in the crimes against the Afro-Colombian communities (Sentencia no.054, 2014. Catalina Rendón Henao).

AOP establishment is in part promoted through the "alternative development" program sponsor by the USAID in the framework of "plan Colombia" and the Colombian government. Money from both the USAID program as well as FINAGRO has been given to companies that have linkages with paramilitaries and narco-traffickers as illustrated by the cases of Gradesa and Urapalma. Gradesa the company owner of one the oil extraction and refinement plants in the region got resources from USAID. 50% of the company belongs to the Zuñiga brothers known narco-paramilitaries (Verdad abierta; http://www.verdadabierta.com/paraeconomia/1969-el-lado-oscuro-del-plan-colombia; CLIP, 2005).

2.3.2.1 Underlying Causes of Oil Palm Establishment

The initial establishment of AOP in the region before 2000 was the result of many factors among them: Colombian development plans, the crisis of the banana sector, and the geographic expansion of the conflict. The further expansion of the palm crop between 2001 and 2005 happen after property rights were granted to the Afro-Colombian communities while new government incentives to the palm sector were created and the paramilitary demobilization process was ongoing.

The development plans and the policies of the Colombian government aimed at the integration of the country into the global markets created the incentives for the initial establishment of AOP in the region. A coalition of interest groups including multinationals, banana entrepreneurs, cattle ranchers, high range militaries and other political, and economical elites formed (CNMH, 2012). The paramilitaries became "corporative and counter-insurgency mercenaries" in charged of "organizing" the "development projects"(Franco and Restrepo, 2011).

The long-lasting crisis of the Banana sector during the late 80s and 90s was the result of the ban imposed by the European Union against Latin American Banana, low prices in the international market, and excess in production. For some, the events in the lower Atrato River were the expansion of the processes that have made the Urabá region a violent one and the "cradle" of paramilitary and insurgent groups alike[15] (Romero and Avila, 2011). The

[15] The colonization process in Uraba and the establishment of banana industries has been characterized by land concentration, social unrest, violent coercion, and lack of estate control (Botero, 1990).

economic sectors in Urabá were looking for alternatives to banana production and AOP was the best prospect.

The geographic expansion of the conflict is not surprising. Since the mid 1980's the guerrilla used the area as a shelter and for the smuggling of weapons and later on drugs. The presence of the paramilitary on the Urabá region and the banana axis just North of the Lower Atrato River basin (a guerrilla dominated region) make the confrontation for the territorial domination unavoidable.

2.3.2.2 Consequences of Oil Palm Establishment

The lands occupied by the companies were considered ecologically invaluable. The process of AOP establishment involved the deforestation of the area and the construction of drainage channels; the impact of these two processes in the previous ecosystems has not been assessed, as the human rights violations have been the primary focus. However, the peasants themselves find it impossible to resume their previous activities due to the profound transformation of the landscape (Flórez- López and Millán-Echeverría, 2007; Mingorance, 2005).

The occupation of the land by the companies has some social impacts that have been mentioned briefly but not widely analyzed. There is a rupturing of the social fabric and cohesion of the communities as family members, in particular the leaders, have been murderer or disappeared (Clip, 2005; Mingorance, 2005). Previous settlements, houses, and communication networks have been destroyed. There are divisions inside the communities about how to proceed with the recuperation of the land, some do not want the palm at all others would prefer to be part of the AOP business since it could potentially improve their livelihoods (Clip, 2005, Colombia land, 2013).

The paramilitary development projects included the mobilization of hundreds of peasant families; some of them demobilized paramilitaries, to live in the region. The new families have changed the ethnic composition and undermined the cultural heritage that was "protected" under the 1991 Colombian constitution (Mingorance, 2005; Clip, 2005). The companies have used the new settlers to created false peasant associations to access development and agricultural funds and constitute the work force to establish and maintain the AOP plantations. Although, these new inhabitants are in many cases part of the internal displaced population in Colombia (victims of the conflict themselves) they are seen as "part of the companies" by the Afro-Colombians communities (CNMH 2012, Romero and Avila, 2011, Colombia land, 2013).

2.3.3 Property Rights

The Colombian state in the 1991 constitution with the transitory article 55 and later on with the "Ley 70 of 1993", established the property rights of the Afro-Colombian communities over communal lands. In reference to the land the transitory article 55 states:

"The creation of a law that recognizes the collective property rights of black communities that have inhabited the empty lands (tierras baldías) in the rural riparian zones of the Pacific coast, in accordance with their traditional production practices. The law will aim to establish mechanisms for the protection of the cultural identity and rights of these communities, and to promote their economic and social development" (Republic of Colombia 1991).

In 1993 the formulation of law 70 (Ley 70 1993) further developed the legislation for the application of the transitory article 55. In chapter III the law recognizes the right to collective property. The property is entrusted to the communities with an understanding that they will be the stewards to the biological diversity. Between 1996 and 2002, 92 land property titles were given to 92 communities encompassing 4,015,515 Ha. In 2011 the president signed the law of reparation and land restitution to the victims of the conflict.

Although temporary article T55 and the legislation that followed granted the ownership of the land as well as the protection of the Afro-Colombian communities, the reality on the ground is quite different. The establishment of African oil Palm in the Curvaradó and Jiguamandó rivers is just one example of the powerful economic and political interests that are behind the action of Paramilitary and other armed groups (Escobar,2004; Rosero, 2002).

The AOP industries in the Atrato River have appropriated the land using coercion and violence violating ethnic rights and international human rights (Clip, 2005, Mingorance, 2005, CNMH, 2012). Further they have used legal and illegal strategies to support their land ownership or at least their right to develop it. Common strategies have included; false contracts, lands sold by dead people, coercion and threads to individual land owners, change of property boundaries, "strategic alliances", and lawsuits (Romero, and Avila, 2011; CNMH, 2012).

Colombian Institutions such as INCODER and the constitutional court have ratified the illegality of the occupation in the Curvaradó and Jiguamiandó watersheds (Clip, 2005; Colombia Land, 2013). However, the situation on the ground is far from being resolved.

2.3.3.1 Land Restitution

In the period from1980 to 2010 about 6.8 million Ha of land was taken from small farmers increasing the already high concentration of land. A factual agrarian "counter-reform" has taken place supported by the paramilitaries, Colombian economic, and political elites, and narco-trafickers (Escobar, 2008; Reyes- Posada, 2009).

In 2008 the "Victims' Bill" was debated in the Colombian Congress The bill included specific mechanisms aimed at guaranteeing the restitution of land to victims of the Colombian armed conflict. The bill was not approved at that time and was again subject to debate by the Santos administration in 2011 where a final bill was approved.

The victims and land restitution law (law 1448 of 2011) came into effect on June of 2011. The Victims' Bill –as it is commonly called in Colombia– includes a chapter on specific mechanisms aimed at guaranteeing the restitution of lands that were abandoned or transferred under pressure by victims as a consequence of crimes committed against them. The consensus of political fractions is puzzling regarding a topic that is considered the root of violence and the armed conflict in Colombia: the distribution of the land (Saffon, 2010).

The law seems paradoxical and contradictory with the agricultural economic models promoted by the Uribe and Santos administrations where industrial agribusiness and mining operations are favored. Furthermore, the apparent consensus of some fractions of the government may conceal the adoption of divergent strategies aimed at fulfilling their true interests: legalizing the land grabbing (Saffon, 2010).

In the 20th century different administrations attempted to introduce agrarian reforms that resulted in an escalation of rural violence and further deepened Colombian civil conflict (Machado, 1998; CNMH, 2013). Some fear the law will provide the illegal occupants of the land with the tools to legalize land grabbing. The former owners, poor peasants, do not posses the necessary resources to file the claims (Saffon, 2010). On the other hand the violence, to the IDPs that are claiming their land is commonplace (CNMH 2010; Semana, 2012), the restitution unit has registered threads to 447 land claimers in 27 departments (Human Rights Watch, 2013; Semana, 2012).

The law of victims and land restitution has some positive aspects to it (even if the government fails to implement it). For the first time the government is recognizing the conflict and its victims, a historic reconstruction of the conflict is taking place, an important first step towards reconciliation. In the past the government denied the conflict and its victims and thus the law opens the possibility to hold the government accounted for the conflict.

The land grabbing in the Jiguamiandó and Curvaradó watersheds is emblematic and the Colombian government has staked its reputation in regards to land restitution in these communities. Nevertheless, little has changed on the ground since 2009. The restitution of the land to its legitimate owners includes the eviction of the “bad-faith occupants” a move that the Colombian government to present is reluctant to take. The powerful economic interest behind the land grabbing and the protection of the paramilitaries prevents any local public servant from taking any action. In fact the position of Police inspector, the one who should order and handle the evictions, has been vacant for more than 4 years. In the mean time the illegal occupants of the land are using any possible legal and illegal mechanism that will allow them to retain the control of the land (Colombia Land, 2013).

If the government fails to properly return the land in these communities, where it has invested significant financial and political capital, there is little hope for other communities that do not have the same profile (Colombia land, 2013). The consensus in the many studies of the Colombian armed conflict is that in Colombia peace, equity and development will not be possible without the structural changes needed to have a fair distribution of the land (Lopez, 2013). Hence the failure of the land restitution will hinder the peace process and prolong the armed conflict with devastating consequences for the rural poor.

CHAPTER 3

A first approximation to the analysis of the Chocó socio-ecological complex system and its emergent property the conversion from primary forest to AOP plantations can be undertaken using Land change systems science. From a methodological perspective, the first step is the observation and characterization of the change through remote sensing observations and land use land cover mapping. The second step is an understanding of the proximal and underlying causes of the change. For this region it implies, at the very least, recognition of the social, cultural, economic and political factors in play, particularly, the Colombian conflict and the war on drugs. In addition, it requires an understanding of the AOP agribusiness and inter-scale linkages. The underlying causes and consequences of the change should thus be analyzed through a political ecology framework. The third step in the process is the construction of a land use model. I selected DINAMICA-EGO model, a stochastic cellular automata platform to conduct the exploration of the land change process in the Chocó bioregion (e.g. Soares-Filho et al., 2002).

The first part of this chapter presents then an overview of AOP, its Industry worldwide and in Colombia. The second part reviews the main aspects of land use change science and how it has been used to study the different aspects of AOP expansion and the third part presents a review of the state of the art in land use modeling with an emphasis in DINAMICA-EGO.

3.1 African Oil Palm

3.1.1 AOP Origin and Plant Characteristics

African Oil Palm (Elaeis guineensis) is originally from the Guinea Gulf in western Africa. It is a tall palm (8-20 meters high) with a heavy, ringed trunk. It is monoecious with male and female flowers in separate clusters on the same tree. The palm is naturally found in lowland or riverine forests rather than in primary forest; it acts as a pioneer species in disturbed areas and is likely to be found in close relation with human settlements (Corley and Tinker 2003). AOP growth is limited to altitudes below 600 meters and requires a wet tropical climate with mean low temperature of about 22^{o}C and mean maximum temperature of 33^{o}C. A regular annual rainfall of 1800 mm or greater is required, although it can survive with 1500 mm per year if the rainfall is distributed throughout the year with a dry season of less than three months duration (Moll 1987; Corley and Tinker 2003). It requires adequate light and soil moisture, and can tolerate temporary flooding or a fluctuating water table (Corley and Tinker 2003; Goh and Chew 2000; Hartley 1988). Oil palm grows in a wide range of soils, though soil moisture appears to be a more important limiting factor than nutrient supply (Moll 1987). AOP starts to flower at 2.5 to 3 years of age, and continues producing for up to fifty years. However, the natural trees are often too tall to be harvested after 25 years and are typically replaced, this characteristic has encouraged the development of new varieties that are shorter and most productive for only 15 to 20 years (Corley and Thinker, 2003).

The genus Elaeis is also found in tropical America. *E. oleifera*, known as American palm or noli, occurs naturally in wet tropical ecosystems in central and northern South America. It grows along the riverbanks, tolerating well both shade and flooding, indicating a broader environmental adaptability compared with the African variety (Corley and Tinker 2003). *E. guineensis* is vulnerable to a wide range of diseases in the neotropics (De Franqueville 2003). In the 1960s, efforts began to hybridize AOP with the native E. oleifera in order to increase resistance to several of the most problematic pests (Pedersen and Balslev 1990). In addition to increased resistance, the resulting hybrids have been shown to have other advantages compared with *E. guineensis*. Their annual height increment is lower, allowing harvests to occur for a longer time span. In addition, the oil of the hybrids is richer in unsaturated fatty acids. In spite of these improvements, AOP plantations in the neotropics are still vulnerable to diseases, calling into question the sustainability of the crop in the region (De Franqueville 2003).

3.1.2 AOP Market

Vegetable oils are a staple food of significant economic and social importance to all countries. The USDA reported an increase in production of the five major vegetable oils[16] of about 6 per cent per year. The production went from 90.2 million tons in 2000/2001 to 147.3 million tons in 2010/2011 (Palm oil accounts for 33% of the production). Palm oil production globally is increasing faster than the other oils with 9.5 % increase per year since 2000 from 24.3 million tons in 2000 to 53 million tons in 2012 (Oil World, 2013; ITC, 2013). In Colombia the annual production of crude palm oil exceeded a million tons for the first time in 2013 with 1,050 million tons (Fedepalma, 2013a, 2013b).

Since 2006 oil palm is the leading oil in the global vegetable oil market-surpassing soybean. In spite of market fluctuations the palm industry is highly profitable and has evolved into a global agro-industry. The dominant position of palm oil is due to its production advantages: the oil palm yield per hectare is 5 to 10 times higher than other oil crops and its cultivation has the lowest requirements of fuel, fertilizer and pesticides. The down side is that the production cannot be easily adjusted with short-term changes in demand, as it is the case with annual oilseed crops (ITC, 2013).

[16] The major vegetable oils are palm, soybean, sunflower, palm kernel, and rapeseed. Together they cover about 88 % of the world production.

The behavior of the vegetable oil markets is closely linked to governmental policies the volatility of the prices, and the impact of speculation. The correlation between consumption and prices of several oils due to their substitutability for major uses is another factor (ITC, 2013). For instance, during 2013, taxes adopted in India, Indonesia and Malaysia resulted in a decline of 14 % in the price of crude palm oil from US $ 999 in 2012 to US $ 857 a ton in 2013. The lower price compared to soy oil stimulated a demand that reduced the stock of oil palm in Malaysia by 28% (Fedepalma, 2013a).

An analysis of the oil palm market in the period from 1950 to 2005 shows an increase in production along with a steady decrease in price. Prices in 2003-2004 however were above this long-term trend. This strengthening in the oil price during that period most probably was a consequence of biodiesel demand (Thoenes 2007). For Colombia, the net market from 2000 to 2005 was estimated at US$ 300 million dollars per year. The industry with 184,000 mature Ha generated 27,000 direct jobs and an estimated 25,000 indirect ones (Gómez et al. 2005; Mesa-Dishington 2008). The Colombian oil palm yield per hectare has historically trailed Malaysia and Indonesia (the main producers of oil palm). In 2013 Colombia crude oil palm production was 3.1t/ha whereas Malaysia and Indonesia had 4.1 and 3.9 t/ha respectively. The low productivity is associated to water stress and phytosanitary crisis caused mainly by Bud rot "Pudricion del cogollo" PC in several areas of Colombia (Fedepalma, 2013a).

The long-term trend of the crude oil palm market is volatile and strongly linked to political and management decisions regarding biofuels production. The European Union has restricted the imports of biofuels (via quotas) from food crops amidst environmental and human rights concerns, EU policies were followed by blending mandates[17] in Indonesia aimed at increasing

[17] Biofuel blending mandates create an internal demand for oils (ITC, 2013).

the local consumption of oil palm. However, blending targets to ten per cent by 2020 are part of the climate mitigation estrategy of the EU (ITC, 2013; UNCTAD, 2013).

3.1.3 AOP Production Systems

Traditionally AOP was grown in slash and burn parcels in small intercropping systems where the oil extracted from the plant constituted a key ingredient of the local cuisine (Corley and Tinker 2003). However, over the last fifty years AOP has experienced a steady increase in production, rising from being a minor crop as late as the 1960s to a major global crop (Murphy 2007; Rupilius 2007). The main use for African palm oil, until recently, was for edible products, and it is expected that the need for edible palm oils will increase as the Chinese and Indian economies continue to expand (Murphy 2007). However, the growing demand for biodiesel from European countries and the U.S. has changed the market perspectives (Murphy 2007). The top global producers are currently (in order) Indonesia, Malaysia, Nigeria, Thailand, and Colombia, which is first in Latin America (Corley and Tinker 2003; FAO 2008). China and the EU are the principal importers (Murphy 2007).

Industrial cultivation of AOP is mostly on large plantations in Asia and Latin America (Clay 2004). Early development of AOP plantations in Asia and Africa was promoted following the "state" model. A state-owned company designs development plans that include securing the production of small farmers for the state-owned mills. In exchange, the company provides farmers with inputs, planting materials (through credits), and technical support. Currently, most state-owned companies have been privatized as part of economic liberalization and modernization processes. Privatized plantations typically do not provide the farmers with either credit or technical assistance (Cheyns and Rafflegeau 2005).

In Colombia different AOP production models are represented: the traditional intercropping system and the monoculture. The monoculture model has been described as entrepreneurial (horizontal and vertical) and associative (Mingorance et al., 2004). In the vertical monoculture model all the stages of AOP production are concentrated under a single owner. In the horizontal model more actors participate at each of the stages and processes of production. Two types of situations occur under the horizontal model, one where the farmer becomes a "stock holder" of the AOP agro-industry, exchanging his produce for supplies and a part of the revenues and one where small famers sell their produce to an AOP company. The latest situation is the equivalent to "nucleus states" system in Malaysia and is known in Colombia as "alianzas estrategicas" or "alianzas productivas" (strategic or productive alliances) between small and medium producers with large entrepreneurs and the state (Mingorance et al. 2004, Aguilera 2002). Under the "alianzas estrategicas" the farmer is constrained to sell produce to a particular company for a period of 12 years. The benefits of the scheme are not clear. For some, this is a way for the companies to decrease production costs and lower the risks by passing them into the farmers (Mingorance et al. 2004, Ó Loingsigh 2002).

The associative model has been implemented as part of an alternative development program funded mainly by the EU (peace laboratories program). The best-known example is the "Programa de desarrollo y paz del Magdalena Medio (PDPMM)" (development and peace program of the Magdalena Medio) (Barreto 2007, Mingorance et al. 2004). This model appears to follow the experience of the agro-industrial project of Coto sur in Costa Rica (Cano 2002). Under this model small producers are organized or "associated" to promote independence and increase bargaining power with the AOP agro-industries. The strategy seems to be successful only when either the state or the international community supports them in the beginning stages with fiscal incentives, low interest credits and/or donations (Barreto 2007).

Regardless of the production system the establishment of an oil palm plantation requires preparation of the land, as well as development of infrastructure to process the fruit into oil (e.g., mills, roads). When a plantation is started in an isolated area, development requirements are quite large. Initial land preparation involves the removal of most of the standing vegetation, which is either burned or sold. This may also require construction or modification of existing drainage systems. Road construction is often needed to permit transportation of the fruit to mills. AOP is typically planted on grids with spaces between trees of 7.5 to 10 meters to avoid crowding since shadows reduce AOP productivity. This typically results in 115 to 205 palms per hectare (Corley and Tinker 2003; Hartley 1988).

Plantation management requires the use of fertilizers, herbicides, and pesticides. Fertilizer cost constitutes forty to sixty percent of the total maintenance cost or up to twenty percent of the total production (Clay 2004). The use of herbicides and pesticides is variable (Clay 2004). Countries with high yields such as Indonesia, Malaysia, and Colombia use more fertilizer than countries with lower yields (Moll 1987).

Palm fruits must be processed within two days of harvest before the seed spoils. Road conditions in most of the developing countries prevent long distance transportation of AOP fruits, especially among small farmers. Oil mills for the most part are standardized and consist of the following operational units: bunch reception, sterilization of bunches, bunches threshing, fruit digestion, pulp pressing, oil clarification, and oil drying and packing. Oil mills were originally designed to be efficient at large scales of AOP fruit production; the previous oil mill model required thirty to forty thousand hectares of AOP trees to be economically viable. Recently, smaller crusher/expellers have been developed which are competitive at a scale of four hundred hectares. These new mills require nine years of operation before initial investments are recovered. The resulting crude oils produced are stable and can then be transported for further refining and bleaching (Clay 2004).

The scale of production and the proximity to processing plants determines the farmers' competitiveness, and therefore constrains market access. Comparison of the production costs of crude palm oil in 1997 shows that in Colombia the cost of cultivation, harvest transportation and mill processing are above the world average, for example, transporting a metric ton of palm fruit cost US$ 78.9 in Colombia compared to US$ 40.2 in Indonesia (Clay 2004).

3.1.4 AOP Uses

African oil palms are at the foundation of a complex industry. Three main products and several derived ones are obtained by the extraction and processing of palm fruit bunches. Extraction, bleaching and neutralization of the fruit flesh produces the crude palm oil, crude palm stearin, and olein. From the seed (kernel) of the fruit is extracted the palm kernel oil, further refinement of the kernel oil produces palm fatty acids, esters and glycerine derivatives. Palm kernel oil meal is a by product of the process and is used as animal feed (ITC, 2012; Ospina Bozzi, Martha L., 2013) .

The empty bunches as well as the palm kernel shells and fiber are used as fertilizers and as fuel. A sap tapped from the palm flower is processed into palm wine in West African countries. The trunk of the tree is used as supportive frames in buildings and the leaves of the palm are used for making brooms, roofing and thatching baskets and mats. In east African villages the thicker stalks are used to reinforce the walls of huts (ITC, 2012; Corley and Tinker, 2003).

African oil palm is part of a wide variety of industrial processes. The glycerin derivatives are widely used in the cosmetic and pharmaceutics' industries in creams, lotions, skin oils, make up, lipsticks, etc. It is also an ingredient of detergents, waxes and degreasing agent in pipes. It is used as raw material for candles, crayons, textile pigments, paints and pencil leads. Its use in soaps manufacturing is on the rise, as it does not require a process of deodorization, as do the fats from animal origin. In addition, it is better at retaining perfumes and is resistant to oxidation (Ospina Bozzi, Martha L., 2013).

The main use however is in food production or direct consumption of the oil. In the past, oil palm was regarded as undesirable "tropical oil" amidst health concerns. Saturated fats have been widely regarded as harmful components of the diet due to the associations within fat consumption and hearth disease. Crude oil palm is composed of half saturated fats (palmitic) and half unsaturated fats (mainly oleic) fatty acids. Oil palm is a balanced oil (having equal saturated and non-saturated content) and one that is trans fat free (Mohd Basri Wahid et al., 2005). Furthermore oil palm intake appears to raise the levels of high-density lipoprotein (HDL, 'good" colesterol) at the expense of the low-density lipoprotein (LDL, 'bad' cholesterol) (Mohd Basri Wahid. et al., 2005; Ibraheem et al., 2014). In addition, recent studies have pointed oil palm as a nutritious alternative due to its content of phytonutrients such as tocotrienols, carotenoids, and phytosterols considered to be healthy antioxidants (May and Nesaretnam, 2014).

3.1.5 AOP as Biofuel

Fossil fuels have provided the world with the energy for transportation, lighting, heating, cooking, manufacturing, and information. However, the advances have come with a high environmental cost. Mitigation efforts have included finding alternative energy resources. In this quest biofuels have appeared as a suitable alternative. In order to mitigate the effects of climate change several countries have introduced mandates and targets for biofuel expansion (ITC, 2012; UNCTAD et al., 2014).

The use of biofuels or bioenergy is changing the traditional value of land. Land scarcity and the drive to produce biofuels have the potential to affect 1.5 billion livelihoods globally (Creutzig et al., 2013). In 2011 biofuels accounted for 0.8 % of the total world energy consumption, a very limited share. Fossil fuels remained the main source of energy with 78.2 %. The demand for biodiesel is shaped not only by the market fluctuation but also by the regulatory frameworks adopted by different countries (UNCTAD et al., 2014; Creutzig et al., 2013). During 2012 the investment in biofuels dropped by 50% as a result of overcapacity in some markets (e.g. European Union) and the reconsideration of biofuel support policies. The EU is the world's biggest biodiesel producer and the largest importer of biofuels. EU adoption of quotas and caps to limit the imports of biofuel derived from food crops along with a change in the blend goal from 10% to 6% by 2020 have impacted the biofuels market (UNCTAD et al., 2013, International Energy Agency, 2013).

In Colombia the authorization regarding the mix of biodiesel with petrol diesel was established through a bill passed in December 2004 (Bill 939). The Bill provided for 10-year tax exemptions for some feedstock production, including palm oil, and for 10-year tax exemptions for biodiesel used in diesel engines domestically produced. The biofuels blend mandate establishes a biodiesel blend at B10 and an ethanol blend from E8 to E10. The decree was implemented on January 1, 2012. Biofuel production in 2012 was 895 million liters of biofuels, from which 362 million liters were bioethanol and 533 million liters biodiesel. Despite new production facilities coming online in 2015 and the palm federation Fedepalma hopes for an increase to B20 the percentage of biofuels allowed in the blend, the Colombian government has not adopted any new mandates (UNCTAD et al., 2013; Ospina Bozzi, Martha L., 2013).

3.1.6 AOP Environmental Concerns

No human activity has changed the landscape of the planet more than agriculture (Foley et al., 2005). As such AOP establishment is an example of a proximate cause of land use change, it is often established as a large operation that requires vast stretches of land. Expansion has occurred not only for AOP but also for other crops such as soya, rice, wheat, and maize (Phalan et al., 2013). AOP however has been the focus of attention because the climatic requirements for AOP cultivation are met in the tropical areas cover by forest. The expansion of oil palm plantations has led already to extensive wildlife habitat conversion in SouthEast Asia (Willcove et al, 2013).

3.1.6.1 Habitat Conversion and Biodiversity

AOP cultivation has been linked in Asia to declines in biodiversity, deforestation, soil degradation, environmental pollution, and appropriation of indigenous lands (Aratrakorn et al. 2006; Linkie et al. 2003; Schroth et al. 2001; WRM 2001; Schroth et al. 2000). In SouthEast Asia the main concern with AOP production has been habitat conversion, resulting primarily in loss of tropical forest (Clay 2004). In Malaysia, Indonesia and Ecuador, expansion of AOP has taken place in areas that were previously covered by forests (Angelsen 1999; Ashley 1987; Dodson and Gentry 1991). The establishment of AOP plantations also requires infrastructure development such as the creation of roads to support agro-industry also facilitate illegal lumbering, as has been reported in Thailand (Mansfield 1999). In addition, forest conversion to AOP plantations represents a significant source of GHG emissions. Deforestation and land conversion contribute 15% to 25% of global carbon emissions. Estimates show that the conversion of low land tropical rain forest to AOP plantations results in a carbon debt of 610 Mg CO_2 per hectare (Danielsen, et al., 2008).

Although it is generally agreed that oil plantations have resulted in deforestation in countries such as Indonesia (Gibbs at al., 2010). Different accounts of the process show different results. The Indonesian Oil Palm Research Institute (IOPRI) claims that only 3% of the 7.3 million hectares of the crop have been established in primary forest. According to Casson (2000) about six million ha of forestland were transformed into oil palm plantations between 1982 and 1999.

In Colombia the situation appears to be different, although a thorough inventory of the areas under palm cultivation and their previous land cover is not available. African palm agro-industries reported in a survey that 82.5 percent of the areas with AOP were previously used either for cattle ranching or for other crops (Rodríguez and van Hoof 2003), and that only 17.5 percent of the AOP area was directly converted from natural ecosystems (Rodríguez and van Hoof 2003). However, local impacts have occasionally been severe; the establishment of 456 Ha of AOP in the Tumaco province resulted in clearing of forest and construction of 86 km of drainage ditches and 11 km of roads (Ospina-Bozzi 2001).

An assessment of the effects of habitat conversion for AOP on biodiversity in Colombia has not been conducted, but studies in Asia have shown that the conversion has a devastating effect on the fauna with at least a sixty percent reduction in species richness (Aratrakon et al. 2006). For example, Malaysia's primary forest hosts nearly eighty species of mammals, a disturbed forest hosts over thirty, but only eleven or twelve are found in oil palm plantations (Wakker 1998). Similar reductions occur for insects, birds, reptiles, and soil microorganisms

(Clay 2004). Land use transition matrices used to model biodiversity loss., projected biodiversity declines at subregional level ranging from 0.2 % in central Kalimantan to ~ 35 % in Bengkulu (Koh et al., 2011).

The reported effects of AOP on biodiversity in Asian ecosystems should raise concerns about the Colombian AOP industry given the country's rich natural endowment. Further expansion of AOP could threaten the conservation of the tropical forests in the Amazon, the gallery and riparian forests of the Orinoco basin, the dry forest in northern Colombia and the natural savannas. The impact of AOP plantations on the biodiversity of adjacent forests is unknown. This is of concern due to the capacity of AOP to disperse and establish itself without human intervention (Aldana and Calvache, 2002). The Colombian African Oil Palm Federation (Fedepalma) includes the control of spontaneous colonization in natural ecosystems as part of plantation management standards. However, this kind of control is unlikely to be a part of small farmers' management practices.

3.1.6.2 Pollution: Air

Habitat conversion, however, is not the only environmental impact incurred by AOP plantations and its industrial processing. Other environmental concerns include air, water, and soil pollution, soil degradation and water scarcity (Clay, 2004). Burning of organic matter often proceeds planting and renewal of AOP plantations, releasing CO_2; in 1997, Indonesian fires from AOP plantations released between 0.81 to 2.57 gigatons of carbon (Page et al. 2002). This represents between thirteen and forty percent of the mean annual emissions from fossil fuels (Clay 2004). However, CO2 emissions from AOP plantations in south East Asia have different sources: waste burning, peatlands oxidation, and the mills. Fires are the predominant method of clearing and managing land for more intensive uses, both in Colombia and in south East Asia, the related emissions adversely affect climate and public health, through CO2 emissions, particulate matter and high ozone concentrations (Marlier et al., 2014). El NIÑO induced droughts couple with changes in land use have resulted in an increase susceptibility of forests in particular peat swamp forest to fires. The peat swamp becomes vulnerable to fires after drainage. Fires from the peat swamps are particularly problematic since an estimate of at least 55 Gt C are contain in the soils (Jaenicke, 2005; Marlier et al., 2014). The frequency and intensity of the fires are negatively associated with rainfall and positively associated with strong El NIÑO events (Spesa et al., 2015). During the fires of 1997-1998 about 1 Gt of carbon was released into the atmosphere. This amount is the equivalent of 10% the average global annual fossil fuel emissions released during the 1990's (van der Welf, et al., 2008).

Fires play an important role in the land use trajectories of the region as well. Deliberate fires are often used in logged forest or in government protected areas. Fires can turn those areas into degraded lands that will be planted either by agribusiness or small farmers declaring in that way de facto ownership of the land (Carlson et al., 2013). MODIS fire product and the rapid response System (Davies, et al., 2009) have been crucial to establish the connection between fires and deforestation in peatland areas during the 2000-2010 period (Miettinen et al., 2012)

A monitoring system to quantify CO2 emissions has been proposed using RADAR base remote sensing. The proposed system suggested the use of COSMO-SkyMed SAR, ALOS PALSAR, TerraSAR-X, IKONOS and worldview (Pohl, C., 2014). ALOS PALSAR has been used to discriminate forest stands from AOP plantations and to predict above ground biomass in Sabah, Malaysia (Morel, et al., 2011). Furthermore, estimations of above ground biomass using ALOS PALSAR have been conducted in the forests of Guinea-Bissau (Carreiras et al., 2012). These efforts are relevant for climate change mitigation efforts in particular for the proposed REDD (Reduced Emissions from Deforestation and Degradation) mechanism as part of the United Nations Framework Convention on Climate Change.

Other impacts of AOP establishment include increases in surface temperature in AOP plantations. Temperature surface estimates from Landsat TM and ETM+ thermal bands show an increase of 0.2 ^{o}C. The new land cover (AOP plantations) with lower and simpler structure, less density of the close canopy in comparison with the rainforest appears as the culprit (Ramdani et al., 2014).

3.1.6.3 Pollution: Soils and Water

The use of pesticides in Asian plantations is minimal and is mainly restricted to control of rats that are attracted to the AOP fruit. In the past, the use of poison to kill rats also killed other native species attempting to recolonize the plantations (Clay 2004). In Colombia, the situation may be different, as inclusion of the palm in a new environment has resulted in the development of new diseases (Gómez et al. 2005). It is not unreasonable to expect this to worsen as the palm is introduced in new environments, increasing at the same time the demand for pesticides.

High AOP yields require large amounts of fertilizer (Moll 1987). An alternative is to plant leguminous covers to provide the crop with nitrogen. This strategy, along with intercropping systems, only works until the palms create a closed canopy, after which the amount of light available to other plants is greatly diminished (Clay 2004; Corley and Tinker 2003). Another problem with intercropping is the selection of the other crop. Food crops such as maize and cassava are not suited to growing in shade, and competition for light and nutrients result in lower yields. The ideal situation would be to have the crops sufficiently spaced so as to eliminate competition for nutrients and light (Corley and Tinker 2003; Hartley 1988).

In addition to fertilizer, another source of pollution comes from the mills during the extraction of oil and other products. Mills in Thailand have been found to produce large amounts of organic waste (Prasertan, 1996). In the process of oil production, considerable amounts of water are needed; the organic matter dissolved in water is known as palm oil mill effluent (POME) (Yacob et al. 2005). This liquid effluent is usually a combination of the waste streams coming from the sterilizer, the bunch separator, and the clarification processes (Borja et al. 1996). POME is a brown liquid containing dissolved and particulate solids, oil, ammonia, and nitrogen; it incurs high chemical and biological oxygen demand, causing negative impacts to water quality (Borja et al. 1996). POME is the most significant waste generated during the oil extraction process. For every ton of fresh palm fruit, 0.5–0.75 ton of POME is discharged, with characteristics of the effluent varying according to the season and mill management practices (Yacob et al. 2006). In the past POME was directly discharged to nearby water bodies; but currently, treatment is primarily by ponding or open digestion tank systems (Davis and Relly 1980). The open digestion system has been identified as a source of methane (Yacob et al. 2005), an important greenhouse gas, (Yacob et al. 2005; Reijnders and Huijbregts 2008). In Colombia, POME discharge in 1996 was estimated at 56 thousand tons, or the equivalent of the organic waste produced by a city of over four million inhabitants (Garcia 1996). The actual discharge may be lower since most processing plants have residual water treatment systems, but there are no studies that report the actual POME discharge to water bodies (Garcia 1996).

Besides water pollution a topic rarely addressed is the amount of water that is needed for the palm to grow as well as the water that is needed in further processing (Clay, 2004). Of major concern are the impacts to water resources due to the large quantities of water and fertilizers needed to grow the crops. Between one and four thousand liters of water are needed to produce a single liter of biofuel (UN 2009). In Colombia water is likely to become a big concern as AOP development advances into the Llanos Orientals a region of natural savannas peppered by riparian forests (morichales) and crops[18] (Romero-Ruiz et al., 2010),

3.1.7 Sustainable AOP Production

In spite of the environmental costs, the economic and social benefits of AOP development can be high (Risk et al., 2010; Lee et al., 2011), making this agro-business attractive for governments and investors alike. In order to offset the environmental cost of AOP business operation a variety of initiatives and schemes are at distinct stages of development (ITC, 2012). A unique system of certification as well as a unique set of rules about what constitutes sustainable AOP production and processing seems unlikely. At present the EU has in place a set of rules for the import of biofuel crops. Indonesia and Malaysia are in the process to create their own rules and certification. Amidst this wave of policymaking, two initiatives hold promise in the goal for clear unified criteria about sustainable AOP production: RSB and RSPO (ITC, 2012).

Roundtable of Sustainable Biofuels (RSB): This roundtable was launched in 2007 by the Ecole Polytechnique Federale in Lausanne, Switzerland, its objective is provide a platform to bring together multi-stakeholders in the quest for ensuring the sustainability of biofuels production and processing. In 2007, RBS released a draft of guiding principles: " Draft Global Principles for Sustainable Biofuels Production" outlining the ideal scenario towards which producers and processors should work (RSB, 2007).

[18] This area of the country has been targeted for AOP development (Bochno, 2009)

The Roundtable on Sustainable Palm Oil (RSPO): RSPO is a voluntary non profit association of oil palm growers, palm oil processors, traders, consumer goods manufacturers, retailers, banks and investors, as well as environmental, nature conservation and developmental NGOs. It was created in 2004 with the objective to promote the growth and use of sustainable oil palm products through credible global standards and engagement of stakeholders. RSPO and its members have established a set of guiding principles and criteria for sustainable palm oil production and a voluntary certification system designed to create a market for certified sustainable palm oil. In 2011 about 6 million tons of palm oil and 1.4 million tons of palm kernel oil, about 10% of the Global AOP production, were RSPO certified.

In Colombia Fedepalma has developed an environmental guide for improving monitoring and management practices throughout the AOP production process (Mazorra 2002). The Federation has join RSPO and its actively working to guide its members thought the certification process (Ospina Bozzi, Martha L., 2013).

3.1.7.1 Minimizing AOP Environmental Impact

The significant effects on the environment in South East Asia have caused concerned scientists and conservation groups to suggest different mechanisms to diminish the impact of AOP plantations (Clay, 2004; Sodhi et al., 2010, Wilcove et al., 2013). Suggestions included: restrictions to forest conversion, promotion of smaller mills, reduced fertilizer use, integrated pest management and biological controls, eliminate burning, reduced water use by reusing water from effluents, and elimination of organic and toxic materials from the effluents (Clay, 2004; Basri et al., 2005). In Colombia the specific recommendation is to target AOP development into the vast areas currently under pastures and cattle ranching. Such an approach may spare the forest but is not without social and economic costs (Garcia-Ulloa et al., 2012).

The most critical issue is habitat transformation and biodiversity loss. The proposed solutions will have to be enforced through incentives and certification mechanisms such as the one proposed by RSPO (Sodhi et al., 2010; Huay Lee et al., 2011). Incentives from the governments to use already degraded land, pastures, and agricultural lands with low productivity are paramount as the industry is often reluctant to do so. The industry rational to establish AOP plantations in primary forest is that the cost of AOP establishment can be offset by selling the timber resources from the forest, second the vegetation (by burning) provides soil with nutrients, decreasing the need for fertilizers. Finally, soil and water conditions are usually better than in degraded lands were they may have to deal with compacted and depleted soils (Corley, 2009; Sodhi et al., 2010; Lee et al., 2011).

Another factor that will contribute to limit the expansion of AOP industry into the forest is yield improvements. The biological characteristics, and natural diversity of *Elaeis guinensis* are remarkable: it has an unusual source-sink interaction,[19] high efficiency of solar radiation interception, and continuous year round fruit production (Corley and Tinker 2003; Barcelos et al., 2015). These characteristics along with genetic and molecular advances such as the completion of the DNA sequence, the identification of specific genes, and the creation of hybrids will contribute to reach the estimated 11-18 ton ha in global oil production (Barcelos et al., 2015).

[19] Unlike other studied angiosperms, oil palm does not regulate photosynthesis to adjust source–sink imbalances, instead photosynthates are converted into a reserve pool of non-structural carbohydrates (NSC). The NSC reserve pool in oil palm is so large that in theory it could sustain tree growth and maintain fruit development for 7 months, regardless of cloud cover or periodical suboptimal growth conditions (Legros et al.,2009).

Successful implementation of the environmental strategies needs to be coupled with social concerns. Land tenure and property rights need to be addressed. The concessions given by governments to industries in forested lands ignored the customary rights of the local people, leading to human rights abuse (Marti, S., 2008). In Indonesia more than 630 land disputes have taken place between oil palm companies and communities (Marti, S., 2008; Colchester, 2011). Furthermore the livelihoods of the local people are deeply affected by the companies, as their traditional ways of life are often unattainable without the forest resources (Obidzinski, 2012). On the other hand the integration of smallholder suppliers to the certification process is challenging as this group has limited access to financial capital, buyers, technology and information (Lee, et al., 2011).

3.1.8 AOP in Colombia

Colombia is a "palm country", the Arecaceae family (the palm family) is represented in the country with 48 genera and 247 species, 50 of which are endemic (Galeano, 1992). In the Pacific region there are 69 species of palms grouped in 30 genera (28% of the palms reported for Colombia), with 10 species being endemic (Ramirez and Galeano, 2010). Native palms are widely used by local communities as a source of oil, food, and beverages and as raw material for houses, fishing, wickerwork (including hammocks), and furniture construction (Galeano, 1992).

In the neotropics *Elaeis americana* is the counterpart of the African oil palm *Elaeis guinensis* (Corley and Thinker, 2003; Barcelos et als., 2015)). Natural stands of palms are common in the flooded plains of rivers and meanders (Galeano, 1992). Before the introduction of *Elaeis guinensis*, *Elaeis americana* (noli) palm was used in the Northern Atlantic plains of Colombia. The local populations conducted manual extraction of the oil and a few attempts of industrialization were made (Ospina Bozzi, Martha L., 2013). The activity was displaced by the expansion of cotton and rice agribusiness and the incipient industry of "red lard" slowly faded (Ospina Bozzi, Martha L., 2013).

Colombia offers a variety of habitats suitable for AOP establishment but also provides genetic diversity for the production of hybrids that potentially will provide resistance to the myriad of phytosanitary problems confronted by *E. Guinensis* in Colombia (Ospina Bozzi, Martha L., 2013; Barcelos et al., 2015).

3.1.8.1 History of the Industry

African oil palm was first introduced in Colombia in the year 1926 several attempts were made at the time to establish AOP agribusiness. However, the efforts were abandoned and the palm was considered more as an ornamental plant than a commercial species. United Fruit in Urabá region established the first AOP plantation in 1947. The conditions during WWII motivated the initial interest for AOP production. United Fruit, before the war, had banana plantations but during the war there was no transportation for the bananas to US or Europe. In addition during that time there was a shortage of oils and after the war there was a substantial increase in the price of the Palm oil (Ospina Bozzi and Ochoa-Jaramillo; 2001; Ospina Bozzi, Martha L., 2013).

AOP as an agribusiness was established in Colombia during the 1960's under government protection and with the World Bank support as large-scale plantations (Escobar, 2009; Ospina Bozzi, Martha L., 2013). The establishment of plantations was promoted in the Llanos, Tumaco and Magdalena regions in the agricultural frontier. From the outset the conception of the industry was meant for large capital investment (Escobar, 2009). According to Fedepalma, the business produces rents after 5,000 Ha of the crop.

During the 1970s and 1980s the growth of the industry was slow in part as a reflection of the two to three years needed for the palm to enter the productive stage. However, it was in the 80's that the industry consolidated and the internal demand of Colombia for vegetable oils grew exponentially. During the 90s the area under AOP cultivation grew 40% and production increased 131%. During that period Colombian AOP industry tested the international market. The main challenges for Colombia in the international market are the high cost of production and the lower productivity per ha compared to East Asia (Clay, 2004: Ospina Bozzi, Martha L., 2013).

In the first decade of the 21st century the industry got a boost during the Uribe administration that was comparable to the support given in the 60's. The creation of the biofuels market, availability of credits, and tax exemptions opened a new era in the industry. The area under palm cultivation has doubled in the last 10 years and the production has increased in 55%. According to Fedepalma Colombia possess 3.5 million ha with potential for AOP plantations establishment and development (Ospina Bozzi, Martha L., 2013).

Colombia ranks as the 5th exporter of AOP in the world and the 1st in Latin America. During 2012, the total production was 1,663,941 tons with a commercial value of more than a billion dollars (US $ 1,425,997,437) of which exports amounted to 188.432 tons (Fedepalma, 2013a, Fedepalma, 2013b).

3.1.8.2 Colombian Agriculture and AOP

Colombian agriculture is a paradox. Colombia ranks 25 in a FAO list of 223 countries with potential for agricultural expansion, excluding areas of primary forest (Vélez, et al., 2010). Its location and geographic (landscape) complexity provides a wide variety of climatic and agro ecological conditions year round. It ranks 7th in the world in water resources availability

(IDEAM, 2012). And yet of the 22.1 million ha suitable for agriculture, only 24 % or about 5.3 millions are used (IGAC, 2012). In spite of this situation agriculture is an essential part of Colombian economy. It contributes about 10% of the national gross domestic product (GDP) employs 19% of the country work force with 66% of the employment in rural areas (Perfetti et al., 2013).

In 2013 there were 4,950,680 Ha under agriculture production of which 476,782 Ha were AOP and 950,000 were coffee (a staple Colombian product) (Fedepalma, 2013a). AOP was the second agro-industrial export after sugar and molasses[20] (Proexport Colombia, 2014). Three factors have been central for the development and consolidation of the industry since its start in the 60s: Individual initiatives, board management, and supportive public policies. Among them board management has been a constant force to move forward the industry even in the absence of government support (Ospina Bozzi, Martha L., 2013).

The Federación Nacional de Cultivadores de Palma de Aceite Fedepalma (the national federation of palm growers) was created in 1962 by a group of palm growers and investors. Today it represents a big portion of the area under production and most of the processing infrastructure in the country. A board of trust selected by the members of the federation guide the industry. Fedepalma effective management has resulted in the creation of other institutions such as CENIPALMA (research and technology) and C.I. ACEPALMA (marketing).

The Corporación Centro de Investigación en Palma de Aceite CENIPALMA (Corporation Center for Oil Palm Research) was created in 1991. Although, it was created under Fedepalma financial and infrastructure resources, it is an independent research body. At present, it has its own resources and has become a national and international authority in the research of AOP

[20] During 2012-2013 production of Coffee increased by 10.4 whereas AOP grew 0.7%. Coffee is still a primary export product of Colombian agriculture. AOP is compared in the agroindustrial exports since the processing gives it added value. Ministerio de Agricultura y desarrollo rural and Fedepalma, 2013.

sanitary problems, in technology transfer, and supports the needs of growers and processors (http://www.cenipalma.org/).

The Comercializadora de Aceite de Palma ACEPALMA S.A. (Institution for oil palm Marketing) was created in 1991 after the first exports of oil palm were handled by Fedepalma. The intent was to create an institution that will deal with the export not only of Crude oil palm but one that will search international business opportunities and look for ways to find products with added value for the national and international markets.

Fedepalma has enough leverage at the national level that it is able to negotiate with the central government exceptions and benefits for the industry such as the fondos parafiscales (parafiscal[21] contributions funds). The funds are used and managed by Fedepalma to be invested in technology transfer, research and to create mechanism to promote the industry and stabilize the internal prices.

The success of the business is in sharp contrast with the social realities in the places where it has been "imposed", Escobar describes the process of AOP establishment as "global colonialism" (Escobar, 2009). In the Tumaco region, for instance, people were slowly displaced by the shrimp and palm industries. The rural landscape was transformed from small parcels of land with many land holders to vast extents of palm owned by external investors (Escobar, 2009) In Colombia, concerns about the oil-palm sector has been mainly associated with human rights violations (Mingorance,2006), rather than environmental impacts (Rodrıíguez-Becerra and Hoof, 2005).

[21] Parafiscal funds are special forms of taxation were the taxes rendered to the state by law do not go into the state budget.

3.1.8.3 AOP and the Environment

The environmental effects of AOP in Colombia have been largely ignored as the civil conflict and human rights abuses have been the main concern. Colombia possesses 58.6 million Ha with various degrees of suitability for AOP development. 80 % of this area is natural vegetation distributed as forest 70 %, shrublands 0.2%, and grasslands 9%. The remaining area is agricultural land of which 86 % is dedicated to cattle ranching (Garcia- Ulloa, 2012). AOP expansion in Colombia at present is not perceived as a threat to the tropical forest. The assumption is that the development of AOP will occur in natural savannas or in grasslands and pastures of low productivity (Garcia-Ulloa et al., 2012; Castiblanco et al., 2013). However, these assumptions do not take into account the feasibility of the establishment or the high cost of land.

A biodiversity survey on the Llanos of Colombia with a focus on ants, beetles, birds, and herpetofauna communities found that plantations have similar or higher species richness compared to improved pastures (Gilroy et al., 2015). For dung beetles species richness was equal to that of the forest where as the other three groups present higher species richness in the forest. The study suggests that AOP development in areas currently under pastures will not negatively impact biodiversity. However, the preservation of riparian forest and forest remnants are a must to protect high biodiversity and that is particularly true for birds (Gilroy, et al., 2015).

3.1.8.4 AOP Phytosanitary Problems

Oil palm cultivation is confronted with a wide variety of diseases worldwide but most importantly in Latin America (Ntsefong, et al., 2012; De Franquesville, 2001). The oil palm is susceptible to three main specific diseases on each of the three continents where it is cultivated. Vascular wilt caused by *Fusarium oxysporum* f. sp. *elaeidis* is the most damaging disease of oil palm in Africa (Wardlaw, 1950; Renard and de Franqueville, 1989; de Franqueville and Diabaté, 1995; Tengoua and Bakoumé, 2005), causing up to 70% mortality. Vascular wilt was observed in Brasil and Ecuador (Renard and de Franqueville, 1989). In Southeast Asia, basal stem rot has been known to cause up to 80% mortality (de Franqueville & Renard, 1990; de Franqueville et al., 2001; Cochard et al., 2005). This disease is caused by *Ganoderm sp.*, a soil borne fungus that attacks palm oil roots. No control method against this disease has so far been successful (Ntsefong, et al., 2012). In Latin America, bud rot is the most damaging disease. It is found primarily in Ecuador, Brazil, Panama and Surinam and it is of considerable economic importance as it had caused in many cases 100% mortality (de Franquesville, 2003, Ntsefong, et al., 2012).) De Franquesville described two types of bud rot one lethal in Ecuador and many areas of Colombia, Panama and Surinam, and one mild in the "llanos orientales" (Colombia) were the palm trees can recover after 18 to 24 months (de Franquesville, 2003).

The illness was reported in Colombia for the first time in 1964 in Turbo (Urabá region) in a few years the disease destroyed 49,000 palm trees (De Franquesville, 2003; Ospina-Bozzi and Ochoa-Jaramillo, 2001). In recent years PC caused in Colombia the complete lost of 70,000 Ha of AOP in the areas of Tumaco (Pacific coast) and Puerto Wilches (Central Colombia) according to statistics from Fedepalma (Fedepalma, 2013a). A disease affected the AOP plantations in Curvaradó and Jiguamiandó Watersheds during 2007 (Colombia land, 2013); but reports of the illness in this region are not registered by Fedepalma.

Although, research into bud rot disease has more than 40 years only recently the etiological agent was identified[22] . The etiological agent *Phytophtora palmivora* a Fungus or fungus like organism in the genus *Phitophtora* was[23] found to be responsible for the PC in Colombia (Torres, et al., 2010; Martinez et al. 2011). *Phitophtora sp.* is a diverse genus of plant pathogens, which name derived from Greek means "plant destroyer".

The disease causes yellowing and drying of young leaves. Bud rot and yellowing of unopened leaves and the death of the palm if the rot spreads to the meristem (de Franquesville, 2003). The infection is present in all stages from nursery to the end of the production cycle (Martinez, et. al., 2011).

3.1.8.5 AOP Other Diseases

Although the but rot (PC) is the main cause of disease at a national level, a variety of pests and infections are reported in different regions of the country (see Table 3.1). During 2013 in the central area 37,700 palm trees were eliminated as a result of pytosanitary problems (Fedepalma, 2013a). In the eastern part of the country "llanos orientales" the bud rot affects all the plantations. However, in this region the illness is not lethal and the palm trees recover in months or years, presenting a decrease in productivity during the recovery period (de Franquesville, 2002, Pichón, 2010). The marchitez letal on the other hand is responsible for the destruction of 214,000 palm trees since 1994, 40,000 of which were reported during 2013. A new problem was reported in the zone; it causes the drying of the central part of the tree and a substantial decrease in productivity has being observed. The new disease is "secamiento del

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[22] In Colombia Cenipalma reseachers identified the ethiological agent as *Pythophhtora palmivora* (Martinez et al., 2011; Torres et al., 2010). However, the microorganism has not been isolated from diseased plantations in Ecuador and there is still skepticism in the scientific community as if whether or not the microorganism is the causal agent of the disease.

[23] Taxonomically *Phytophtora sp.* is not a fungus it is a oomycete (water mold). *Phytophtora* sp. belongs to the kingdom: *Chromalveolata*, class : *Oomycete*s, family : *Pythiaceae* (Crouse et al., 2004).

tercio medio" (drying of the third half). The causal agent and complete symptomatology of the disease are not known (Fedepalma, 2013a).

Table 3.1: AOP Diseases. This table summarizes the diseases found in the different AOP areas in Colombia. Source: Fedepalma 2013

Region	Plant Disease
Northern	Bud rot "Pudrición del cogollo" PC Surprising Wilt "Marchitez sorpresiva Red ring "Anillo rojo" Pudricion del Estipite *Rhynchophorus palmarum*
Central	Bud rot "Pudricion del cogollo" PC Surprising Wilt "Marchitez sorpresiva" Letal wilt "Marchitez letal" Red ring "Anillo rojo" Pudricion del Estipite *Rhynchophorus palmarum* *Strategus aloeus*
Eastern	Marchitez letal Bud rot "Pudricion del cogollo" PC Secamiento del tercio medio *
South-western	Bud rot "Pudricion del cogollo" PC *Sagalassa valida*

* A new desease reported in recent years

Another threat to the crop has been reported as well:" palmas tipo plumero" (feather-duster palm type). The illness is characterized by a morphological change of the new leaves of the palm that do not kill the palm but renders it unproductive. The causal agent of the disease is unknown, 14,000 cases in 40 different plantations have been reported (Fedepalma, 2013).

The areas affected with bud rot PC in Tumaco, Puerto Wilches and the Curvaradó river have been replanted using a interspecific hybrid OxG: *E.guineensis* × *E. Oleifera* (CENIPALMA, 2011). The hybrid in young plantations (7 years) has reported a lower incidence of bud rot. The hybrid seems to give at least partial resistance to bud rot in field conditions but the experiment is still under way (CENIPALMA, 2011; Navia et al., 2014).

3.1.8.6 AOP and Climate Change

The future of AOP crops in Latin America is further jeopardized by climate change. A general increase in temperature and decrease in soil moisture (IPCC, 2007) will stress the palm trees increasing the susceptibility to fungal diseases (Paterson, et al., 2013). Climate change will induce a change in the microbial communities (Singh, et al., 2010). On the other hand changes in temperature and water availability beyond the optimal conditions for AOP growth could make AOP production in the region infeasible (Paterson, et al., 2013).

3.2 Land Change Science

Concerns about the changes in land use/cover change date to the 1970s with the realization that land-surface processes influence climate. Changes in the land surface result in changes in albedo that in turn modify surface-atmosphere energy exchanges which eventually will alter climatic conditions at regional levels (Otterman, 1974). From that point on observations about the consequences of the changes introduced by humans emerge from different disciplines. For instance, the seminal paper by Vitousek[24] and colleagues increased awareness of the amount of natural resources consumed by humans and the environmental changes required to sustain that rate of consumption (Vitousek et al., 1986). Abundant evidence of the broad range of impacts on ecosystems services were identified. Changes in land cover are tightly linked to many environmental issues. Land use change has impacts on biogeochemical cycling (carbon, nitrogen); and atmosphere fluxes (energy, water) – Environmental quality (water, air) – Livelihoods and well-being (food supply, disease vectors) – Biodiversity loss and cropland loss (Geist et al., 2006; van Asselen and Verburg, 2013).

[24] 40% of the global NPP production is consumed directly, indirectly or foregone by humans.

Human's ability to modify their environment was assisted through three major advances in human civilization: fire dominance, agriculture, and the use of fossil fuels. Agriculture expansion has been a major driver of land-cover change since the domestication of plant species 10,000 years ago. (Ramankuty, et al., 2006; DeFries, 2008). At present, agricultural intensification/expansion and urbanization are behind deforestation and degradation processes of land use change (Ramankuty et al., 2006).

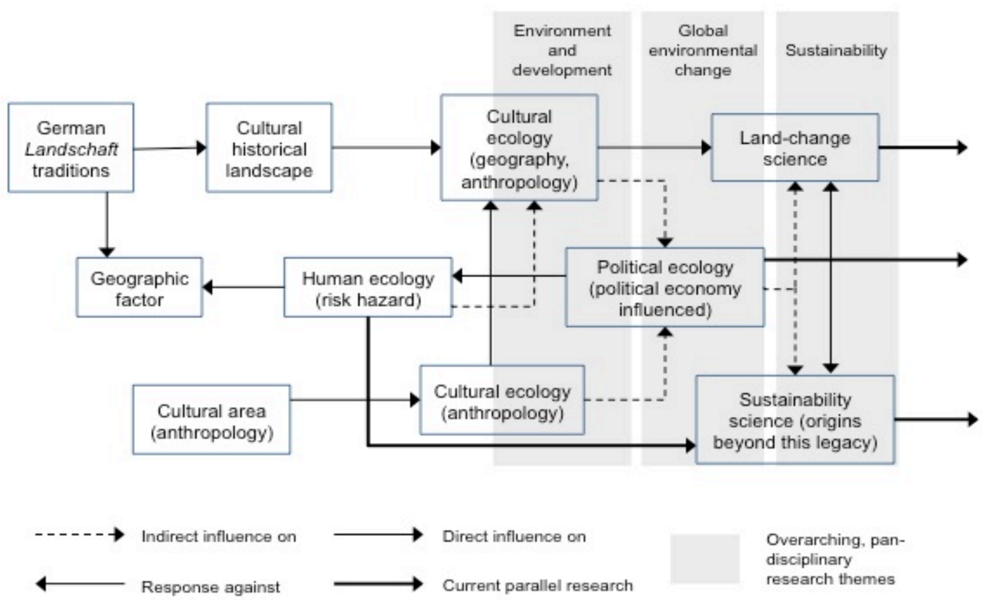
Research around the characterization and understanding of the changes has resulted in substantial improvements in our ability to measure land cover change, understand its drivers, and the construction of predictive models (Lambin et al., 2006). The research has been supported through different international programs designed to understand the Earth as a system and to answer the questions pertain to the land-use and land-cover changes and the impacts of these changes for human well being and for the planet (Moran et al., 2004).

The scientific community was first organized around the Land-Use and Land-cover change (LUCC) project of the International Geosphere Biosphere Programme (IGBP) and the International Human Dimensions Programme on Global Environmental Change (IHDP) commissioned by the International Council for Science (ICSU) and the International Social Science Council (ISSC) (Lambin et al., 2006; Verbug et al., 2013). In 2013, a new vision with a stronger focus in knowledge that supports sustainability transitions and the creation of management solutions involving stakeholders lead to the creation of 'Future Earth' program (Reid et al., 2010; Verbug et al., 2013).

3.2.1 Land Change/ System Science

Land change science (alternatively, land system science) has evolved to become a multidisciplinary field of study. The initial purpose was to understand, explain, and project land use and land-cover change (DeFries, 2012, Turner et al., 2013). With the emergence of sustainability science (Figure 3.1) its goal has expanded to provide the scientific foundations and applications for the sustainable management of ecosystems (DeFries, 2012).

Figure 3.1: Multidisciplinary lineages. One interpretation of the way the different disciplines are connected with land change science. Source: Turner and Robins, 2008.



An understanding of the coupled nature-human systems requires (Lambin and Geist, 2006; DeFries, 2008;DeFries et al., 2012):

1. Observation, characterization and measurement of the change: Mainly conducted through remote sensing data, processes and analysis.
2. An understanding of the underlying and proximal causes of the change: Undertaken by Political ecology and other disciplines.

3. Simulation and modeling aimed at either understanding the process that brought about the change or projection or both: Land Change Modeling.
4. Provision of the knowledge and suggested management practices that could lead to the sustainable use of natural resources: Sustainability science.

3.2.1.1 Distinction Between Land Cover and Land Use

Land cover refers to the vegetation and artificial constructions covering the land (Burley, 1961), and land use is the human activities on the land, which are directly related to the land (Clawson and Stewart, 1965). Both are clearly connected since changes in land use can change land cover, and changes in land cover can change land use. However, the connection is often complex since a given use (e.g., grazing) may be associated with several different types of land cover (e.g., grassland or forestland), and a specific land cover (e.g., forestland) may have several different land uses (e.g., timber production, grazing, or recreation) (Loveland and DeFries, 2004).

3.2.1.2 Observation, Characterization and Measurement of the Change

Systematic long-term observations of the environment are central to land change research. Several efforts have been made to provide international coordination of observational systems working within the framework of international organizations. One of those efforts is Global Observations of Forest Cover / Global Observations of Land Cover Dynamics GOFC/GOLD which was originally developed as a pilot project by the Committee on Earth Observation Satellites (CEOS) as part of their Integrated Global Observing Strategy. GOFC-GOLD is now a panel of the Global Terrestrial Observing System (GTOS) (Gutman, et al., 2004). GTOS is working to provide ongoing space-based and in-situ observations of forests and other vegetation cover, for the sustainable management of terrestrial resources and to obtain an accurate, reliable, quantitative understanding of the terrestrial carbon budget (Gutman, et al., 2004).

3.2.1.3 Underlying and Proximal Causes of Land Change

Finding the causal and contextual factors responsible for the change and assigning them causal power is not an easy task. Biophysical factors define the natural capacity or predisposition of the land for change. The variability of biophysical factors interacts with the human causes of land use change in complex way to generate the land patterns and processes that we observe (Geist et al., 2006).

Pathways to land use change have shown to be complex involving economic, demographic, technological, cultural, and political factors acting at multiple scales, and influenced by geopolitical interest, governance, social and ethnic struggles (Geist et al., 2006). The characterization and analysis of biophysical parameters using remote sensing is critical but are not sufficient to gain an understanding of the changes occurring in the socio-economic functions of land (Ellis and Ramankutty, 2008; Verbug et al., 2009).

Political ecology has been suggested as a necessary and complementary approach to Land use change (Brannstrom and Vadjunec, 2013). The focus of political ecology is on the relationships between; political, economic, and social factors in relations to environmental issues. As such it has been suggested that Land use change and political ecology together can demonstrate the global-to-local linkages of factors generating land use change, the general patterns of the drivers and how those change at different scales of analysis (Turner II and Robins, 2008; Brannstrom and Vadjunec, 2013).

3.2.2. Land Change Science and Remote Sensing

Remote sensing provides the tools to accomplish continuous observation, characterization and measurement of the changes taking place on the Earth surface. As such, it has become an integral part of land use change studies (Sohl and Sleeter, 2012). It offers several advantages: it is relatively inexpensive, up to date (depending on the sensor), provides access to remote areas, and for the most part has consistent measurements over time. In addition satellite products provide direct observational evidence of LCLUC impacts, measurements of biophysical parameters, and boundary conditions (DeFries, 2008; Sohl and Sleeter, 2012).

The most common application of remote sensing data, land cover and land cover change mapping, has evolved from simple unsupervised approaches to various complex supervised classifications (e.g., maximum likelihood classification, support vector machine, decision tree, wavelet transform classification, artificial neural networks classification, random forest, among others), and from pixel-based methods to subpixel (e.g., linear spectral unmixing, support vector regression, and decision tree regression) and object-oriented methods. The scales of studies range from local, regional, continental to global. LCLUC methods are continuously improving LCLUC detection methods, which are evolving along with newly developed classification methods (Lu et al., 2004).

A variety of biophysical applications are available now to understand the processes occurring in the terrestrial biosphere. Biophysical applications of remote sensing in the terrestrial biosphere include indirect measurements of photosynthetic activity: Vegetation indices, Green leaf area, FPAR (Fraction of Photosynthetically Active Radiation), above ground biomass, land surface phenology, gross primary production of terrestrial vegetation, and CO2 fluxes between the terrestrial biosphere and the atmosphere (De Fries, 2008; Sohl and Sleeter, 2012).

The number of civilian satellites with Earth observation capabilities has grown ever since the launch of the Landsat mission in 1972. In the last 40 years, 33 nations and groups have provided the resources to launch 197 individual satellites. By the end of 2013, 98 were still operating (Belward and Skoein, 2015). The Landsat program was the first civil satellite intended to map land resources at finer scale resolutions that the AVHRR. Seven Landsat systems with additional spectral bands and improved spatial resolution have been launched. Landsat with 30 m resolution has been used extensively in the studies of land cover change around the world. Similar sensors for land observation have been launched: SPOT (Satellite pour l"Observation de la Terre) with 20 m resolution, the Indian Remote Sensing (IRS) in 1998 with 23 m resolution, among others (De Fries, 2008).

The pioneering work in the use of remote sensing to map deforestation was done in the Amazon (Tardin et al., 1980). A decade later, new surveys of Amazon deforestation were performed (Tardin and Cunha1989; Skole and Tucker, 1993). In spite of the many local and regional applications for satellite imagery the characterization of land cover at global scales was faced with several challenges. It was resource intensive and it lacked the temporal frequency needed to account for changes in phenology and to overcome the almost constant cloud cover over large areas of the tropics. All these factors prevented until recently the production of global interpretations of land cover.

The NASA EOS system with MODIS (the Moderate Resolution Imaging Spectroradiometer) provided a sensor better suited for regional and global monitoring of the Earth surface. The medium spatial resolution and the increase in temporal frequency allows for the daily monitoring of vegetation over broad scales. The growing concern about human induced environmental changes and the impacts that land cover changes produce in the climate system were the rational behind NASA EOS system. The purpose of the mission is to study and understand all components of the Earth as a dynamic system. The MODIS sensor onboard of the Terra (1999) and Aqua (2003) satellites collects four observations per day at most earth locations (Justice et al., 2011).

Global and continental categoric and continuous maps of vegetation have been produced, starting with the pioneer works in the 1980s using multitemporal data acquired by the AVHRR. Categorical Global land covers at 1 degree (De Fries and Townshend, 1994), 8 Km (DeFries et al.; 1998) and 1 km (Hansen et al., 2000; Loveland et al., 2000) are now available. Vegetation continous fields have been derived from AVHHR data (DeFries et al., 2000) and MODIS data (Hansen, et al., 2003). This product has become a modeling input for GLCMs, fire emissions models, and maps of plant functional types (DeFries, R, 2008).

In addition, MODIS products have allowed the establishment of monitoring systems. For instance, the fire product through the MODIS Rapid Response System provides quick access to data, and the Fire Information for Resource Management System (FIRMS) provides Web-GIS capabilities for MODIS fire data in nearly real time. This application delivers MODIS active fire data to natural resource managers using Internet mapping services and customized e-mail alerts to users in more than 90 countries (Davies et al., 2009). Another example is GEOGLAM a global initiative in agricultural monitoring through the use of earth observations. The objective is to develop a reliable, accurate, timely, and sustained crop monitoring and yield forecast (Whitcraft et al., 2015).

The LCLUC community is moving towards the production of high spatial resolution data products (e.g. global Landsat wall-to-wall MODIS-like products), the improvement of global products (e.g. EU Copernicus Global Land Service), and the integration of socio-economic, political, cultural dimensions of land use change.

3.2.2.1 RADAR

The use of active sensors has not been as widespread as the use of optical ones such as MODIS, Landsat or SPOT, and the potential of RADAR data has not been fully explored. RADAR (RAdio Detection And Ranging) is an active sensor that provides its own electromagnetic radiation to illuminate the scene under observation. It sends pulses of energy from the sensor to the scene and then records the radiation that is reflected or backscattered from the scene.

Different RADAR systems have been developed: Real Aperture RADAR, Synthetic Aperture RADAR, Interferometric Synthetic Aperture RADAR (InSAR), scatterometer and bistatic SAR. Most RADAR systems for earth observations are Synthetic aperture RADAR or InSAR such as ERS-1 (1991), JERS-1 (1992), RADARSAT-1,ERS 2 (1995) and ASAR (2002) which all used C-band sensors. More recent missions such as ALOS PALSAR, TerraSAR-X, and COSMO SKYMED are expanding the available data into the L- and X-Bands.

ERS - SAR: ERS the European remote sensing satellites ERS-1 and ERS-2 are part of a multimode RADAR operating at a frequency of 5.3 GHz (C band), using vertically polarized antennas both for transmission and reception. Both ERS1 and ERS2 are currently not operational.

RADARSAT: is the Canadian Earth Observation Satellite program. It operates a series of RADAR sensors in the C-band: RADARSAT-1 (no longer operational) HH polarization, RADARSAT −2 HH, VV, HV, VH, multipolarization and in the near future a 3-satellite RADARSAT constellation mission that will provide daily coverage over Canada. The new sensors will have the HH, VV, HV, VH (same as RADARSAT-2) plus compact polarimetry and will be launched in 2018.

PALSAR is a phase array type L-band Synthetic Aperture RADAR microwave sensor. It was launched in 2006 onboard of the ALOS (Advanced Land Observing Satellite "DAICHI") satellite. It was intended to provide data for estimating biomass, forest monitoring, agriculture monitoring, oil spills, and soil moisture among other applications. It was declared inoperative in 2011.

New efforts to continue RADAR data acquisition are in progress with the NISAR (NASA-ISRO SAR) mission and the Canadian RADARSAT constellation mission. NISAR is a dedicated joint venture between the U.S. and India in partnership with ISRO. The objective is to provide RADAR data for the study of hazards and global environmental change. PALSAR 2 was launched by the Japanese agency JAXA in March 2014.

3.2.3 AOP Remote Sensing

Palm oil research groups have long promoted remote sensing applications. Several potential application areas have been identified: establishment and management of plantations, crop monitoring, yield prediction, and carbon sequestration (Corley and Tinker, 2003; da Costa, 2004). A common requirement for the successful development of these applications is the establishment of a digital set of methods that first attempts to clearly distinguish African palm from the surrounding land-cover classes, and second, accounts for stand ages (Corley and Tinker, 2003). Previous studies have used either differences in biomass or ancillary stand age structure to attempt such a distinction (McMorrow, 2001; Thenkabail et al., 2004). Ikonos data have been used to map African palm plantations at local scales with accuracies ranging from

84 to 92 percent. However, the distinction of palm ages was unsuccessful, suggesting that the four spectral bands available with Ikonos are insufficient (Thenkabail et al., 2004).

The most relevant previous attempt to map oil palm with RADAR data used JERS-1 and ERS-1 data over a plantation in Malaysia (Rosenqvist, 1996). Malaysian plantations are organized following a symmetrical triangular pattern on predominantly flat ground and in terraces on relief. Palms are allowed to grow for a period of 20 to 25 years before clearing or transplanting. The result of this cycle was an easily discernable mosaic of clear cuts and fields, but significant challenges emerged in determining stand age, vitality, and production status (Rosenqvist, 1996).

In another attempt, McMorrow (2001) explored the feasibility of using a single TM band or vegetation indices to obtain information at pixel and stand levels in a commercial African palm plantation in Malaysia. The author found that the relationships between palm age and spectral response were negative, significant, and asymptotic, suggesting that regression models could be used to predict dichotomous age categories (McMorrow, 2001). One significant problem remains the paucity of cloud-free optical imagery over the requisite tropical environments (Naert et al., 1990; Nguyen et al., 1995). However, even when cloud-free imagery is available, the complicated spectral mixed pixel relationships of palm plantations have frustrated many other research efforts (Corley and Tinker, 2003).

The threat of AOP expanding all around the tropics and the pervasive environmental impacts of its establishment in South East Asia have mobilized the scientific community in the pursuit of methods to characterize and measure the extent of this land cover transformation and its environmental impacts. After 2007, efforts to map AOP plantations with optical and/or RADAR sensors have been more and more successful. Although SAR has being mostly considered as a complementary data set (Pohl and van Genderen, 1998; Qi et al., 2003), the particular relationships between the backscatter and the singularity of the African palm tree geometry and the planting pattern of the crop allow it to stand alone in a classification scheme. The distinct relationships between the C and L wavelengths to AOP in the backscatter will be further explored and explained in section 5.2.1.

3.2.3.1 Land Use Change: AOP Plantations in Southeast Asia

The need for a monitoring system for AOP development is more imperative. A total of 8.3 million ha of close canopy AOP plantations occur in Peninsular Malaysia (Koh et al., 2011). AOP is expanding not only in South East Asia[25] but also to forest rich nations such as Papua New Guinea, Colombia, and Liberia (Koh and Wilcove, 2009; Wilcove and koh, 2010). More recently oil palm concessions in Africa have been shown to overlap with the home range of great apes in Cameroon, Gabon, Republic of Congo, and Equatorial Guinea (Wich et al., 2014).

Although, South East Asia forests are smaller in size compared to South America or African forests, the high rates of deforestation since the 1990s have made them the focus of attention (Miettinen et al., 2011). These forests of high diversity and endemism have experience rates of deforestation up to 5% yearly during more than a decade. The deforestation is closely tied to industrial AOP and timber plantations where as a small percentage is attributed to small holders (Miettinen, et al., 2012). Land use change and remote sensing methodologies have been used to measure the extent of the transformation and the environmental effects that have resulted. However, definite numbers are hard to come about as a wide variety of methodologies, sensors, and categorical classifications have been used. Table 3.2 summarizes

[25] The AOP plantations in Malaysia are projected to reach 13 million ha by 2020 (National statistical Bureau, 2011).

some of the land change research. Remote sensing analysis of land use change across Peninsular Malaysia, Borneo and Sumatra suggest that from 1990 to 2010, approximately 50-85 % of industrial AOP plantations were established on intact or logged forested lands (Carlson et al., 2012; Carlson et al., 2013; Miettinen, et al., 2012). From 1990 to 2010, oil palm converted primarily intact (47%) and logged forests (22%) as well as agroforests (21%). Only 10% of plantations were established on non-forested lands. Under BAU (business as usual) vision all unplanted areas within allocated oil palm leases are to be developed by 2020. On the basis of these awarded leases, oil palm is projected to clear a further 93,844 km^2, comprising 90% forested lands (41% intact, 21% logged, 27% agroforest) and 10% non-forests. Over 18% of projected conversion occurs on peatlands.

In Sumatra in the Period between 2000 and 2010 AOP establishment accounted for the loss of 4,774 Ha of Mangrove, 383,518 ha of peat swamp forest, 289,406 Ha of lowland forest, and 1,000 ha of lower montane forest. Private industries were responsible for 88% of the transformation, 10.7 occurred through smallholders and the remaining was due to state-owned plantations (Lee et al., 2014).

Table 3.2: AOP in Southeast Asia. This table presents a summary of remote sensing studies for African oil palm in Southeast Asia.

Author	Location	Sensor	Deforestation/years
Curran et al., 2004	Kalimantan	Landsat ETM +	56 % decline 1985 − 2001
Koh et al., 2011	Peninsular Malaysia Borneo Sumatra	MODIS ALOS-PAlSAR	2 M Ha* 2.5 M Ha 3.9 M Ha -2010
Carlson, et al., 2012	Kalimantan	Landsat	80 % of the area under AOP was forested area 1990 − 2010
Miettinen, et al., 2011	Insular South East Asia	MODIS	Average 1 % / yr 2000− 2010
Miettinen, et al., 2012	Sumatra Kalimantan	MODIS Landsat ATRS	Peatlands 3.4 %/ yr 1990 − 2010
Margono et al, 2014	Indonesia	Landsat	6.02 Mha 2000 − 2012
Gaveau, et al., 2014	Borneo	Landsat ALOS-PALSAR	30. 2 % decline 1973 − 2010

* The analysis included only mature palm plantations with close canopy

3.2.3.2 AOP Elsewhere

The characterization of AOP plantations in the Neotropics has not drawn as much attention and has been local in scope. For instance, in Latin America a multi sensor (ETM+ and RADARSAT) approach was used to improve the detection and discrimination of AOP plantations of different ages in the Ecuadorian Amazon (Santos and Messina, 2008). Gutierrez and DeFries, used a multi sensor approach at coarse (MODIS and TM/ETM+) and fine-scale resolutions (PALSAR + ETM) to study AOP plantation in the Peruvian Amazon (Gutierrez et al., 2013). Both studies suggest that optical sensors alone do not suffice for the characterization of AOP plantations in the tropics.

In Colombia land cover characterizations that describe the use of the land previous to AOP establishment are not available. According to surveys carried out by Fedepalma the consensus is that most of the AOP development has taken place in already deforested land (Castiblanco et al., 2013). A preliminary study with Landsat images in Meta department showed that new AOP plantations replaced riparian forests and natural savannas from 1998 − 2005 (Pinzon, 2009). However, an account of the extent of riparian forest that was loss to AOP plantations is not reported. Anecdotal evidence from the Tumaco region (south in the Pacific) recalls the transition of lowland forest into AOP plantations (Escobar, 2009).

3.3 Land Change Models LCMs

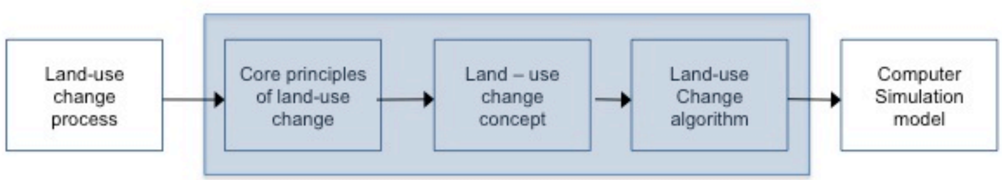
Models are abstraction of real systems. They are not a replacement for field observations but they can be used to unravel the processes that give rise to the observed phenomena (Wainwright and Mulligan, 2013). Land change models (LCMs) are useful experimentation tools that support the analysis of causes and consequences of land change, and the exploration of scenarios of future change (Verbug et al., 2004). This later capability makes them valuable in land management by providing the knowledge to make more informed decisions.

The developments in land change science and the increase in computational power during the last two decades have resulted in a wide variety of LCMs (NCR, 2013). Inventories of LCMs show an overwhelming amount of models and applications. The focus of the reviews vary from in depth discussions of common models and their theoretical background (Briassoulis, 2000), succinct overviews of models and future directions (Waddell and Ulfarsson, 2003; Verburg et al. 2004a), to detail technical descriptions of frequently used models (Agarwal et al, 2002, U.S.EPA, 2000). More recent overviews have focused in large-scale land use modeling (Heistermann et al., 2006) or in the theoretical ideas, concepts and methodologies that give the foundation for LCM's (Koomen et al, 2007).

In spite of their variety they are based on a limited number of theories, methods and assumptions. **Economic theories** are often used to explain land-use patterns and their dynamics (e.g. Bockstael and Irwin, 2000; Irwin and Geoghegan, 2001). **Spatial interaction modeling theory** is used in classical land use models where the concepts of scale and distance are introduced in the description of spatial relations (Haynes and Fotheringham, 1984). **Cellular automata (CA)** methods from complexity theory and mathematics are very well suited for imitating spatial processes on the basis of simple decision rules (Wolfram, 1984, Verbug et al., 2004). **Statistical analysis** an integral part of LCMs either in their own right as econometric analysis or as a tool to calibrate the model (e.g. regression analysis is often used to quantify the relative contribution of the individual drivers of land-use change) (Rietveld and Wagtendonk, 2004; Verburg et al. 2004c) **Optimization** applies mathematical optimisation techniques such as linear integer programming or neural networks. The optimal land use configuration is calculated using a set of prior conditions, criteria and decision variables (e.g. Aerts, 2002; Pijanowski *et al.*, 2002). **Rule-based simulation**s use a set of rules that indirectly specify a mathematical model, it is often use in combination with a GIS (Lavorel et al., 2000). **Multi- agent (MA) models** have human agents (individual or collective) and interactions as a central element. Agents are autonomous entities that impact their environment through communication, interaction, and decision-making (Parker et al. 2003). **Microsimulations** carried out at the level (scale) where decisions are made. It attempts to include all the individual actors who influence changes in land use. The drawbacks are the amount of data and computational demands required plus the issue of scaling up to macro-scale socio-economic processes (Waddell, 2002; Alberti and Wadell, 2000).

Apart from the theories behind LCMs a number of other characteristics create distinctions among models. Models could be spatial explicit or not, descriptive or prescriptive, deductive or inductive, dynamic or static, agent base or pixel based representations, global, regional or local in scope (Verbug et al., 2006). Thus the model selection should be base in the ability of the model to answer a particular question. A review of all LCMs is not intended here. The rest of the chapter will be restricted to cellular automata in general and to DINAMICA- EGO in particular.

Figure 3.2: Land use change concepts. Relationship between the land-use change process and the computer simulation model.



Source: van Schrojenstein et al., 2011

3.3.1 Cellular Automata

In a recent review of the core principles and concepts in land use modeling van Schrojenstein, et al.(2011) provide an overview of the relationship between the land-use change process, principles, concepts and simulations (Figure 3.2). Their view was shared in the report: Advancing Land Change Modeling: Opportunities and Research Requirements (NRC, 2013).

Land use change is defined as ‘the result of socio-economic and biophysical location, scale, and existing land use” (Turner et al., 1995; Briassoulis, 2000; Lambin et al., 2001; Verbug et al., 2004). All simulation models in Land use are based on at least one of four principles:

continuation of historical development, suitability of land (in monetary or other units), result of neighborhood interactions or result of actor interaction (van Schrojenstein, et al., 2011; NRC, 2013). Common concepts used to build the models are: logit functions, markov chains, cellular automata (CA), and agent base modeling.

CA appears to be a well-known land change concept (Langdon, 1998; White and Engelen, 1994). A data base search conducted in 2008 showed that CA appeared in over 40% of the papers published in land use modeling either by itself or in hybrid approaches (van Schrojenstein, et al., 2011).

CA is a mode of computing, a conceptual tool, useful for understanding and taming a complex system (Hoekstra et al., 2010). Complexity theory states that a complex system is one that contains more possibilities than can be deduced. The objective is to find simple, fundamental rules and processes that combined would produce complex holistic systems (Manson, 2001; Wolfram 1984, 2002). Coupled human-natural systems are complex systems; they manifest characteristics such as heterogeneity, non-linearity, feedback and emergence. Complexity theory and the use of CA to understand complex systems appeared almost simultaneously in many disciplines. CA has been used in computer science, biology, economics, physics, chemistry, and geography among others (Manson, 2001; wolfram, 2002; Walsh et al., 2011).

The notion of CA is built upon the advances by Ulam and Von Neumann (Von Neumann 1966). The CA characteristics and fundamentals are well illustrated by the famous game of life invented by Conway (Gardner 1970). In Conway's game of life a two dimensional automaton, starts with random conditions where each cell in a grid may be dead or alive. The future status of the cell depends on very simple transitions rules. The signature feature of the game of life and of CA is the realization that "Simple rules can give rise to complex behavior" and to multiple levels of organization (Hoekstra et al., 2010).

A CA comprises four elements: cell space, cell states, time steps and transition rules (White & Engelen, 2000). The structural properties (cell space) define the topology of the cellular grid. The grid consists of a regular n-dimensional array of cells (usually 2-dimensional) that interact within certain vicinity. The functional properties are a list of the discrete states that a cell may realize and the transition rules.

The basic principle of a LULCC CA is that land- use change can be explained by the current state of a cell and changes in those of its neighbors. It is, thus, based on the core principles of continuation of historical development and result of neighborhood interaction but usually incorporates land suitability as well. Two main types of CA can be distinguished: unconstrained and constrained. Unconstrained is the 'classic' CA, as it only uses decision rules to calculate land-use change. In constrained CA, the amount of land-use change per land use class is limited; the limit of a certain land-use class is either expert-based or calculated from historical land use (van Schrojenstein, et al., 2011).

Continuation of historical trends and patterns: this principle assumes that future trends of change follow patterns of change corresponding to recent or historical changes. It is applied through the calculation of transition matrices from observed recent or historical changes or through empirical estimations of the relationship between land change and allocation characteristics. A common approach is the use of Markov chains to construct models based in past changes (van Schrojenstein, et al., 2011; NRC, 2013).

Land suitability: the assessment of the suitability of land units for other land uses other that the one they exhibit at time 0 is used as a determinant for the conversion rules. The foundation for its use was outlined by the theoretical work of von Thünen (1966) and Alonso (1964). It follows the premise that land users aim to maximize profits, therefore, land use patterns are based on the spatial variations in land rent for different land uses (van Schrojenstein, et al., 2011; NRC, 2013).

Results of neighborhood interactions: This principle states that land use change is dependent on the land use of its surrounding cells (van Schrojenstein, et al., 2011). Neighborhood interactions allow for the mergence of complex spatial patterns from relatively simple rules. Transition rules specify what land changes are likely to happen based on the nearby land cover types. The rules can be expert based or derived from statistical analysis (Verbug et al., 2004b).

The relative simplicity of the CA structure along with the wide range of applications have resulted in the development of many CA models in the past two decades, SLEUTH (Clarke and Gaydos, 1998), GEOMOD (Pontius et al., 2001), CLUE-s (Verbug, et al., 2002) and DINAMICA (Silveira et al., 2002) are among the earlier models. Many models have been improved and reengineered, as new advances and understanding of the land change process are available.

3.3.1.1 DINAMICA-EGO

DINAMICA-EGO acronym for Environment for Geoprocessing Object is the most recent release of DINAMICA developed by a research team of the Remote Sensing Center of the Federal University of Minas Gerais, Brazil (www..csr.ufmg.br/dinamica). DINAMICA is a cellular automata type model originally designed to simulate the landscape dynamics in the Amazon colonization frontier, particularly in areas occupied by small farmers (Soares-Filho et al, 2002). Over the years it has been reengineered to become a platform to study landscape trajectories and spatial dynamics at local to meso-scale applications. The flexibility of this generic model allows for its application in urban expansion (Almeida et al., 2003; Thapa and Murayama, 2011), tropical deforestation at local to basin scales (Soares-Filho et al., 2002, 2006, 2013; Cuevas and Mas, 2008; Mas and Flamenco, 2011), fire regimes (Silvestrini et al., 2011); and carbon reduction assessments (Nepstad et al., 2009; Nunes et al., 20013). More recently, DINAMICA EGO was used as the platform to develop the SimCongo model, a model to simulated changes in land cover for the Congo basin based on Bayesian statistic methods (Galford, et al. 2015).

The structure of the model follows the conventional cellular automata model (White et al., 2000). The model consists of a euclidean space (two dimensional) divided in identical units in an array (a raster model), a cell neighborhood of defined size and shape, a list or set of discrete cell states, a set of transition rules, and discrete time steps at which all cell states will be updated simultaneously according to the transition rules (Soares-Filho et al, 2002).

Functionally the model incorporates multi-scale vicinity-based transition functions, stochastic multi-step simulation, a diffusion module, spatial feedback approach through the calculation of dynamic variables, and the application of either weights of evidence (Almeida et al., 2002) or logistic regression (Soares-Filho, et. al. 2001; Soares-Filho, et al. 2002a) to calculate the transition probability maps using information stored in a GIS.

3.3.2 AOP LCMs in Colombia

In Colombia policies to boost the demand for biofuels include statutory mandates for mixtures and economic incentives (DNP, 2008). In 2010, AOP plantations cover 404,104 ha, 160,000 ha of which were used for biodiesel production (Fedepalma, 2011). The target mixture for 2020 was set to B20 (20% ethanol) achieving it will require an increase of 600,000 ha in the area under cultivation. However, government plans allocate 3 million ha for AOP cultivation (Bochno, 2009). This scenario has prompted research around land change projections and impacts of AOP expansion in Colombia.

Castiblanco et al., (2013) used an econometric model time series to forecast the area of oil palm plantations in 2020. The study was done through four independent types of analysis: 1) a map overlay to identify the previous land cover of areas under AOP cultivation in the period 2002 −2008 2) a Time Series Intervention Model Analysis to project the cultivated area for the year 2020 3) a logistic regression model of explanatory biophysical and socio-economic variables, to produce a probability map of AOP presence and 4) a map overlay to identify the land cover in 2008 of the areas projected to be cover by AOP in 2020. The study reported that only 16.1% of the AOP plantations established in the period 2002-2008 were found in areas of natural vegetation (forest and savannas) and regrowth. However, 250,000 ha of AOP were established before that date. The maximum AOP expansion projected for 2020 was 930,000 Ha far from the 3 million-government expectations; the study suggests that only 12.7% of the projected AOP plantations will replace natural vegetation. On the other hand food production of crops such as rice, bananas and livestock may be at risk.

Garcia-Ulloa et al., 2012 used a spatially explicit GIS model to identify an optimal "low impact" scenario for AOP development. The trade-offs and impacts of the projected expansion with regard to food security, natural ecosystems, biodiversity, and carbon stocks under different development scenarios were analyzed as well. They identified sugar cane, maize and sugar cane production at risk of replacement.

Both studies agree that the impact of AOP in Colombia in terms of biodiversity and carbon stocks will be highly reduce if it is located in pastures and savannas. Both studies used the oil plantation thematic map produced by Fedepalma (scale 1:1,500.000) and published in 2009, the map excludes the AOP plantation established in Chocó.

These studies do not mention the issues about land property rights or the effects of the Colombian armed conflict in the African oil palm industry. Even though, Climate change, trade liberalization and the violent conflict have been identified as the main stressors for Colombian agriculture (Feola et al., 2015). Further evidence of the need to include the armed conflict in any analysis of AOP comes from an study of the industry in the east of the country that establishes the links between the Colombian armed conflict and the palm oil exports from the Meta[26] region (the area under pastures and savannas). The study unveils the close relationship between paramilitaries and AOP development (Maher, 2015). In the next chapter the data and methods used to study the land use change in Chocó will be explained.

[26] Meta, the fastest growing aOP region, has experience endemic forced displacement with 128,591 people forcibly displaced in the 1998-2010 period (Acción social 2011)

CHAPTER 4

This chapter presents the methods used to derive the land cover maps for the study area and the land change model approach using Dinamica-Ego platform. The textures methodologies have been published before in Santos and Messina, 2008. A detailed description and a map of the study area are included in chapter 2 and chapter 1, Figure 1.1.

4.1 DATA

4.1.1 RADAR

RADAR images from different sources were used to map the land cover in the study area (table 4.1). ERS 1- SAR.PRI (SAR precision image) image from 1995 is a multi look, ground range, digital image generated from raw SAR image mode data using auxiliary parameters and corrected for antenna elevation gain and range spreading loss. Three RADARSAT-1 images standard beam mode SGX (SAR Georeferenced Extra) (ground range, un- signed 16-bit integer number), and ALOS PALSAR FBD (Fine Beam Double Polarization) Level 1.5 products with HH and HV polarization (ground range, unsigned 16-bit integer number).

Table 4.1: RADAR Data. RADAR data used in this study and their characteristics.

Sensor	Pixel Size m	Date	Band	Polarization
ERS-1	12.5m	Oct 1995	C	VV
RADARSAT-1	12.5	Apr 1997	C	HH
RADARSAT-1	12.5	May 2000	C	HH
RADARSAT-1	12.5	Jul 2005	C	HH
PALSAR	12.5	Aug 2007	L	Dual HH-HV
PALSAR	12.5	May 2008	L	Dual HH-HV
PALSAR	12.5	Sep 2009	L	Dual HH-HV
PALSAR	12.5	Sep 2010	L	Dual HH-HV

4.1.2 Secondary Spatial Data

In the absence of field data and the impossibility to collect ground truth for safety reasons an effort to gather ancillary data, expert opinions, and published/unpublished studies was made. During 2007 and again in 2013-2014 informal meetings were conducted with researchers and workers at national and international institutions based in Bogota, Colombia. The institutions visited included: the Alexander Von Humbolt Institute, Colombian geographic institute (Instituto Geográfico Agustin Codazzi (IGAC)), UNODC- SIMCI, UNODC – alternative development office, WWF Colombian office, National University, Javeriana University, Fedepalma, instituto de Hidrología, Meteorología y Estudios Ambientales de Colombia IDEAM, DANE, ombudsman office, and Fundación NATURA. All the groups have worked in the Chocó bioregion during the past two decades. As a result of those meetings I was granted access to a wide variety of information, much of it unpublished. It is particularly important to mention that many of the thematic maps used in the DINAMICA EGO model are modifications of maps obtained directly from these proprietary studies in Colombia. Table 4.2 has a list of the thematic maps and original sources.

The base and thematic maps were imported and reprojected to the UTM WGS 84 Zone 18 N projection. Nearest neighborhood was the resampling method used. The maps where combined, resampled to either extract or modify the information for the study area. A new thematic map was created for the boundary conflict between Chocó and Antioquia. Not all the maps in the table were used in the model. For instance the area does not have national parks, reserves or other type of protected areas and the land cover and land use were derived from the RADAR images.

Table 4.2: Secondary Spatial Data.

Thematic map	Spatial resolution	Source
Elevation	ASTER 30 m resolution	EOSDIS *
	Area: Belén de Bajirá Elevation Contours	CODE -IGAC
Geology	Area: Belén de Bajirá	INGEOMINAS 1994 SIG IIAP 2005
Geomorphology	Area: Belén de Bajirá	IGAC SIG IIAP 2005
Watersheds	Area : Cell size 250 m	WWF 2004
	Area: Belén de Bajirá	IGAC SIG IIAP 2005
Climatic zones	Area: Belén de Bajirá	IGAC SIG IIAP 2005
Soil Units	Area: Belén de Bajirá	IGAC IIAP and the municipality
Vegetation	Original Vegetation Cell size 250 m	WWF Unpublished data
	Current Vegetation Cell size 250 m	WWF Unpublished data

Table 4.2 (cont'd)

Ecology	Ecoregions Cell size 500 m	WWF Unpublished data
	National parks Cell size 250 m	WWF Unpublished data
	Other reserves Cell size 250 m	WWF Unpublished data
Population	Ethnic distribution and influences Area: Cell size: 500 m	WWF Unpublished data
	Population density Area: Cell size 500 m	WWF 2003 DANE population census
Land use	Area: Belén de Bajirá Current land Use	IGAC SIG IIAP 2005
	Area: Belén de Bajirá Potential Land Use	Municipality development plans SIG IIAP 2005
	Area: Productive Systems Cell Size: 250 m	WWF Unpublished data
Political boundaries	Area: Belén de Bajirá Administrative boundaries	IGAC SIG IIAP 2005
Land tenure	Area: Belén de Bajirá Legal Status of the land	IGAC SIG IIAP 2005
Transportation	Rivers and roads	WWF Unpublished data

4.2 Methods

4.2.1 Preprocessing

Land cover change studies imply the use of at least two data sets from the same location at different points in time. Many of the applications to identify the change and model the process require pixel scale comparisons. Therefore adequate geometric fidelity is paramount. To accomplish that goal image to image registration was performed between the RADARSAT

2000 selected as the master image and the other SAR sources. The co-registration was performed using ENVI 5.2. Although automatic techniques are available in the software to locate control points, they were not used due to large RMS[27] errors (> 200). Control points were then selected manually mainly along the rivers in areas of no evident cha The RMS error ranged from 0.54 to 0.94 and the numbers of points ranged from 10 to 16. A first order polynomial was then applied. All the images were reprojected to the UTM WGS 84 Zone 18 N projection,

Speckle[28] is a common problem in RADAR images. Conventional RADAR based classifications requires the removal of speckle, the reduction methods improve the signal to noise ratio improving the visual interpretation of the image. However, the use of second-degree co-ocurrence matrix statistics requires the use of the raw images without speckle correction. It has been shown that speckle removal reduces substantially the amount of information that could be derived using the co-ocurrence texture measures (Herold and Haack, 2002; Treitz et al., 2000). Eight co-ocurrence textures were calculated for the RADARSAT images and for the each of the Palsar polarizations.

4.2.2 RADAR Textures

Textural information may be as important as spectral information for RADAR images (Anys and He, 1995; Haralick, 1979; Haralick et al., 1973); for RADAR images the information resides not only in the intensity of individual pixels but also in the spatial arrangement of those pixels (Herold et al., 2005). Texture refers to the variation presented in discrete tonal features across an image and provides information about the structural characteristics of surfaces and their relationship with their surroundings (Jensen, 2005).

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[27] RMS is reported in units of pixels.

[28] Speckle is a granular "salt and peeper noise" that impacts the quality of the RADAR image. It is the result of the random interference caused by multiple returns within a resolution cell.

Image texture analysis and characterization is important for image interpretation. Many methods have been proposed to incorporate texture in image processing using either statistical or structural approaches (Haralick, 1979; Atkinson and Lewis, 2000; Balaguer et al., 2010; Trevisani and Roca, 2015). Statistical methods use texture features based on first, second, and third order statistics in the spatial domain (Jensen, 2005). The second-order statistics method was proposed by Haralick et. al., (1973) based on brightness value spatial-dependency grey-level co-occurrence matrices (GLCM) (see e.g., Nyoungui et al., 2002). The GLCM measurements have been widely accepted by the remote sensing community and have been used in both optical and SAR remote sensing for classification procedures (Franklin et al., 2001; Jensen, 2005).

GLCM texture measurements of RADAR images have used successfully for wetland mapping (Arzandeh and Wang, 2002), forest classification (Oliver and Quegan, 1998), crop monitoring and classification (Anys and He, 1995; Pultz and Brown, 1987), ice texture estimations (Barber and Ledrew, 1991) and land cover classification (Arzandeh and Wang, 2002; Nyoungui et al., 2002; Peng et al., 2005, Santos and Messina, 2008, Guiying Li et al., 2012). Arzandeh & Wang (2002) examined GLCM texture measurement using different sized matrices, and concluded that the use of texture measurements greatly improved the classification of wetlands. Furthermore, they suggested that GLCM texture measurement was an appropriate method for land cover classification of single date RADARSAT information. Anys et al., (1995) used multipolarization data and texture measures from airborne RADAR data and reported an increase of 9.79% in the correct classification of crops. Pultz and Brown (1987) used five of the GLCM measurements (contrast, correlation, dissimilarity, mean, and standard deviation) proposed by Haralick, (1973; 1979), and found that the classification of agricultural targets improved significantly over the use of traditional classification on multispectral data.

However, the process is difficult and not always successful. Prasad and Gupta (1998) in the Godavari region of India used texture measures preceded by speckle-filtering which resulted in a 10% decrease of the overall accuracy. The texture measures they used were contrast, entropy, angular second moment, and homogeneity. Frequently, overall accuracy is improved by using GLCM texture measures over the RADAR raw data but not all measures achieve positive results. It is important to include measures that account for the majority of the variance in the data. The fusion of optical and RADAR data in LULC change research has improved the discrimination of classes not distinguishable with spectral optical information alone (Toll, 1985). Data fusion has been used successfully for precision agriculture (Qi et al., 2003), LULC mapping (Haack and Bechdol, 2000; Haack et al., 2000; Raghavswamy et al., 1996), and urban delineation (Haack et al., 2000). Conversely, Henderson (2002) reported that the synthesis and concatenation of raw SAR and optical imagery did not clearly improve the land cover class separability. No conclusive agreement has been reached as to the optimal combinations of optical and RADAR data for LULC applications (Herold et al., 2005).

The textural procedure used here to extract information from the RADAR images was the co-occurrence measure filter as proposed by Haralick (1973) (Table 1); the textures were extracted directly from the RADAR images, without speckle correction. The grey-level co-occurrence matrix (GLCM) measurements are based on the pixel spatial arrangement in the RADAR image and provide the co-occurrence probability of pairs of grey-level pixels within a local window (Santos and Messina, 2008). There are four parameters to be considered when generating GLCM products (1) window size, (2) inter-pixel angle, (3) inter-pixel distance, and

(4) quantization level. The window size defines the extent over which the GLCM is computed, inter-pixel angle and inter-pixel distance define the neighborhood relationships for the pairs of the pixels, and quantization level refers to the number of grey levels in an image, i.e. radiometric resolution (Haralick et al., 1973; Herold et al., 2005).

Table 4.3: Texture Measurements. The terms in the formulae below are: N= is the number of grey levels; P = is the normalized symmetric GLCM of dimension N6N; and Pi,j = the (i, j)th element of P (Haralick et al., 1973; Oliver and Quegan, 1998).

Parameter/Significance	Formula
Mean: a measure of both tone and texture information: calculates the average grey level over a defined window size. *	$MEAN = \mu_I = \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} i \cdot P_{i,j}$
Contrast : the measure of the contrast or the amount of local variation present in the image. High values indicate contrasting grey tones in the image.*	$CON = \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} P_{i,j} \cdot (i-j)^2$
Angular Second Moment: a measure of textural uniformity. This value is large when there is less local texture variation; the case when the grey-level distribution is constant or is periodic.	$ASM = \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} P_{i,j}^2$
Correlation: a measure of grey tone linear dependencies in the image. It is expressed by the correlation coefficient between grey levels and the probability densities at each of the grey-level pairs *	$COR = \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} \frac{(i-\mu_I) \cdot (j-\mu_J)}{\sigma_I \cdot \sigma_J}$
Entropy: a measure of image disorder. If the image texture is not uniform several of the measurements for the GLCM will have small values causing entropy to be large.	$ENT = \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} -P_{i,j} \cdot lnP_{i,j}$
Dissimilarity: a measure similar to contrast that shows the differences.	$DIS = \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} P_{i,j} \cdot \lvert i-j \rvert$
Variance: a measure of image heterogeneity.	$STD = \sigma_I = \sqrt{\sum_{i=0}^{N-1} \sum_{j=0}^{N-1} P_{i,j} \cdot (i-\mu_I)^2}$

Table 4.3 (cont'd)

Homogeneity (inverse difference moment): a measure of homogeneity; if the differences in pairs of grey levels are small this value will be large	$HOM = \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} \frac{P_{i,j}}{1+(i-j)^2}$

* Textures selected for the classification

Previous studies indicated that the size of the moving window used to calculate texture measurements could affect the accuracy of the classification. Smaller window sizes were suggested as causes of misclassification at the boundaries between classes (Hsu, 1978). Similarly, Haack (2000) argued that increasing window sizes produced a systematic increase in the overall classification accuracy. Based on the previous literature and the extent of the study area, moving window sizes of 3x3, 5x5, 13x13, 19x19, 25x25, and 31x31 were explored and tested for the RADAR texture derivation. In order to reduce processing time and storage space the images were subset to cover only the study area. Therefore textures were calculated only for that extent.

For each RADAR image 8 textures (see table 4.3) for each window size were calculated. A total of 48 textures per image were then available. The number of possible combinations could be overwhelming (247 * 6 = 1482 following the equation below) for each RADAR image:

$$nCr = n!/\ r!\,(n-r)$$

Where C is the number of combinations, n is the number of textures (8 n! factorial = 4,320) and r the number of textures in each combination (r varies from 2 to 8). The number of combinations multiplied for the number of windows (6) is equal to 1482. In the ideal scenario the evaluation of which textures and textures combinations will be the best for classification will be performed through a separability analysis of the classes using ground truth data. In the absence of that a visual analysis was performed. The analysis was carried out in the RADARSAT 2000 for the 19x19 window size. The RADARSAT 2000 image was chosen because (1) it covered the entire study area, (2) had the biggest area of overlap with the other RADARSAT and ERS data and (3) was representative of the data type.

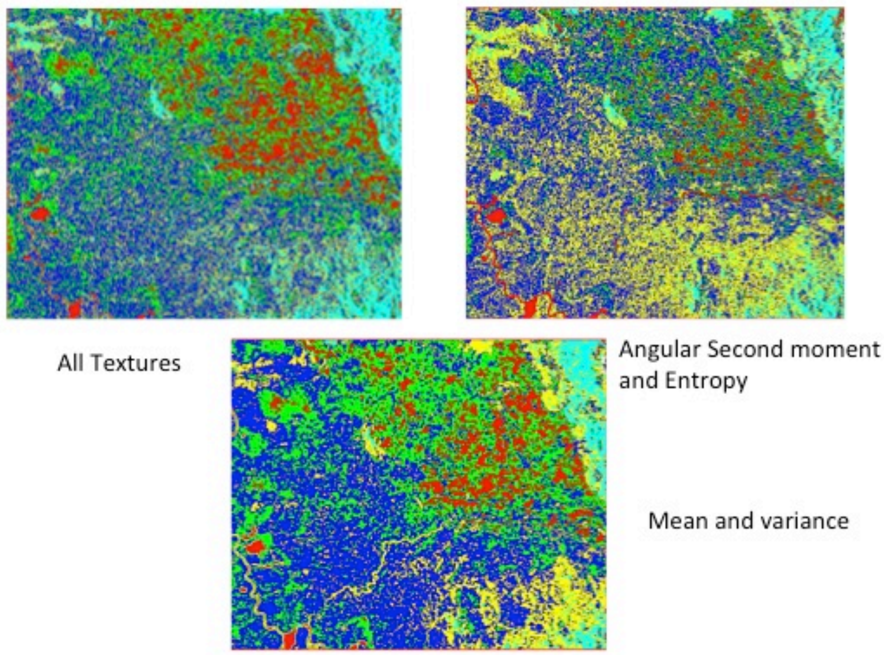
4.2.2.1 Textures Analysis

An unsupervised classification for 5 classes was performed using K-means (Isodata was tested as well for the first couple of trials but no difference was visually apparent). Based on the images, the original vegetation thematic map (Figure 4.1), and the informal meetings with experts in Colombia, a spatial structure pattern with rivers on the left and bottom of the image, mountains on the right, bottom and center of the image and an agricultural front in the right was expected. The images were evaluated as in the following examples (Figure 4.2 and Table 4.3). The images show the results of the unsupervised classification using: 1) all the textures, 2) angular second moment and entropy 3) mean and variance. The idea was to evaluate which texture or texture combinations will provide more structured classes versus "salt and pepper" noise like classes. In order to do that each class was given a 0 = "salt and pepper" and a 1 = more structure (Table 4.4).

Table 4.4: Texture Analysis.

Texture Combination	River	Mountain	Forest	Agricultural Frontier
All textures	0	1	0	0
Second and Entropy	1	1	1	0
Mean and Variance	1	1	1	1

Figure 4.1: Texture Analysis. The figure shows some examples of the combinations that were visually inspected.



4.2.3 Classification

After the selection of the best texture combination, a maximum likelihood supervised classification was performed. The land cover classes for the RADARSAT and ERS images were: water, flooded lowland rainforest, lowland forest, mixed agriculture and a barren/sand class. The Palsar images had six land cover classes, the five corresponding to the same classes in the RADARSAT plus the one corresponding to African oil palm. Based on the knowledge of the area, training areas were selected for each of the classes. The number of pixels used for training of the different land cover types ranged from 20,127 to 106,507 pixels for each class. Two separability tests among the classes were conducted: the Jeffries-Matusita distance and the transformed divergence (Richards, 2013; Jeffrey, 1946).

In the absence of ground truth, alternative datasets were researched. A fruitless attempt was made to compare the 30 m resolution continuous fields of tree cover dataset with the forest classification of the study region. The product is a combination of MODIS VCF (vegetation continuous fields) rescaled to 250 m, Landsat images circa-2000 and 2005 along with ancillary data (Sexton et al., 2013). The assumption, which was proven wrong, was that the MODIS and Landsat composites would provide free cloud data for the area and the forest class could then be evaluated against an independent data set. In essence, not even optical image composites provide cloud free data for this area at the moment.

4.2.4 Model Design and Implementation

4.2.4.1 DINAMICA EGO vs. Other LCMs

DINAMICA EGO is an environmental modeling platform developed in the Remote sensing laboratory at UFMG (Universidade Federal de Minas Gerais) (Soares-Filho et al., 2002). Initially called DINAMICA, it has evolved over the years from a land change model into DINAMICA EGO a refined modeling platform designed to build simple or complex dynamic spatial models.

This platform was chosen after a literature review of LCMS comparisons. For instance, a comparison between DINAMICA-EGO with CLUE-S (another popular LCM) found that both models predictions matched broadly with the actual land cover. CLUE-S was better in overall accuracy whereas the Markov process in DINAMICA could more precisely predict the amount of land-use change. Moreover, the spatial pattern of the simulation map based on Dinamica EGO was more consistent with empirical results (Yi et al., 2012).

In another comparison, Mas et al., 2013 compared four LCMs all based on inductive pattern approaches. The models evaluated were IDRISI's CA-MARKOV, CLUE-S/Dyna-CLUE, DINAMICA and Land Change Modeler (available in IDRISI or as an ArcGIS extension). The comparison focused on the tasks used to calibrate the model (evaluation of the quantity of change, elaboration of the change potential maps), running the simulation (allocation of change, landscape patterns simulation) and model assessment. The results suggested that DINAMICA is very flexible with a wide range of tools that allow the construction of custom made models, enables users to apply expert knowledge and exhibits a enhanced stochastic behavior for the simulation of more realistic landscapes (Mas et al., 2012, 2014).

DINAMICA EGO operates in a raster format, a feature that makes it compatible with remote sensing data. The land change model uses transition probability maps that are based on the weight of evidence and genetic algorithm methods (Soares-Filho et al., 2002). These maps simulate landscape dynamics using Markov chain matrices to determine the quantity of change and a cellular automata approach to reproduce spatial patterns. The exploration of the land use trajectories involves several steps (Figure 1.7): Data preparation, calibration, simulation, validation and projection.

4.2.4.2 Data Preparation

Besides the land cover maps derived from remote sensing, DINAMICA EGO uses a set of biophysical and socio-economic variables; typical explanatory variables are slope, soil types, land tenure, distance to roads, and population density, among others. These explanatory variables are used during the calibration phase; the goal is to establish their relationships with change potential. The variables can be static or dynamic. Static variables (e.g. slope or soils) will not significantly change during the simulation period. Dynamic variables such as distance to roads, and land tenure can change and need to be calculated at different time steps.

Explanatory variables can be continuous or categorical data and may be presented in different formats (vector, raster, or tabular). DINAMICA EGO uses the weight of evidence method to calculate the probability map (Bonham- Carter, 1994), but this method is applied in the platform only to categorical data. Therefore, data such as distance maps, altitude and slope need to be categorized. The process involves selecting the number of intervals and the buffer sizes aiming to better preserve the data structure, which is an important issue in the categorization process.

4.2.4.2.1 Data Transformation

The data transformation method used is an adaptation from Agterberg and Boham-Carter, (1990) to calculate ranges to categorize gray-tone variables. The basic idea is to build buffers, then the numbers of cells in each buffer (*An*) is plotted against a quantity An* exp (W^+) where W^+ is the weights of evidence, a line generating algorithm is used to locate the breaking points in the curve. The ranges are determined by linking the breaking points with straight lines. The following paragraphs describe the procedure and the equations used in this process.

This module first establishes a minimum delta – specified as the increment in the graphical interface – (Dx) for a continuous gray-tone variable x that is used to build n incremental buffers (Nx) comprising intervals from Xminimum to Xminimum + n Dx. Each n defines a threshold that divides the map into two classes: (Nx) and (Nx2). *An* is the number of cells for a buffer (Nx) multiple of n and dn is the number of occurrences for the modeled event (D) within this buffer. *An* and dn are obtained for an ordered sequence of buffers.

The next step is to calculate subsequent values of W^+ for each buffer. A further explanation about the weights of evidence meaning and purpose will be provided in the calibration part. The weights of evidence of a spatial variable on a transition from i to j in a binary map can be calculated from the ratios of conditional probabilities:

$$W^+ = \log_e \left\{ \frac{P(B \mid D)}{P(B \mid \overline{D})} \right\}$$

Where W^+ is the weight of evidence of occurring event D, given a spatial pattern B, whereas D and $\overline{D}$ refer to the present or absence of the event. The calculation of the weights of evidence of a spatial variable on a transition $i \Rightarrow j$ for multiple sources of evidence is

$$o\{D \mid B\} = \frac{P\{D \mid B\}}{P\{D \mid B\}}$$

$$\log\{D \mid B\} = \log\{D\} + W^+$$

Where O{D} is the prior odd ratio of event D, O{D/B} is the odd ratio of occurring event D, given a spatial pattern B, and W^+ is its corresponding weight of evidence. O {D} is assumed to be equal to one. The post-probability of a transition i to j, given a set of spatial data (B, C, D,… N), is expressed as:

$$P\{i \Rightarrow j \mid B \cap C \cap D.... \cap N\} = \frac{e^{\Sigma w_y^+}}{1 + e^{\Sigma w_y^+}}$$

Where B, C, D, and N are the values of k spatial variables that are measured at location x,y and represented by its weights W^+N.

Once the weights of evidence are calculated, the quantities An are plotted against An* exp (W^+). The breaking points in the resulting curve are chosen through the application of a line-generalizing algorithm (Intergraph, 1991). Using three parameters;

- minimum distance interval along x, minDx,
- maximum distance interval along x, maxDx, and
- tolerance angle ft

Dx is the distance between two points along x . A new breaking point is placed between minDx and maxDx, whenever Dx >= maxDx exceeds the tolerance angle ft. Thus, the number of ranges decreases as a function of ft. The ranges are finally defined by linking the breaking points with straight lines.

4.3.4.3 Calibration

Model calibration refers to the process of selecting biophysical or socio- economical explanatory variables and establishing their relationships with change potential. In the modeling exploration of this task was accomplished through 3 steps: the generation of the transition matrix, the calculation of weights of evidence coefficients and a map correlation analysis to verify the independence of the probability maps.

4.2.4.3.1 Transitions Matrix

The transition matrix describes a dynamic system that changes over discrete time increments. The quantity of any variable in any given time is the sum of fixed percentages of quantities of variables at the previous time step. In DINAMICA EGO the changes are computed from a Markov matrix that is generally obtained through the comparison of the LUC maps from two dates. The historical transition matrices for Chocó are calculated for yearly time intervals using land cover maps derived from the 2000 RADARSAT t0 image and the 2007 t1 PALSAR image. Markov chain projection provides the model with the estimated areas of each LUC category for future dates and the amount of change for each transition ("from-to" quantities). The transition matrix for the period between dates t0 and t1 (t1 ¼ t0 þ T) is obtained by overlaying the two LUC maps dated t0 and t1. This matrix indicates the area (or number of pixels) for each transition and can be transformed into a Markov chain probability matrix for the entire period. This matrix will be the basis for projecting to a future date after one or several periods. DINAMICA EGO calculates both net and gross rates of change. Net rates is the percentage of the land that will change to another state (transition from one land cover or use to another), it is a dimensional. Gross rates on the other hand are defined as area unit per unit of time. The gross rates are converted into net rates, dividing the extent of change by the fraction of each land use and cover class prior to change, before passing it to the transition CA simulation rules (patcher and expander).

In DINAMICA EGO, the base transition probability matrix B is transformed into an annual matrix A by matricial calculation to project the trends of change on an annual basis (Soares-Filho et al., 2002; Takada et al., 2010):

$$B = A^{\frac{1}{c}} = H \begin{pmatrix} (\lambda_1)^{1/t} & & 0 \\ & \ddots & \\ 0 & & (\lambda_n)^{1/t} \end{pmatrix} H^{-1}$$

$$H = \begin{pmatrix} u_1 & \ldots & u_n \end{pmatrix}$$

Where B is the original base transition matrix, A is the annual matrix, c denotes the power root matrix, t is the number of years, λ_1 is the i-th eigenvalue of A, and H is the corresponding eigenvector of A (n-by-1 column vector).

The transition rates are passed on to the model as a fixed parameter within a given phase, and the model can handle, as many as necessary, different dynamic phases. As the quantities of rates represent percentages of transition, it is necessary to calculate the amount of cells to be changed by each specified transition during iteration. This process is performed multiplying the number of cells of each land-use and land-cover class, occurring in a time step, by the transition rate.

4.2.4.3.2 Weights of Evidence

The weights of evidence method is based on conditional probability and the Baye's theorem. It is useful as an inductive tool to search and test for spatial associations between point distributions and map patterns; it can also be used as a deductive tool to determine the outcome of modeling the combination of explanatory maps. DINAMICA EGO uses the land cover maps from t0 and t1 and the ranges (weights) of gray-tone variables pre-defined intervals to obtain coefficients for selected spatial variables with respect to a transition or set of transitions. Suppose we have several evidence layers (A, B, and C) represented as map layers that are positively correlated with the occurrence (distribution) of a land cover class, the objective of the weights of evidence is to integrate the information carried by each evidence layer to update the posterior probabilities of a small area containing that particular land cover class.

The weight of evidence used in the land use change model is an adaptation of what has been applied by geologists to point out favorable areas for geological phenomena such as mineralization and seismicity (Agterberg and Bonham-Carter, 1990; Goodacre et al., 1993; Bonham-Carter, 1994).

The conditional probability that an event (D), such as a land-use change, occurs and coincides according to the presence or absence of a geographical pattern (B), such as slope, given a binary map is expressed as:

$$P\{D \mid B\} = \frac{P\{D \cap B\}}{P\{B\}}$$

The conditional probabilities in this formula are determined by measuring the areas of overlap between the number of occurrences of (D) (the number of cells (D) in a raster map) with the binary map patterns defined as

$$\mathrm{P}\{\mathrm{D} \cap \mathrm{B}\} = \frac{(\mathrm{D} \cap \mathrm{B})}{\mathrm{D}}$$

and the fraction of area occupied by pattern (B) with respect to the entire study area (A):

$$P\left\{B\right\} = \frac{B}{A}$$

The weighting factor W^- can be calculated from the ratios of conditional probabilities as follows:

$$W^- = \log_e\left\{\frac{P(\overline{B}\mid D)}{P(\overline{B}\mid \overline{D})}\right\}$$

Where B and $\overline{B}$ refer to the presence or absence, respectively, of the binary map pattern and D and $\overline{D}$ refer to the presence or absence, respectively of the event D, which is the land cover of interest (*i.e.* African oil palm). When the occurrences of (D) in association with the binary pattern (B) are found more often than would be expected due to chance, W^+ will be positive and W^- will be negative otherwise. The contrast C, a measure of spatial association between the binary pattern and the event is given by $C = W^+ - W^-$. The contrast is considered statistically significant with 95% probability if $|c| > 1.96\,S^2(C)$.

The variance of the contrast S^2 (C) can be estimated from the expression:

$$s^2(C) = \frac{1}{\text{area}(B \cap D)} + \frac{1}{\text{area}(B \cap \overline{D})} + \frac{1}{\text{area}(\overline{B} \cap D)} + \frac{1}{\text{area}(\overline{B} \cap \overline{D})}$$

This method can be extended to multiple predictive maps. Therefore, each weight of evidence represents the degree of association of a spatial pattern (B,C,D…N) with the occurrence of (D) according with :

$$P\left\{D \mid B \cap C \cap D \cdots \cap N\right\} = \ln D + W_B^+ + W_C^+ + W_D^+ + \ldots + W_N^+$$

To model transition phenomena, some changes in the meaning of the variables and the equations need to be introduced. For example, (D) will stand for a change from class i to j, such as deforestation or AOP establishment. In order to determine the influence of the set of spatial patterns on a modeled transition, assumptions such as the prior odds ratio of event (D) will be equal to 1 (See data transformation). This allows for the calculation of the post-probability of a transition *i* to *j*, given a particular combination of spatial patterns in a location (x,y) according to:

$$P\{i \Rightarrow j \mid B \cap C \cap D \cdots \cap N\} = \frac{e\sum W^{+}}{1+e\sum W^{+}}$$

This equation makes use of spatial overlay analysis to derive probability maps showing the probability of a cell at position (x,y) to transition from state i to j.

4.2.4.3.3 Map Correlation Analysis

The assumption in the weights of evidence method is that the explanatory variables are spatially independent. In order to assess this assumption a variety of statistic methods can be used. In the model for this study three methods are used to evaluate the correlation between variables: Cramer's Coefficient, Contingency Coefficient, and Joint Information Uncertainty. The former two methods are based on the Chi-square statistic while the latter is derived from the Joint Entropy measure; all methods are calculated from a contingency table produced by cross-tabulating pairs of maps (Bonham-Carter, 1994). The result of these tests will lead to either the elimination of variables or their combination in the model.

The contingency and Cramer coefficients are used to evaluate the association between categorical variables. Their calculation begins with the calculation of the Chi-Square statistic. Cramer statistics V is computed by taking the chi-square statistic divided by the sample size (n) and the minimum dimension minus one (k-1). The Cramer value is normalized from 0 to 1 where 1 will represent perfect correlation of the two variables.

$$V = \sqrt{\frac{\chi^2}{n(k - 1)}}$$

Likewise, the contingency coefficient is defined as:

$$C = \sqrt{\frac{\chi^2}{n + \chi^2}}$$

With the contingency coefficient values lower than 1 could indicate perfect correlation.

The joint information uncertainty is based on entropy measures or information statistics (Bonham-Carter, 1994). While Cramer's coefficient operates with absolute values of area, the uncertainty coefficient uses relative values (percentage). According to Bonham-Carter (1994), values below 0.5 suggest less association. Therefore, 0.5 has been adopted as a threshold to decide whether a variable should remain in the model or should be excluded from it.

4.2.4.4 CA Simulation

DINAMICA EGO uses two transitional functions: 1) the Expander and 2) the Patcher[29]. The first process is dedicated only to the expansion of previously formed patches. The second process is designed to generate new patches through a seeding mechanism. The combination of these two CA presents numerous possibilities with respect to the generation of spatial patterns of change. The combination of the two processes is shown in the following equation:

$$Qij = r \times (\text{Expander Function}) + s \times (\text{Patcher Function})$$

Where Qij represents the total amount of transitions of type ij specified per simulation step and r and s are, respectively, the percentage of transitions executed by each function, being r+s=1.

Both transitional functions employ a stochastic selecting mechanism. In the first step, the applied algorithm selects the cells with higher probabilities of change and arranges them orderly in a data array. In sequence, the selection of cells takes place randomly from top to bottom of the data array. In a second step, the categorical map is scanned to execute the

[29] The simulation for the Chocó region was initially performed using only the expander function.

selected transitions. The map is always read sequentially from the top left of the raster in order to avoid any bias introduced from the reading of the map.

The same inputs are used for both the expander and the patcher. Both need a categorical map (the land cover classification), a probability map, a matrix of number of changes, and a matrix of transition function parameters. The parameters are mean patch size, patch size variance, and isometry; together they specify the characteristics of the lognormal probability distribution that controls the size of new patches for a given class and the expansion of fringes.

Variations in these parameters can reproduce a diverse array of spatial patterns. The functions are set up to work on a Moore neighborhood (3x3 window), but different neighborhood search window sizes could be used.

4.2.4.4.1 The Expander Function

The Expander function, in spite of its name, is dedicated to the expansion and contraction of previous patches of a certain class. The algorithm is summarized in the following equation:

$$\begin{aligned}&\text{If } nj > 3 \text{ then } P'(ij)(xy) = P(ij)(xy) \text{ else}\\&P'(ij)(xy) = P(ij)(xy) \times (nj)/4\end{aligned}$$

Where nj corresponds to the number of cells of type j occurring in a Moore neighborhood. Using the expander function the patches will either contract or expand according to the type of transition.

4.2.4.4.2 The Patcher Function

The Patcher function is designed to generate new patches through a seeding mechanism. The idea is to avoid the formation of tiny single cell patches that could occur if only a simple cell allocation process was used. The Patcher searches for cells around a chosen location for a joint transition. This is done first by selecting the core cell of the new patch and then selecting a specific number of cells around the core cell according to their P_{ij} transition probabilities. The patch isometry varies from 0 to 2 assuming a more isometric form as this number increases.

4.2.4.5 Validation

4.2.4.5.1 Reciprocal Similarity Map

The comparison of spatial models is better accomplished through the use of neighborhood methods than through a strict cell by cell overlay (Hagen, 2003). Several methods have been developed such as the multiple resolution fitting procedure that compares a map fit within increasing windows sizes (Constanza, 1989), and the hierarchical fuzzy pattern matching (Power et al., 2001). Hagen (2003) developed new metrics that included the Kfuzzy (an equivalent of the Kappa statistic) and the fuzzy similarity, which takes into account the fuzziness of location and category within a cell neighborhood. No consensus exists about which technique yields the most appropriate validation or what fitness value should be taken as a threshold to accept or reject a model. However, a simulated map presents good result when it has a fitness value higher than the one obtained through a comparison between the final and initial historical maps (Hagen, 2003).

The validation method used in this study is a modification of Hagen (2003). It applies fuzziness to the simulated and the true maps of change, alternatively. As simulated maps with scattered small patches tend to score higher, the minimum fit value from the two-way comparison is used in order to obtain a conservative assessment of the model.

The fuzzy similarity test is based on the concept of fuzziness of location. Fuzziness of location means that the spatial specification found in a categorical map is not always as precise as appears; a category that in the map is positioned at a specific location may be interpreted as being present somewhere in the proximity of that location (Hagen, 2003). The calculation of fuzziness of location is based on the notion that the fuzzy representation of a cell depends on the cell itself, and to a lesser extent on the cells in its neighborhood. The extent to which the neighboring cells influence the fuzzy representation is expressed by a distant decay function (Hagen, 2003).

The fuzziness of location can be represented first by a crisp vector associated to each cell in a map. The crisp vector does not involve fuzziness at all; its membership values are set according to:

$$\text{Original category i} \rightarrow \mu_{\mathrm{crisp,i}} = 1, \mu_{\mathrm{crisp,j}} = 0, (\mathrm{i} \neq \mathrm{j})$$

This vector has as many positions as map categories. 1 is assumed for a category = *i* and 0 for categories other than *i*. The fuzzy neighborhood vector (V_{nbhood}) for each cell is given as:

Crisp vector: Fuzzy category vector:

$$V_{crisp} = \begin{pmatrix} \mu_{mcrisp1} \\ \mu_{mcrisp2} \\ \vdots \\ \mu_{mcrispC} \end{pmatrix} \qquad V_{mnbhood} = \begin{pmatrix} \mu_{mnbhood1} \\ \mu_{mnbhood2} \\ \vdots \\ \mu_{mnbhoodC} \end{pmatrix}$$

Where $mcrisp_{ij}$ is the membership of category *i* for neighboring cell j, assuming as in a crisp vector; mnbhood = the membership for category *i* with a neighborhood of N cells (usually $N=n^2$), m_j is the distance based membership of neighborhood cell j, and m= represents the distance decay function.

4.2.4.5.2 Exponential Decay Function

Similarity is calculated through an exponential decay function:

$$S = \frac{1}{_2\left(\frac{d}{A}\right)}$$

Where d is the distance from the window center and A is the attenuation factor. The attenuation parameter can be used to control how fast the exponential function value decreases.

Another option to evaluate spatial fitness between two maps can be built by using a multiple window similarity analysis. This method applies a constant decay function within variable window sizes. If the same number of cells of change is found within the window, the fit will be 1 independently of their locations. This represents a convenient way to assess model fitness through decreasing spatial resolution. Models that do not match well at high spatial resolution may have an appropriate fit at lower spatial resolutions. For the land use simulation in Chocó both methods were used.

4.2.4.6 Model Parameterization

This step is needed to analyze the effects that changes in the parameters of the Patcher and expander transition function have on the structure of the simulated landscape as variation in these functions allow for the simulation of a variety of spatial patterns of change (Soares-Filho, et al., 2003). These functions control the size, shape and location of the changes between transitions. Three landscape metrics are used to calibrate the functions: fractal dimension, patch cohesion index and nearest neighbor distance (Mcgarical and Marks, 1995). The fractal dimension is sensitive to patch shape and size (Forman and Gordon, 1986) providing information about the patch complexity that is parameterized in the functions as the mean size of the patch to be simulated and its isometry factor. The patch cohesion index is an indicator of the level of fragmentation and the nearest neighbor provides information of the distance between patches showing the dispersion of patches in a landscape. The three landscape metrics vary as a function of the patch mean size. Therefore by changing the patch size and the patch size variance different landscape patterns can be generated. The results using the same parameters are consistent over time and can be predicted from one simulation to the next. Changing the parameters changes the landscape patterns indicating the stability and sensitivity of the functions to parameterization.

In order to fine-tune the functions to replicate the landscape patterns found in the RADAR land use 2007 model, exploratory simulations using only patcher, only expander and both functions together were run. Patch mean size was set to the mean patch size of the AOP class and its variance. The percentages of change attributed to the two functions vary in exploratory simulations from 0,2 to 0,8 in 0,2 increments for each function (e.g if expander is set to 0,4 patcher should be set to 0,6 as the join frequency needs to add to 1). The results of the exploratory simulations suggested that expansion rather than creation of new patches is the main mechanism to simulate the land use trajectories in the Chocó region. For that reason the percentage of transitions occurring through the expander function was set to 0.8 whereas 0.2 percent was handled with the Patcher function. In the simulation of the Chocó land use trajectories the isometric factor was kept constant at a value equal to 1, meaning the value is ignored and neither aggregation nor disaggregation are forced inside the patches.

If the areas identified as African Palm in the RADAR classification were homogenously disperse in the landscape and smaller in size, the expander function should have been set to a higher number and the expander for a lower. The mean patch size would need to be set to a smaller number as well to increase patch dispersion. The functions are able to simulate very distinct landscapes varying from salt and pepper landscape (high fragmentation) patterns to continuous patterns depending on the values (Patch size and variance) used to set up the lognormal probability distribution function.

4.2.4.7 Projecting Land Use Trajectories in Chocó

The IPCC Third Assessment Report (2001) identifies a projection as "any description of the future and the pathway leading to it". Through the use of other input sources such as assumptions about land policies and economic activity, predictions could be made. The IPCC distinguishes projections from forecasts or predictions (terms that are often, mintakenly interchangeably) by defining the latter two as projections that are branded as "most likely," often based on models to which some level of confidence can be attached. The distinction is important since for the purpose of this work, projections will be derived from a LCM (e.g., future land use) but no prediction will be presented.

The landscape trajectories in this research are simulated using the same procedure and algorithms used in the CA simulation (4.2.4.4). The difference between the previous simulations and this one is the time frame (30 years or 30 iterations) and that only the initial landscape, which is the land cover classification derived from RADARSAT 2000 is used as input. Since the transition rates are fixed, this projection can be considered the projected historical trend.

A slightly smaller area than the one depicted in the classifications was chosen. The smaller area was selected to match the area covered in the spatial representation of the explanatory variables. The smaller area comprises 2493.75 km^2 and is represented in both the RADARSAT 2000 and PALSAR 2007 land cover classifications. The raster land covers were resampled (using the Nearest Neighbor method in ENVI 5.2) to match the coarser spatial resolution of the explanatory variables, thus the pixel spatial resolution changed from 12.5 m to 250m.

The influence of the explanatory variables was incorporated into the simulation through the construction of a spatial data base that contains the information about soil, geology, geomorphology, elevation, precipitation, climate, cultural distribution, political division, and production systems The area has no roads, rivers are the means of transportation, therefore distance to rivers was also included as a static variable.

The variable “cultural distribution” provides information about the demographic composition and social organization of the area. It divides the area among black communities, indigenous, ethnic groups influence, and farmers (Walshburger et al., unpublished information). The distribution corresponds closely to the customary land tenure regime for that reason the variable is interpreted as a proxy for insecure land tenure[30].

In the model and in the analysis of the land change in this research work, land ownership and management by the ethnic communities is assumed to be “preferable” or less damaging to the environment than agribusiness. Although, the idea of the noble savage as a good steward of the land is the subject of debate and for the most part has been rejected (Allingston, 2001; Hames, 2007). The case of the community councils is in my opinion different. Land tenure for the Afro-Colombian communities is tied to some regulations: the ownership of the land is entrusted to the community councils, the land can not be subject to any kind of economic transaction and there is an expectation for the communities to be the stewards of the land. On the other hand the long process of resistance and organization of the ethnic communities in Colombia has resulted in the development of their identity in association with the land and in

[30] Insecure property rights is a multidimensional phenomena. It has been linked to deforestation (Barbier and Burguess, 2001; Araujo et al. 2009), land conflicts (Puppin de Oliveira, 2008), increase land degradation (Clover and Eriksen, 2009), disaster and vulnerability (Relae and handmer, 2011), land grabs and violent conflicts (Broegaard, 2005; Unruh and Williams, 2013)
The perception of land tenure as insecure in the Choco region is associated with the customary land tenure regime that prompted the organization and activism of the ethnic communities in the 80s and 90s. Customary law globally is often ignored opening the space for land grabs with the endorsement of the state (Kirk M., 1998; Edelman et al., 2013).

the adoption of conservation discourses and actions. These characteristics along with their economic practices more in tune with traditional ways of life portray them, in my opinion, as more friendly to the forest than the agribusiness. Nevertheless, this assumption may not hold true in the future as new economic models are introduced to the region and as the destruction of the forest precludes traditional livelihoods.

CHAPTER 5

The first part of this chapter presents the results of the RADAR land cover classifications for RADARSAT 1997, 2000; PALSAR 2007, 2010 and the Land use change model along with the discussion. The second part summarizes the conclusions, and revisits the theoretical approach proposed at the beginning of this work.

5.1 Textures Results

The textures selected for the classification were the mean, variance and contrast at a window size of 19x19 for the RADARSAT image and 3x3 for PALSAR. Visual inspection allows for an easy separation between textures that result in a “salt and pepper” classification patterns versus the ones that provide a more structured landscape. However, the distinction among those that present a better landscape structure is not obvious. The final selection was made based on previous experience and what has been reported in the literature (Hsu, 1978; Haack 2000; Santos and Messina, 2008). Although it is possible to perform a visual evaluation of the textures, it is a cumbersome task and is subject to the biases of the analyst. Perhaps a better way to evaluate textures in the absence of ground data would be to use landscape metrics such as fractal dimension, Euclidean nearest neighbor, and interspersion and juxtaposition index, among others. The challenge then will be to find the thresholds that will make the texture combinations meaningful for classification.

5.2 Classification

Separability analysis is helpful to analyze the quality of the classification. Although it does not guarantee the accuracy of the classification it does indicate the statistical separability and the repeatability in the process of building land cover classes. In ENVI, the Jeffries- Matusita and the transformed divergence measures range from 0 to 2. 0 meaning that the classes are inseparable and 2 denoting perfect separability. If the value is between 1.7 and 1.9 the separability is good, values bellow 1.0 suggests that the classes may belong to a single class and should be merged (Jensen, 1996).

In general, the classes both in the Palsar and RADARSAT series were statistically distinct. However, the separability in the RADARSAT scenes was lower for all the pair classes than it was for the Palsar scenes. These results can be explained by the characteristics of the sensors rather than the quality of the training data. Palsar, with tits combination of long-wave data (i.e., L-band) and the HV polarization has reported better classification performance (discrimination), in particular for vegetation, than shorter wavelength data (i.e., C-band) (Guiyin et al., 2012; Ryan et al., 2011; Naidoo, et al., 2015).

The two classes with the lowest separability values were found between the flooded lowland forest and the lowland forest. This is not surprising since the backscatter signal from the ground is sensitive to vegetation moisture and soil water content. The flooding extent varies seasonally. A good example of the effect of water content on the classification can be seen in a comparison of the RADARSAT pair 1997 − 2000 (Figure 5.1). The 1997 image is from April 8th right at the onset of the rainy season, while the image from 2000 was acquired on May 30th when it had been raining for almost two months. The flooded lowland forest (bright green) appears to have increased substantially between 1997 and 2000 when in reality the sensor is capturing the changes in flooding and water content in both the soil and the vegetation. The dialectic constant is one of the characteristics of the target (vegetation, soil) that determines the intensity of the backscatter. A saturated soil has a high dielectric constant, compared to a dry soil. At C-HH the majority of the return from both flooded and non-flooded forest is from canopy volume scattering. According to Wang et al. (1995), the C-HH backscatter from flooded forest is about 1.82 times greater than that for the nonflooaded forests at and incident angle of 20^o, but is about equal at an incident angle of 60^o. Thus the presence of water interferes with the discrimination of vegetation types.

Table 5.1 shows the results of the separability analysis for the African oil palm land cover in the 2007 PALSAR image. All the values are above 1.7 indicating that AOP constitutes a statistically separate class than can be identified from the others. Tables 5.2 and 5.3 show the separability analysis between the flooded lowland rainforest and the other land covers. The separability of this class with any of the other land cover classes was the lowest.

Table 5.1: Separability Analysis for AOP. The results of the separability analysis for the African oil palm land cover in the 2007 Palsar image.

To	Jeffries - Matusita	Transformed Divergence
Lowland rainforest	1.795	1.997
Mixed Agriculture	1.906	1.954
Flooded lowland rainforest	1.930	1.999
Water	1.931	1.999
Barren	1.986	2.0

Table 5.2: Separability analysis for flooded lowland forest 2007. The results of the separability analysis for flooded lowland forest in the 2007 Palsar image.

	Jeffries - Matusita	Transformed Divergence
Lowland rainforest	1.511	1.672
Barren	1.764	1.999
Mixed Agriculture	1.999	2.000
African oil Palm	1.930	1999
Water	1.995	2.000

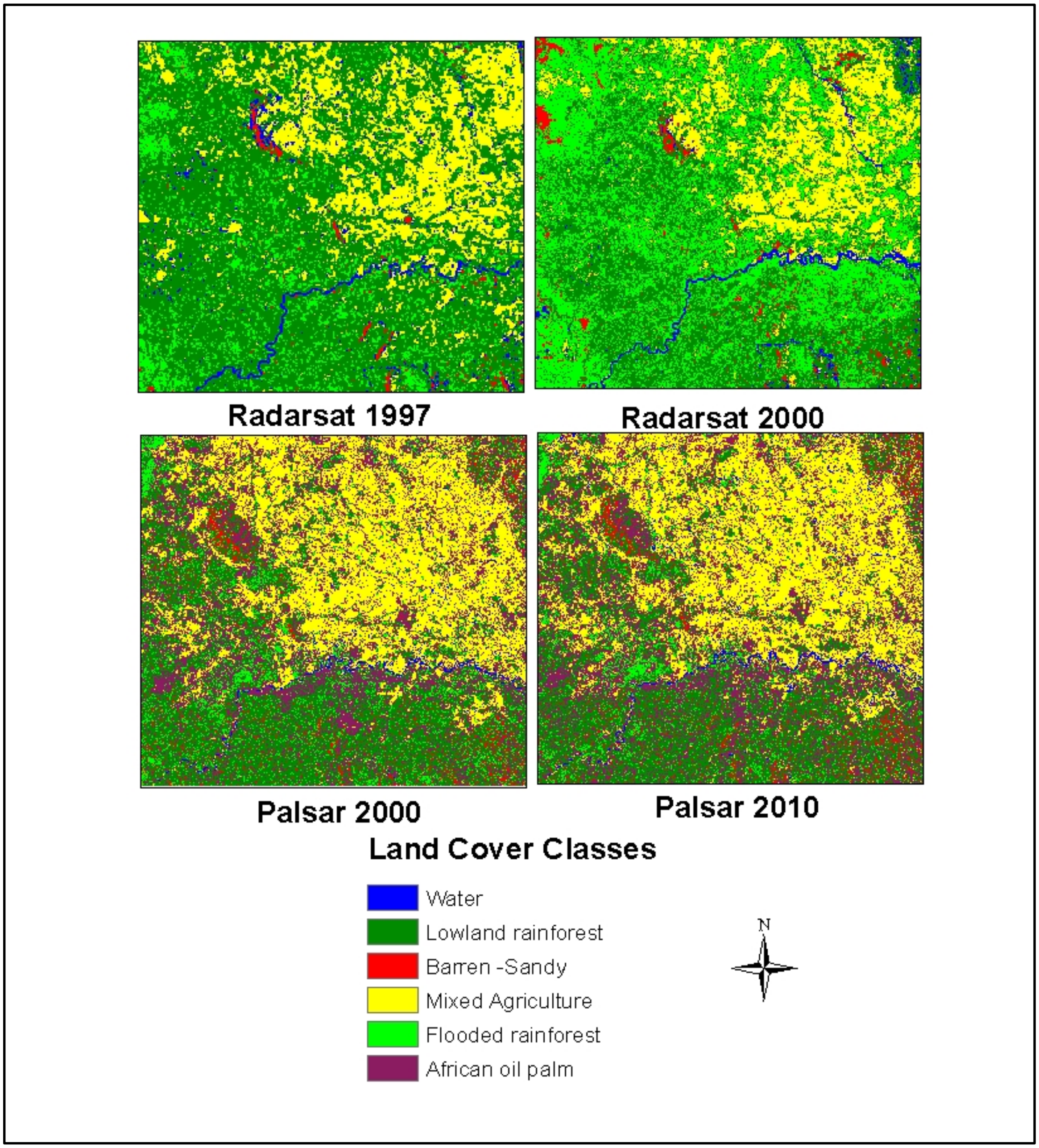
Table 5.3: Separability analysis for flooded lowland forest 2000. Results of the **s**eparability analysis for flooded lowland forest in the 2000 RADARSAT image.

	Jeffries - Matusita	Transformed Divergence
Lowland rainforest	1.147	1.214
Barren	1.664	1.878
Mixed Agriculture	1.466	1.715
Water	1.994	2.000

The use of textural information although not new to remote sensing has not being thoroughly explored. There is no agreement regarding the best window size or texture combination. Each study has to undergo some evaluation of both characteristics usually using either visual inspection or separability analysis. The general idea regarding the selection of windows size associates the window size with the size of the features on the ground and the spatial resolution of the sensor. However, sensor characteristics such as wavelength and polarization must have an effect since different window sizes perform differently in Palsar and Radar over the same landscape (same size features) and with the same spatial resolution. A similar result was reported in a comparison of C-band and L-band over the Amazon forest (Li et al., 2012). The many possible combinations to be evaluated and the lack of a robust statistical metric make it difficult at this point to reach a definitive conclusion.

Land cover classifications for the years 1997, 2000, 2007 and 2010 are shown in Figure 5.1. The largest change from 1997 to 2007 corresponds to the mixed agricultural class.

Figure 5.1: Land cover - Land use classifications. Land cover-land use classifications for the years 1997, 2000, 2007, and 2010 are shown.



The purpose of the land cover mapping was to find the areas where forest was transformed into African oil palm. Figures 5.2 and 5.3 show two areas that were classified as AOP in 2007 that were forest in 2000. The first area is located in the Jiguamiandó community council; the second one is located in the jurisdiction of the Curvaradó. In a last search at the Earth

Explorer web portal of the USGS, a Landsat 8 OLI image corresponding to 2014 was cloud free over the second plantation. Although, the images are seven years apart and it is not possible to say with 100% confidence that the area is planted with AOP it is possible to state that it is a large agriculture operation. In addition the areas coincide with two of the seven coordinates provided by the institute Alexander Von Humboldt where AOP establishment was suspected.

The pattern of distribution of AOP plantations is puzzling. The areas under AOP cultivation appear dispersed in the landscape instead of adjacent to one another as would be expected in forested areas where access is precluded by the presence of vegetation and the absence of roads. The finding of small areas of AOP in the proximity of the big agribusinesses operations illustrates the dynamic and adaptative nature of the system where small farmers adopt the introduced crop to benefit from the infrastructure now in place. Although, in the past the communities have advocated for environmental protection and conservation and spoke against AOP, it is likely that the communities themselves will embrace AOP as economic activity. The adoption of the crop will occur as an adaptation to a system whose biological and biophysical characteristics have changed and illustrate the learning process of communities exposed to new economic models.

Figure 5.2: AOP plantations I. The microwave images show areas of AOP in 2007 that were forest in the 2000 classification.

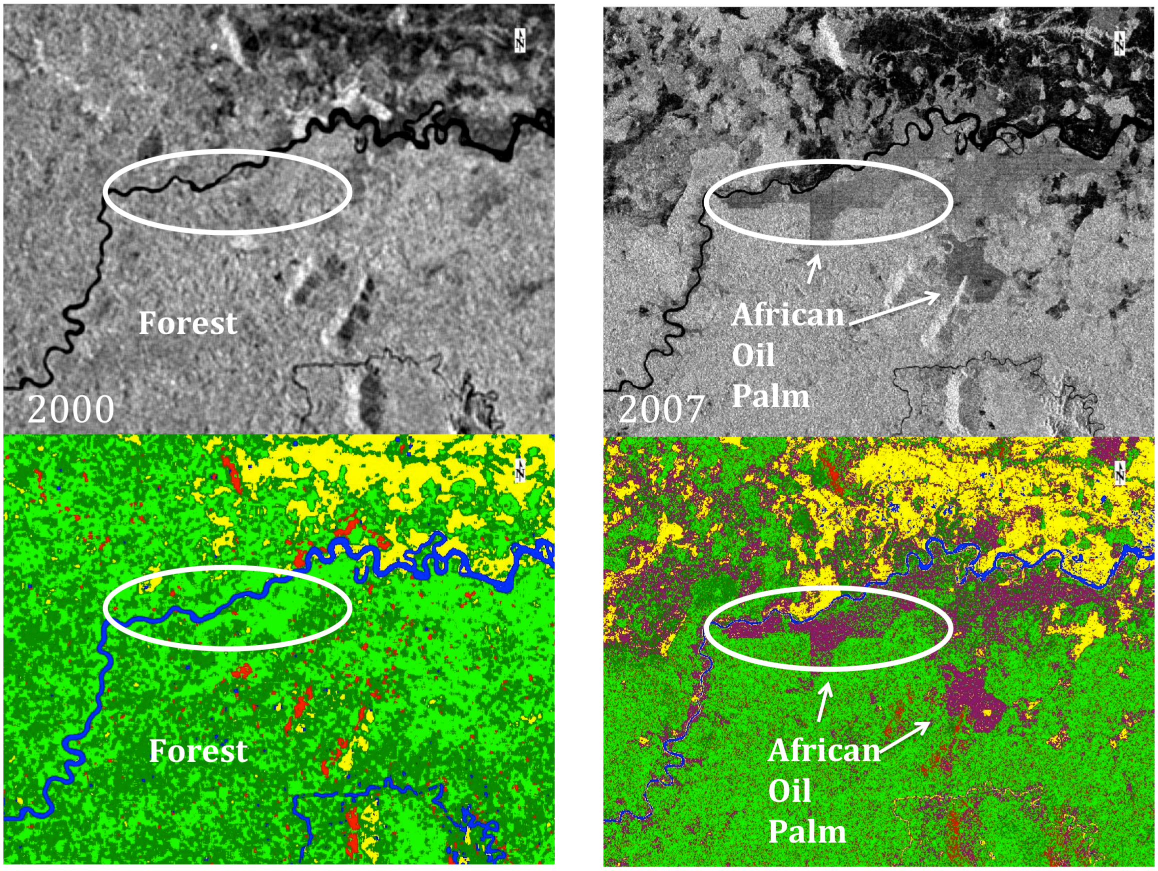
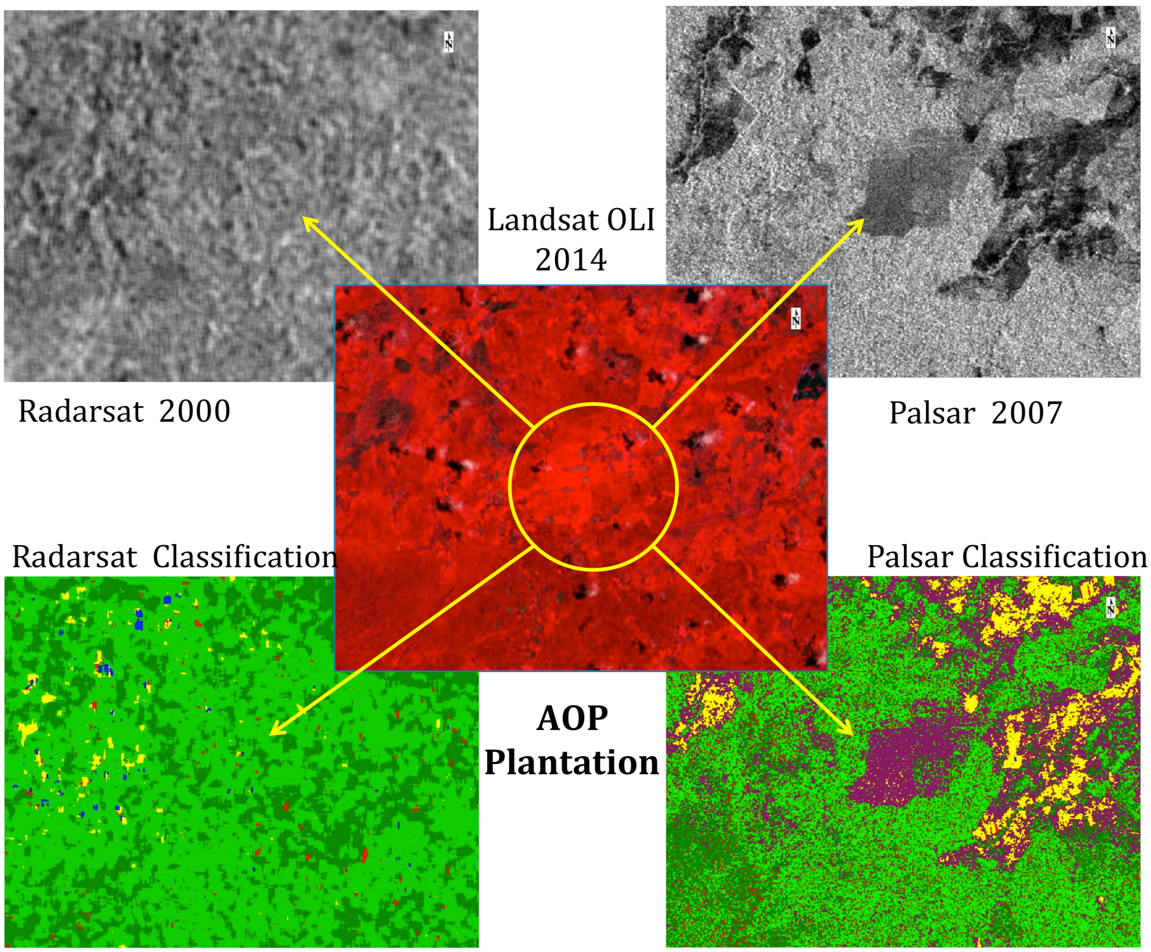


Figure 5.3: AOP plantations II. The microwave images show additional areas of AOP in 2007 that were forest in the 2000 classification. In addition a Landsat 8 image shows a large agricultural operation, which confirms the conversion from forest.



An analysis of the performance of the RADAR classifications for the two forest classes suggest that the RADAR is unable to consistently separate the lowland flooded forest from the lowland forest. A better approach could be to treat it as a single class and explore the changes in the return of the RADAR signal under different moisture conditions.

5.2.1 RADAR Signal and AOP

The backscatter signal in RADAR results from the interaction between the microwave radiation and natural surfaces, it depends on: surface roughness (geometry, structure), the incident angle, the wavelength and the moisture content of the target (dielectric constant).

Therefore, the synergy between different characteristics of the target has an effect in the RADAR backscatter. In forested areas the signal depends on: (1) vegetation type, species, and structure; (ii) Vegetation biomass; (iii) topography and surface roughness; (iv) flooding and the presence/ absence of standing water; and (v) near-surface soil moisture (Leblon et al., 2002).

An analysis of the backscattering in tree canopies identified the following components: Diffuse scattering from the ground; direct scattering from various vegetation components; double bounce vegetation-ground interactions, corner reflector between tree trunks and ground, direct backscatter from the forest canopy, volume scattering from within the forest canopy, diffuse scattering from the ground, shadowing by parts of the forest canopy of other parts of the canopy or ground. The relative importance of each component depends on the microwave wavelength (Ulaby et al., 1990). For surface and volume scattering form the backscatter in longer wavelengths (L band) where as surface scattering is the main component of shorter wavelengths (C-band).

The number of elements influencing the backscatter signal is highly dependent on the wavelength used. RADAR backscatter in the C band is mainly due to smaller tree elements in the upper crown level, as the band does not penetrate the canopy. This characteristic makes it useful to help in the discrimination between forest species, and makes it valuable for AOP remote sensing (Hoekman, 1993; Yatabe and Leckie; 1995; Ahern et al., 1995). On the other hand the RADAR backscatter of the L band, which, penetrates the canopy, originates from the major branches of the crown, from the trunks, the double bounce scattering from the tree trunk or crown to ground and from the ground (Hoekman, 1993, Ahern et al., 1995; Leckie and Ranson, 1998). The backscatter signal in L band could be attenuated due to flooding or a high water content in the vegetation or in the soil (Dobson and Ullaby, 1998).

Palms present a unique structure and geometry. The basic geometry and structure of the African oil palm is established during the first 2 to 3 years after planting the seedling. Early in its development the full crown of leaves is form with later growth being reflected in the elongation of the stem with the crown geometry (roughness) remaining almost unchanged. This characteristic allows the discrimination of African oil palm using both C and L bands. C band will capture the backscatter coming from the upper part of the canopy whereas L band backscatter will receive additional scattering from inside the crown, the trunk and the ground.

In addition AOP crop follows a regular planting pattern designed to obtain the maximum yield per plant and per hectare. The palms are planted in regular rows 7.8 m apart with a constant distance maintained between the plants as well (FAO, 1990). This particular arrangement is very distinctive from the spatial pattern of a forest. Nevertheless, this situation usually holds true for agribusinesses but not for small farmers that often lack the technical and financial means.

The particular growing and planting patterns of AOP and the characteristics of the RADAR backscatter make RADAR data useful to identify and monitor AOP without additional optical satellite data even in areas were cloud free optical imagery is available. Palsar in particular has been used alone or in conjunction with optical imagery to map AOP plantations in Peru and Malaysia (Morel, et al., 2011; Gutierrez-velez and Defries, 2013).

5.3 Model Results

5.3.1 Transition Matrix

The transition matrix shows the probability of a land cover class to transition into another one in a single year. The highest probabilities are from lowland rainforest and flooded forest to African oil palm followed by flooded forest and forest to mixed agriculture. For every land cover, the probabilities to transition to AOP are higher than to transition into any other class except for barren to flooded forest (0.0125), which is slightly more probable than barren to AOP (0.0121). The relatively high rate of transition from flooded forest to forest (0.0518) reflects the seasonal conditions that turn both types of forest indistinguishable. It has been reported that the backscatter of vegetation changes with seasonality and flooding (Zhao et al., 2014).

Table 5.4: Transition Matrix. The probability rate of transition among land cover classes in a year.

	To:					
From:	Water	Forest	Barren	Mix Ag	Flooded	AOP
Water		0.00025199	0.0012378	0.000143662	0.001688515	0.009848178
Forest	0.000131953		0.007044764	0.028007838	0.007296791	0.039264431
Barren	0.000115625	0.00850931		0.004806343	0.012528546	0.012099175
Mix Ag	0.000274164	0.000422239	0.00292906		0.000311558	0.017982849
Flooded	0.000248522	0.051751373	0.009038435	0.045963166		0.063935218
Total	**0.000770264**	**0.060934912**	**0.020250059**	**0.121921008**	**0.021825409**	**0.231763454**

5.3.2 Explanatory Variables

Weigths of evidence, probability maps and correlation between variables were calculated. Table 5.5 shows the results of the weight of evidence for the variable production systems in the land transition from forest to AOP as an example. The negative numbers imply that the variable is negatively correlated with the transition whereas a positive number shows positive correlations (favoring the transition), zero means that the variable has no effect on the transition and therefore is not significant. Each variable is evaluated for the different values that it can assume in the area (Table 5.5).

The variable cultural distribution was significant to explain the change from any land cover to African Palm, the reason being that the paramilitaries targeted ethnic territories for AOP development. Therefore, most of the palm was introduced into territories with either ethnic influence or dominated by Afro-Colombian communities. Elevation was the least significant variable as its variations across the area are minimal. Most of the area is between 0 to 50 m (~165 feet) with a few areas were elevation reaches 850 m (~2788 feet). The analysis of the explanatory variables resulted in the removal of the geomorphology map given its correlation with geology (see Table 5.6). Elevation was kept because of its negative correlation with AOP establishment in areas above 500 m (~1640 feet).

The recognition of the dynamic nature of the cultural distribution variable and the need to explore the social relations established around the palm expansion process lead to an analysis of the demographic changes in the region. The analysis is presented in the following section.

Table 5.5: Weights of evidence. Results of the weigths of evidence for the land cover transition from Forest to AOP – Variable: Production Systems.

Ranges	Possible Transitions	Executed Transitions	Weight Coefficient	Contrast	Significant
3 <= v < 5	518	252	0.44472	0.47402	Yes
5 <= v < 6	1722	782	0.31477	0.39549	Yes
6 <= v < 8	3287	1009	-0.31554	-0.49437	Yes
8 <= v < 9	571	14	-3.18471	-3.2887	Yes
9 <= v < 14	1674	1141	1.2599	1.58161	Yes
14 <= v < 15	949	97	-1.6	-1.81501	Yes
Total	8721	3295			

Table 5. 6: Correlation report for the transition from forest to AOP. In the table Var stands for variable, Sispro for productive systems, and GeoM for geomorphology.

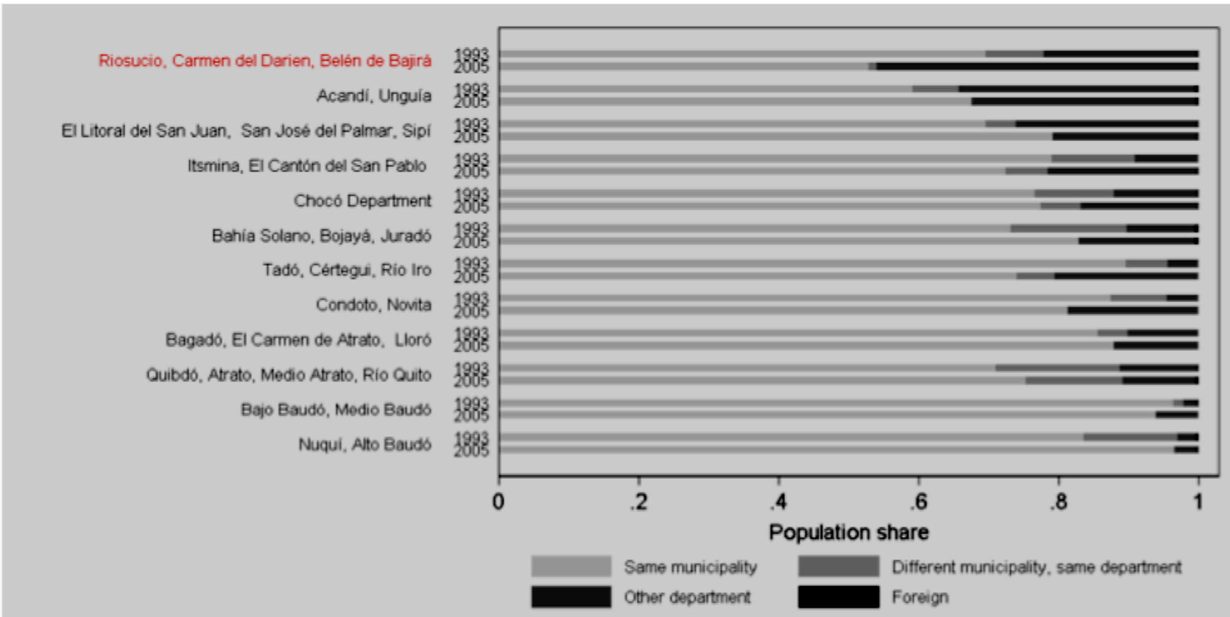
	1 Var.	2 Var.	Chi2	Cramer	Contingency	Entropy	Uncertainty
Forest to AOP	Dist rivers	Geology	9248.128	0.435061	0.524026	1.410914	0.183481
	Cultural	Soils	13512.86	0.333377	0.55475	1.968417	0.216658
	Cultural	Climate	5529.535	0.336409	0.429612	1.583039	0.15183
	Climate	Geology	9146.425	0.432884	0.52212	0.961710	0.215286
	Dist Rivers	Sispro	5529.534	0.336408	0.428612	1.583039	0.151829
	Geology	GeoM		0.974115	0.87658	1.99972	0.91422

5.3.2.1 Demographic Changes

Harmonized census microdata from the University of Minesota were used for a demographic analysis (https://international.ipums.org/international/). The harmonized data were preferred over the aggregated data from DANE to be able to compare the 1993 and 2005 population Census. The original intent was to include the dataset as a dynamic variable into the model however the lack of spatial information precludes this possibility. Nevertheless, the analysis is pertinent to the study in two ways. First, it is an independent observation that supports the claims about the association between AOP establishment and demographic changes. Second, the explanatory variable "cultural distribution" was significant in the model allocation of AOP patches.

Over the past two decades the Chocó department has experienced significant demographic changes. Harmonized microdata information from the last two Population Censuses revealed that the population share born in a department other than Chocó increased between 1993 and 2005 from 12 to 16 percent. Yet the change observed in the municipalities of Rio Sucio, Carmen del Darién, and Belén de Bajirá is significantly higher. For these administrative units, the population share born in a department other than Chocó increased from 21 to 46 percent during the same period (Figure 5.5).

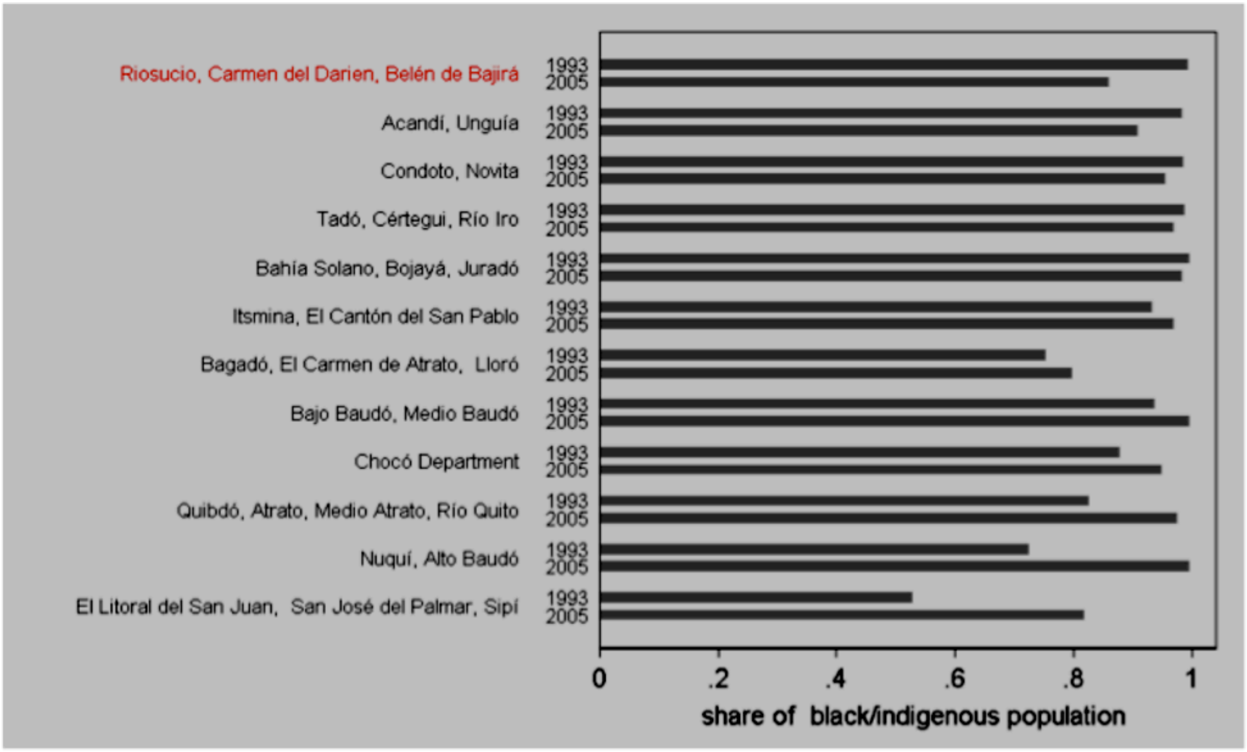
Figure 5.4: Demographic changes I. This graph shows the change in the populations share born in the study area (Riosucio, Carmen del Darién and Belén de Bajirá) in comparison with the rest of Chocó department.



Source: Calculation based on harmonized Census data produced by Minnesota Population Center. Integrated Public Use Microdata Series, International: Version 6.3. Minneapolis: University of Minnesota, 2015. Original data from 1993 and 2005 comes from DANE's XVI National Population and V de Housing Census (10% sample) and the XVII of Population and Dwelling and VI of Housing Census (10% sample), respectively.

Although overall the Chocó department experienced a slight increase in the share of black or indigenous population between 1993 and 2005, this pattern is completely reversed when it comes to the municipalities of Rio Sucio, Carmen del Darien and Belen de Bajirá where the share of black or indigenous has decreased by 13 percent (Figure 5.6).

Figure 5.5: Demographic changes II. This graph shows the change in the ethnic composition in the study area (Riosucio, Carmen del Darién and Belén de Bajirá) in comparison with the rest of the department.



Source: Calculation based on harmonized Census data produced by Minnesota Population Center. Integrated Public Use Microdata Series, International: Version 6.3. Minneapolis: University of Minnesota, 2015. Original data from 1993 and 2005 comes from DANE's XVI National Population and V de Housing Census (10% sample) and the XVII of Population and Dwelling and VI of Housing Census (10% sample), respectively.

5.3.2.2 Land Tenure Dynamics

The cultural variable was used as a proxy for insecure land tenure. Insecure land tenure has been recognized as an important driver in land use trajectories. For the study area, land tenure is a contentions issue. Land tenure in the Community councils of Curvaradó and Jiguamiandó before the eruption of violence was based in customary ownership. The formalization of property rights from customary to statutory was just in the beginning stages under law 70 of 1993.

In Colombia, there is a lack of formalization of property rights especially in rural areas, where ~ 47.7% of landowners do not have formal property titles (Gáfaro et al., 2012). Furthermore, land tenure has been recognized as the root cause of the armed conflict (CNRR, 2013). In the study area, as in the rest of Colombia the inequality in land distribution has given rise to a dynamic land tenure regime (Figure 5.6) where property rights are insecure and are often acquired by violent or fraudulent means.

Figure 5.6: Land Tenure Dynamics. This diagram shows the relationship and feedbacks between land tenure, armed conflict, drug trafficking, and the land tenure systems.

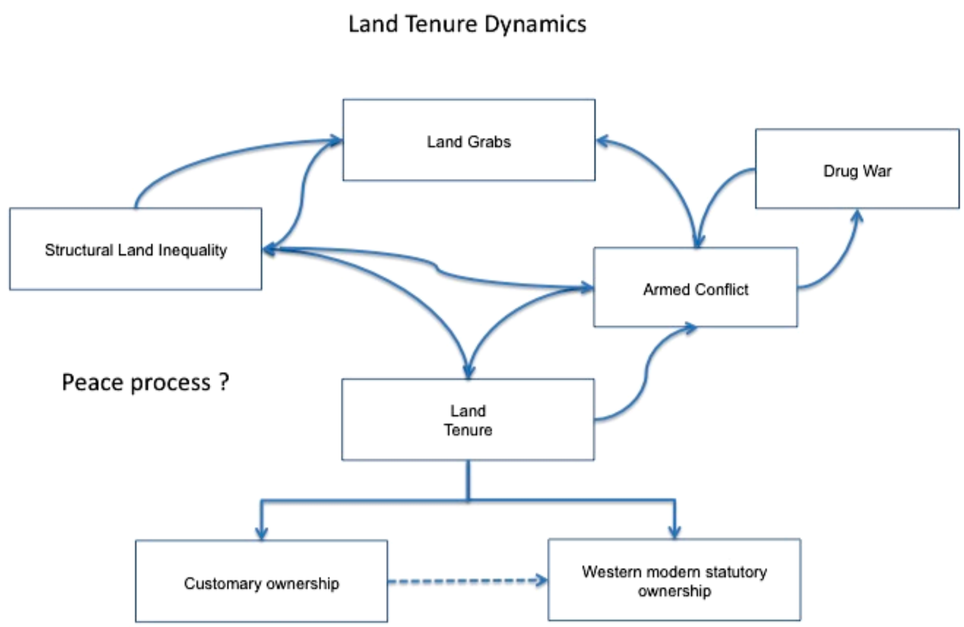


Figure 5.7 shows the overlap of two phenomena occurring over the Colombian territory in the last 20 years: the structural land inequality and land grabs both associated with the armed conflict. Over the years the armed conflict has become more entangled with the drug traffic to the point that is difficult to place boundaries between the two. The armed conflict has provided the conditions for the exertion of physical forced and the drug traffic the financial resources and teleconnections for the land grabs.

The political ecology research has focused on explaining the land grabs either as another advance of "neoliberal capitalism" (Oslender, 2007; Escobar, 2003, 2008) or as a tool for state formation in association with criminal organizations (Grajales, 2013; Briquet and Favarel-Garrigues, 2010). However, in the Colombian case, there is an historical status quo of inequality associated with the land and the appropriation of natural resources that should also be part of the analysis. Paradoxically the armed conflict that was born as a way to counter the inequalities has become a tool to maintain the status quo adding new elites and providing the political ground to justify human rights abuses.

5.3.3 Simulation Results

The simulated landscape for the period between 2000 and 2007 is presented in Figure 5.8, along with the land cover classification of 2007 for comparison purposes. The similarity map calculating the differences between the initial map and the simulated one is also presented in the same figure. The model fitness evaluated at window sizes 1, 3, 5, 7 ,9 and 11 is shown in Figure 5.8.

The simulated landscape shows the emergence of AOP areas in areas previously forested. Although the allocation of some of AOP patches differs from the location in the real landscape, the areas picked in the simulation have no restriction for AOP development.

In the similarity map the white areas are where the two landscapes do not agree. The model overall is preserving the landscape structure. As shown by Figure 5.9 the similarity reached a fitness value over 50% at a spatial resolution of ~750 meters.

Figure 5.7: Simulation. This Figure shows the simulated landscape for 2007, the classification for the same year and the similarity map between the two. The dark purple patches are the areas under AOP both actual and simulated

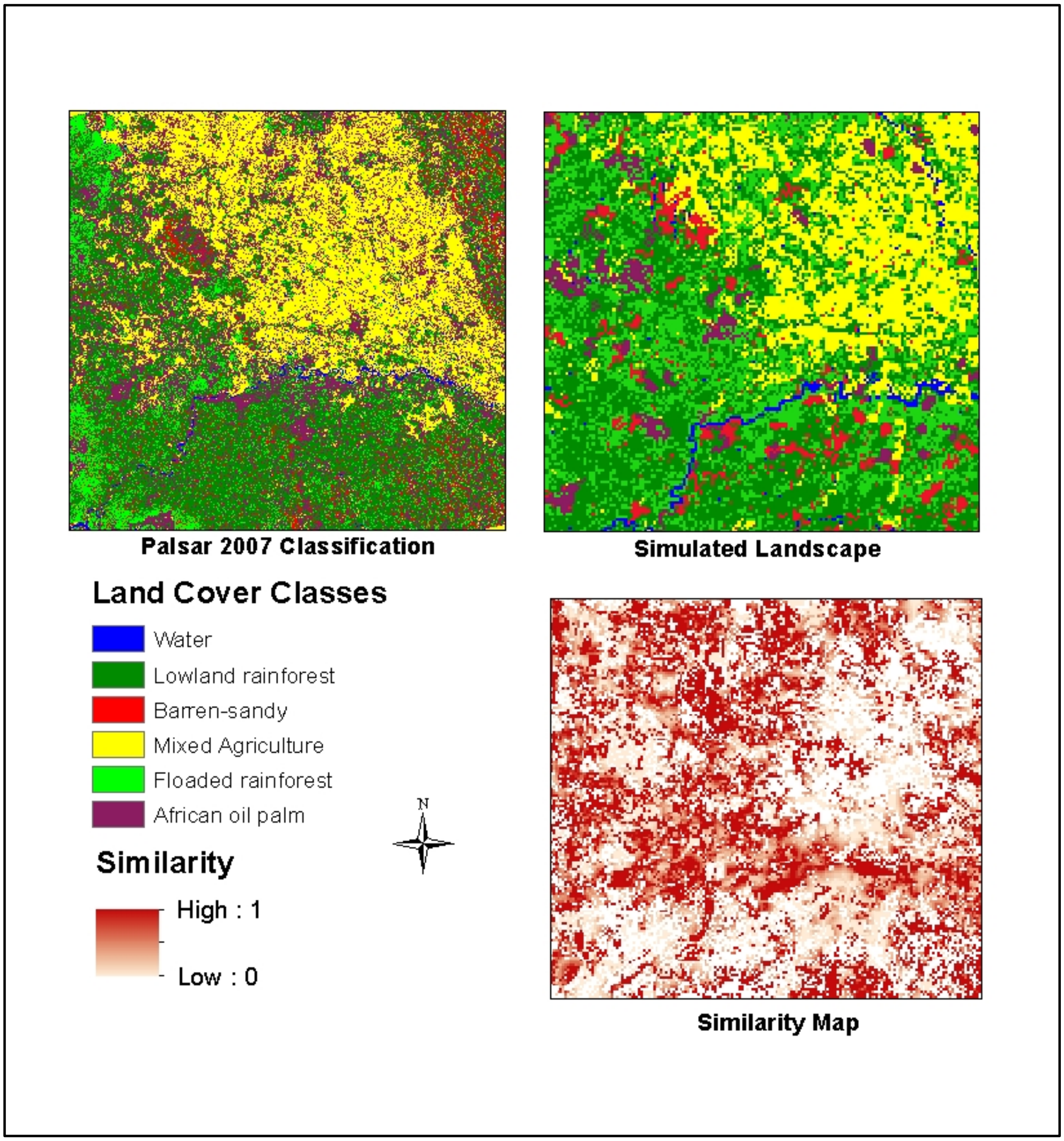
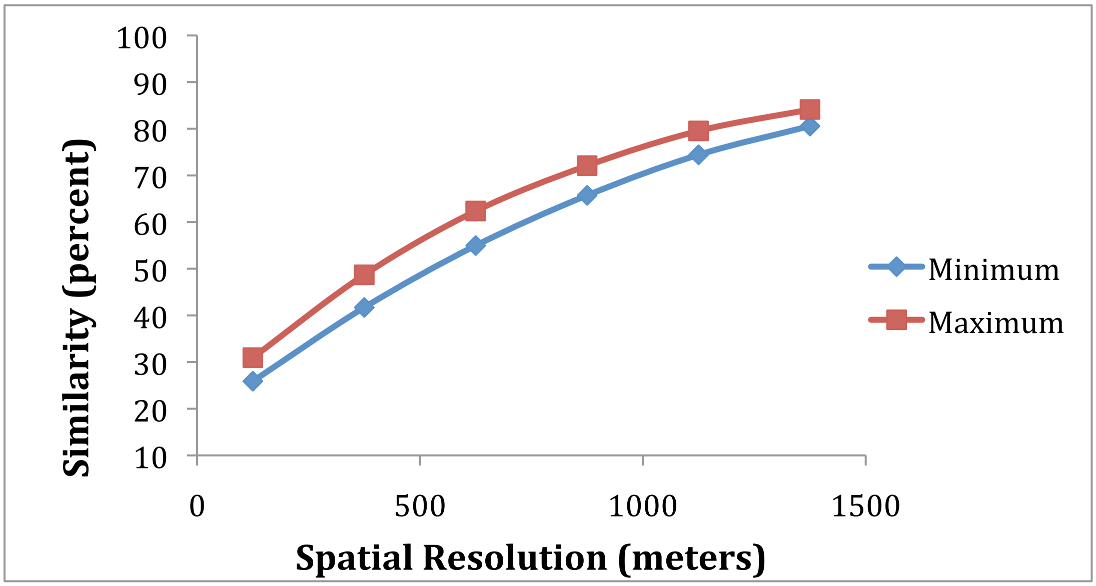


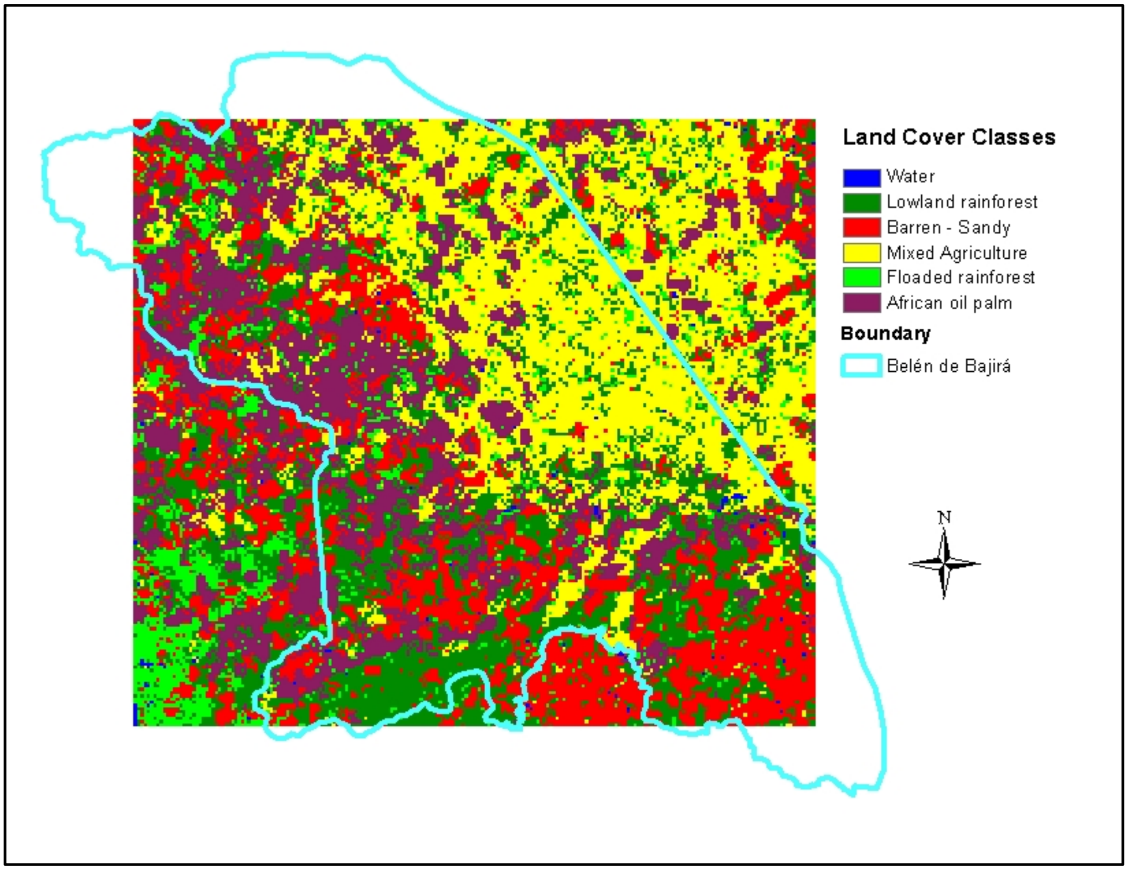
Figure 5.8: Model Fitness. The x-axis corresponds to the window size in meters and the y-axis corresponds to percentage of similarity.



5.3.1 30 - Year Simulation

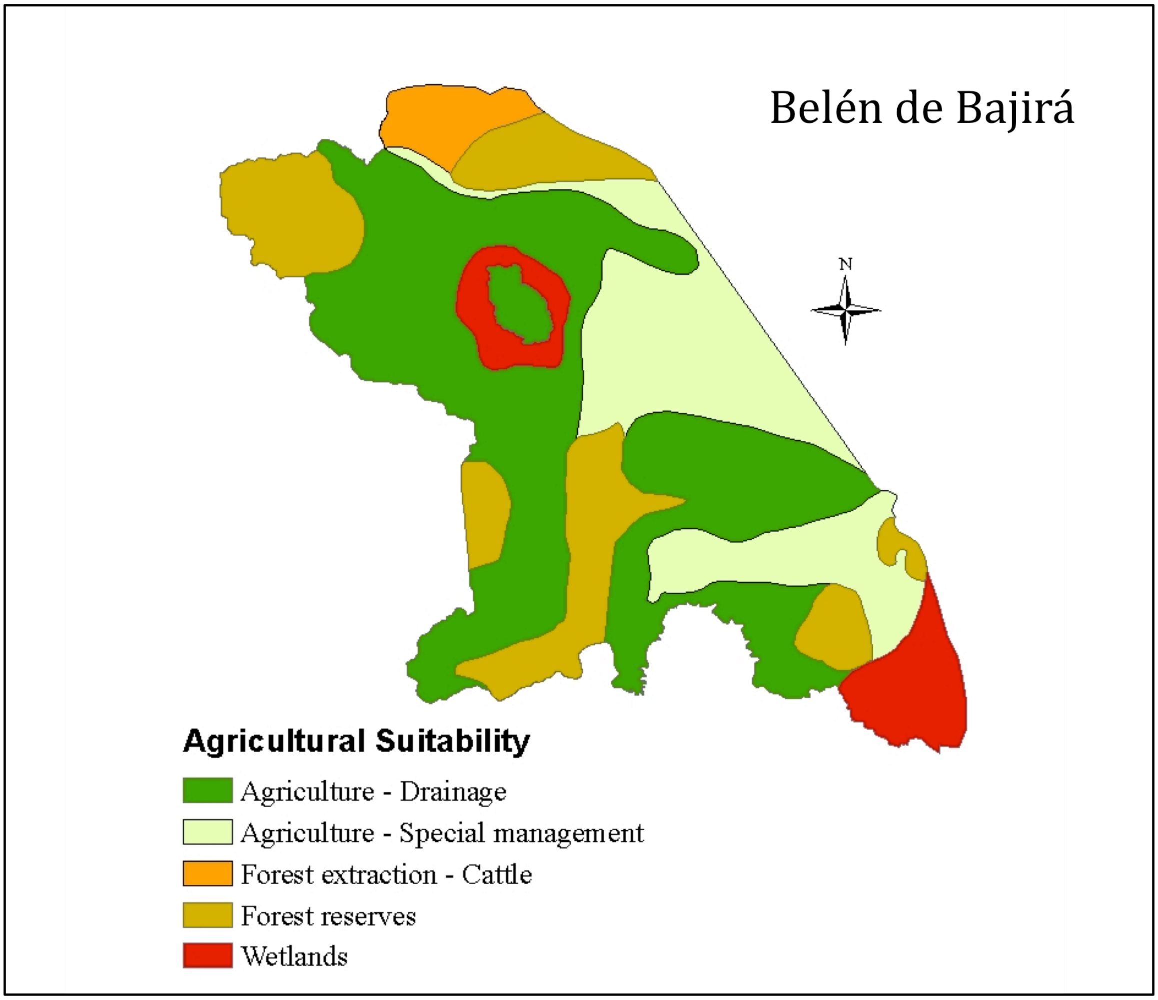
Figure 5.9 shows the results of the 30-year simulation. The projected landscape shows that under the current conditions AOP plantations will continue to expand. The territories under previous Afro-Colombian influence emerged in the model as the most affected by AOP establishment. The area under AOP changed from 0 ha in 2000 to 11,125 ha in 2007 to 55,800 ha in 2030. In the 2030 land use projection, only 4.4 % of the previous forested land (flooded lowland forest and lowland forest combined) is left. The area of forest decreases from 162,600 ha in 2007 to 7,231 ha in 2030.

Figure 5.9: Simulation 2000-2030. The Figure shows the increase in AOP in dark purple by the year 2030.



The 30-year simulation (Figure 5.10) could be compared with Figure 5.11. The map describes the suitability of the biophysical characteristics for agriculture, hence AOP development, based on geomorphology, soils, and slope. Although, the area presents fertile soils associated with the alluvial plains agriculture is not possible without a previous modification of the land. In the map (Figure 5.11) agriculture - drainage indicates areas were agricultural activities must be preceded by the construction of drainage channels. Agriculture - Special management indicates areas were soils are less apt for agriculture and flooding and erosion needs to be managed. Areas of forest extraction – cattle denotes areas that are better off as forest but could be used for cattle ranching. The areas designated as forest reserves, should be kept as forests since their biophysical characteristics prevent agriculture development. Wetlands depict areas of marshes and wetlands were agriculture is not possible. The comparison leads to the conclusion that most of the area could be converted into AOP plantations, granted the financial resources to adequate the land, and that the model projection for 2030 are conservative in relation to the potential area for AOP development.

Figure 5.10: Potential Land Use. The maps show the suitability of different areas for agriculture in Belén de Bajirá. The community councils are included in this municipality.



The initial assumptions regarding the land use change was that the change occurred right after the violent events in 1997 and that after that the rate of change will remain high for a relatively long period of time. However, no change was evident in the lapse between 1997 and 2000.

The LUC models showed an abrupt change in the land cover between 2000 and 2007 suggesting that there was a lag of 10 years from the time of the massive forced displacement of the Afro-Colombian communities and the time when the changes were visible in the land. The lag most probably occurred as a consequence of the time needed to mobilize workers, clear the forest, and the construction of necessary infrastructure (e.g. drain channels and AOP mills).

In the model the transition matrix was calculated using the land models for 2000 and 2007. Although, the transition matrix rates were calculated as a multiple-step transition matrix that is transition rates are calculated at an annual time step, in this case based in a 7-year period, it does not capture the nonstationary nature of the change. A way to better capture the non-linear and nonstationary behavior of the system will be to run the simulations using a combined multi-step transition matrix using different time periods 1997-2000; 2000-2007; and 2007-2011. That way the model will take into account the dynamic behavior of the land transformation rate. The combined multi-step transition matrices could be easily implemented into the LUC model using the land cover models that were derived from the years 1997, 2008, and 2009, those models were created but not shown/used in the research.

Another way to include the non-linearity behavior of the system is to make some of the variables dynamic. The endogenous variables such as soils, elevation, geomorphology, and climate are constant over a long period of time. However the exogenous variables: culture (land tenure insecurity), population density, distance to rivers, and production systems are dynamic and can be modeled as so when the appropriate set of data are available. The static variables are calculated only once in the model; the dynamic variables in the other hand need to be calculated before each iteration.

Future research with DINAMICA Ego could also include the incorporation of agents in a combination of CA and agent base modeling as the platform has recently incorporated that capability.

5.4 Conclusions

The system has adapted and a fundamental irreversible shift in its state has occurred. Using the terminology of complex theory the system has change “attractors”. The pre- AOP system revolved around an attractor where conservation of the forest was key to the survival of groups practicing subsistence activities. The after AOP system revolves around agricultural production and transformation of the forest as a means for individuals to survive. In that sense the land cover transformation and the forced displacement have brought about a change in the values and mindset of the ethnic groups in addition to the land cover change. Under the present conditions the most profitable land use is AOP with coca bushes underneath, such as an agricultural system has been observed in other areas of Colombia (DNE, 2004; Escobar, 2009) and has been informally reported by members of the Community councils.

The processes of land change in the region have change over time. For instance, the establishment of AOP with the consequent transformation of the previous land cover in the region was brought about by actors (agents) interaction. The combination of national and international policies related to biofuels, the drug/security wars and criminal coalitions resulted in land grabbing for AOP development. However, the expansion or establishment of new AOP plantations in the future may be the result of different processes such as continuation of historic development (expansion of the AOP already established); suitability of land (drainage channels were built so agricultural production may be more feasible) and/or neighborhood interaction (independent farmers looking to improve their livelihoods).

The underlying conditions at global and national scales are fluid and have changed as well between the time of the one massive attack to the population in 1997 and the present moment. The effectiveness of the use of biofuels as a strategy to mitigate climate change has come into question and an awareness of the environmental and human rights consequences of AOP expansion is now part of the international scene. Nevertheless, in Colombia the focus in AOP development persist.

Evidence of the slow collapse of the current war on drug policies coming from different sources is suggesting the need to engage in an informed discussion about the effectiveness and costs of the current global regime on drugs. On the other hand the declaration of glyphosate as a carcinogenic has prompted at least temporally changes in the counternarcotics strategies in Colombia. Increased international attention to the Colombian conflict, the prosecution and imprisonment of some paramilitaries and militaries as a result of human rights violations and their involvement with the drug traffic, the formal peace talks between the government and the FARC has had the effect to reduce the intensity of the violence against the population. The forms of violence exerted by criminal networks however have adapted to the new circumstances targeting leaders and visible human rights advocates.

Violence and displacement are ongoing threats in several regions of Colombia and legal and illegal armed actors are still present in the study area. The impact of the ongoing conflict and the more subtle forms of violence are difficult to model and/or link to the changes in land cover. Moreover, there is a lag between violent events and the observed land transformation. While the peak of the violence occurred in 1997, the establishment of AOP plantations did not occur until 2000 − 2003 after the forest was cut and the infrastructure was built. In these conditions establishing correlation and/or causality becomes challenging.

Although, this research concentrated in the transformation of forest to AOP plantations as it is at present the main large scale land cover change, its presence in the region is incidental. Development plans aimed at incorporating the region to the rest of the country and the economic interest looming over the natural resources indicates that the region productive and environmental status was on the way to be alter. For the coalition of military, paramilitary and the elites, the area needed to be claimed and recover from guerrillas to bring development, prosperity, and eventually state presence. In this scenario, AOP happen to be the most profitable crop at the time. In spite of the drastic changes introduced by the drainage channels the choosing of AOP as the economic activity prevents the use of the land for alternative more environmental damaging activities such as gold mining or cattle ranching. On the other hand the high investment needed to establish and AOP plantation may slow down the transformation.

In the remainder of the chapter I will address the present and future conditions of the most relevant exogenous drivers and their possible impact in the land trajectories as well as the suitability of SAR data to identify land cover change in this region.

5.4.1 Exogenous Factors

Political, economical and social factors were clearly more influential than biophysical variables in the initial transformation of the land. In the future their influence is tied to the fate of the armed conflict, the war on drugs, and the ability or inability of the Colombian state to solve the land tenure/security issue.

5.4.1.1 Armed Conflict – Peace Process

Historical changes have taken place in Colombia under the administration of Juan Manuel Santos, the current Colombian president. Arguably the most important one is the acknowledgment of the conflict, the victims, and the state responsibility in the violence against the population. This new position brings the conflict and its victims to the forefront as a national problem instead of being relegated to the periphery as isolated cases of "rebellion" by the enemies of the state.

At present the administration and the main guerrilla group are holding the longest and most successful peace talks in 50 years. The peace talks are undergoing in Havanna, Cuba with international accompaniment. Advances and setbacks have been experienced in the two and a half years of the talks. . In spite of the progress the resolution of the armed conflict is a big question mark. The Colombian society is very polarized as shown during the presidential elections held in 2014 when about 7 million Colombians voted in favor of war as a strategy to end the 50 year old conflict. On the other hand the traditional elites, new elites and armed groups profit from the conflict, as it is fertile ground to acquire wealth by illegal means and provides the elements to maintain the *status quo*. Without the structures of civil society and the support of local elites, the peace process and a change in Colombian land tenure regime are unlikely to be successful.

The volatile socio political conditions of Colombia and the resolution of the conflict affect the land use trajectories in the Choco region as it will affect the legal and the facto grounds to claim land ownership. The future land use trajectories will reflect the struggles, compromises, and the cooperative and antagonist relationships among the different actors in the fierce battle for the land. Under these circumstances and in the absence of the estate, the use of physical force and coercion can escalate at any time in the region if it serves the interest of the powerful.

5.4.1.2 War on Drugs

Reducing the cultivation of illicit crops poses enormous challenges. Four decades of spraying, manual eradication and interdiction have not changed the supply, purity or prices of the cocaine in the consumer countries (ELS, 2014). For Colombia, this war and the ingrained structural problems of the country have promoted coca growing, an agrarian crisis, the absence of effective governance, and the continued proliferation of illegal armed actors – criminal organizations, paramilitaries, neo-paramilitaries, and guerrilla groups – that seek to expand and defend their stakes in the drug trade.

A call for a shift in the paradigm from interdiction and criminalization to treating the problem as a health issue is coming from disparate sources. A radical change in Colombia in the near future is not likely due to internal and external forces that favor continuation of the drug trafficking and the war. The recent presidential move to halt aerial spraying in response tot the declaration of glyphosate as a probable carcinogenic by the WHO is portrayed as a "defiance toward US interests" (Neuman, 2015).

The management of the war on drugs affects the land use trajectories in Chocó as the activities and presence of illegal criminal armed groups are interwoven with the traffic and production of drugs. In addition a big portion of the financial resources for the establishment of AOP plantations in the region has come from money laundry operations. This is perhaps the most difficult problem to overcome for a peaceful restitution of the ethnic communities' rights to the land. The solution does not depend on the Colombian government alone; the concourse of the international community in particular the US willingness to review the current failed drug policies is needed.

5.4.1.3 Land Grabbing and Insecure Land Tenure

Land grabbing and the dispossession of the Afro-Colombian communities is at the center of the land transformation in the region. Recognized in the model, as land tenure insecurity is more complex that the simple notion of who has legal rights to the land and who holds the property rights. Land grabbing in Colombia as shown recently in the literature, is a widespread phenomenon. The process has been described as a de facto land counter-reform (Reyes Posada, 2009). Land grabbing and AOP establishment became an opportunity for large investors and armed actors for money laundry and to transform the power of violence into legitimate capital. The complexity of the legal field and the ambivalent position of the Colombian government have given both land grabbers and dispossessed communities opportunities and potential to claim the land (Grajales, 2015). Although, in the region communal ownership of the land is protected through the law 70 of 1993 and recognized through the enactment of the " land and victims law" of 2011 the new owners linked to paramilitary militias have the use of physical violence and their bureaucratic connections as tools to contest the communities land ownership (Grajales, 2013, 2015). Paradoxically the Colombian government continues the support of agribusiness, in particular AOP establishment through political and economic incentives in spite of the links of this economic activity with paramilitary militias, forced displacement, peasant's dispossession, human rights violations, and lately environmental damage (Grajales, 2015; Davalos, 2015).

The future land trajectories depend to a large extent in the ability of the Colombian government to solve and secure land tenure for the ethnic communities. Effective governance on the ground is currently precluded by the armed conflict, the drug traffic and the regional elites. At present Colombia has a fragmented political order where regions exhibit a high degree of autonomy and an entanglement of legal and political actors and criminal networks (Balvé, 2013; Grajales, 2013). Historically the rule of law has resided in the hands of these regional elites that are more than reluctant to abide with the sentences of the constitutional and Intera1merican Human Rights courts (Brushnell, 1993; Grajales 2015). Their position is illustrated in the violence suffered by leaders of peasant organizations involved in land restitution claims[31]. In this climate the results of the peace process, which has the land problem as a central point in the agenda, and the management of the war on drugs are fundamental for the Colombian government to address effective governance in the periphery of the country.

In order to secure land ownership and the safety of the communities the Colombian government needs to undertake many steps. The first very challenging one is to exert the monopoly of force in the region. This cannot happen without a successful peace process with the guerrillas, and the prosecution of any other illegal armed group. The second one, even more challenging, is to create the conditions to overcome the extreme poverty that the region has historically endured. In this climate the presence and advocacy of local communities and the national and international NGO's to guarantee the human rights of the Afro-Colombians and Indigenous communities acquires a bigger role.

On the other hand a reform in land tenure and the land restitution processes are very challenging in Colombia as they are related to the structural inequalities and the reluctance of local powers to change the status quo. Although, the land legally belongs to the communities, investors (criminal or not) are not willing to forego their assets especially when there are

[31] According to the Ombustman bureau, at least 71 leaders were murdered between 2006 and 2011 (Grajales, 2015)

credits involved. It became then a legal problem that requires the concourse of the civil society to pressure the elites and perhaps new legislation.

Changing land tenure systems and concentration is troublesome as it has been proven in South Africa where after 20 years of ending the apartheid 80% of the land is still in the hands of a privileged elite (Hoeks, et al., 2014). On the other hand, land grabs and their teleconnections are an ongoing process worldwide. The process is well illustrated in the cases of Indonesia and Malaysia. Where big timber and agribusiness moved into forested “empty” lands under large concessions granted by the state. The results for the environment have been “catastrophic” and the returns did not live up to the expectation of the people (Wilcove et al., 2013; Lee et al., 2011).

5.4.2 SAR and LCMs

One of the questions with SAR data was whether it was possible to identify AOP with only RADAR information. The results of this study suggest that RADAR data are able to identify AOP in this region. The HV PALSAR polarization performs better at the task than the HH although further analysis is needed to prove this statement. The appropriate location and characterization of AOP plantations in the tropics is an important topic in remote sensing and in forest conservation. A monitoring system to observe and characterize the expansion of the crop into forested areas will provide timely information to enforce the compliance of the agribusiness with sustainable initiatives such as the ones proposed by RSOP.

Ideally the system should take a multisensor approach using the synergies between optical and RADAR. The multisensor approach is needed in the case of AOP considering that it is located in areas of tropical forests where good quality cloud free optical data are difficult to acquire.

On the other hand, the identification of new or young plantations requires the combination of difference sources of information to be successfully classified.

The use of optical data in automatic monitoring systems is well documented and illustrated (e.g. fire products.). However, the incorporation of RADAR data into an automatic system requires a better understanding of land surface biophysical characteristics and microwave energy. The effects of soil roughness and soil moisture in the attenuation of backscatter signal from leaves, stalks and trunks have not been adequately characterized (Sano, et al., 2005; Zhao et al., 2014).

In addition to a remote sensing based monitoring system, a LCM system should prove useful. The projection of land cover transformations will provide insights into the allocation and probable extension of the AOP change. Although uncertain, it could guide preventive measures to decrease the environmental and social impacts of AOP establishment. In the case of the , the land cover projections could help the communities to decide the best locations to establish the biodiversity zones. At the local and national level, land use trajectories would provide information about areas more likely to be transformed. The timely identification of vulnerable areas ideally would lead to the creation of reserves or national parks before the forest resources are depleted.

Local-scale studies allow the identification of the links, feedbacks and a glimpse into how the chain of causes and consequences cascade from local and international scales into local realms. This study contributes towards the understanding of land use change in the context of social conflict. Although, it is recognized that conflicts impact the land–use and land-cover, few studies have addressed the linkages between particular circumstances and events in the conflict and the consequences for the land. As resource conflicts extend around the globe, a better understanding of how these impact the land and the people is paramount.

5.5 Future Research

Additional methods for the identification of AOP using SAR data could be applied. Two promising approaches are the cloude pottier decomposition classification and object-base image analysis. The Cloude pottier decomposition is based in the idea that a particular type of scatter dominates the backscatter in every cell of the image, be it volume scatter, surface scatter or double bounce scatter (Cloude and Pottier, 1997).

The decomposition extracts the polarimetric scattering information within the SAR data using the Eigen value/eigenvector of the coherency matrix into 4 parameters: Entropy (H), Anisotropy (A), Alpha angle (α), and SPAN (total scattered power). The entropy indicates the randomness of the scattering, the alpha angle identifies the dominant scattering mechanism, anisotropy measures the relative importance of other scattering components using the second and third eigenvalues (Cloude and Pottier, 1997), and SPAN represents the backscatter intensity (Kimura et al., 2003).

Given the particular characteristics of the palm tree and its regular planting pattern it is possible that AOP has a unique backscatter signal among the other land covers in the area. Using the Cloude-Pottier decomposition it may be possible to decompose the signal and find the uniqueness of the AOP scatter. This will increase the separability of this class in the feature space improving the classification. However, it should be expected that the results of the decomposition would vary depending on the data used. As was previously stated C band captures mostly surface scatter, whereas L band has the potential to capture a more complex signal.

The results obtained in the decomposition could be used in an unsupervised classification or in an object base classification. In an object base classification pixels are aggregated into homogenous backscatter signals using an image segmentation algorithm and then a classification is perform over the individual objects. In the absence of ground or high-resolution satellite data the use of alternative methods to identify AOP could help to corroborate the results obtained using the texture base approach.

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