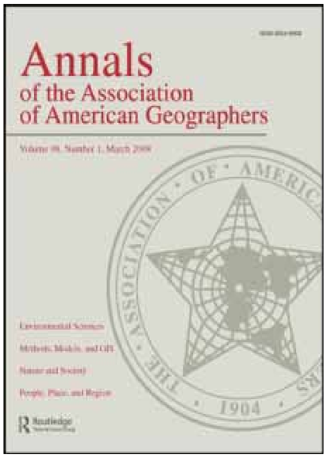

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Historical Patterns and Drivers of Landscape Change in Colombia Since 1500: A Regionalized Spatial Approach

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The extent and the spatial patterns of landscape transformation we observe today are the result of the historic human settlement process, often dating back hundreds or thousands of years. Analyzing and reconstructing those historical patterns helps to advance the understanding of the dynamics and persistence of present-day ecosystems. This article explores this reconstruction by identifying and analyzing historic drivers of landscape change for seven periods between 1500 and 2000, and presents historical land use maps showing major trends and impacts on natural ecosystems. Historic land use maps were built using an ecosystem map of 1998 and a "preclearing" ecosystem map, by constraining the spatial change of transformed areas using data on accessibility to rivers and roads, elevation, slope, moisture availability, and settlement areas. We estimate the transformed area rose from approximately 15 Mha in 1500 to 42 Mha in 2000, and land use changed from cropping in 1500 to predominantly grazing in 2000. Demographic impacts of colonization and the introduction of cattle were major drivers of change, but rates and trends of land cover change varied between regions and from period to period. The most impacted ecosystems have been the Andean and tropical dry forests, with the most recent trends toward clearing of humid lowland forests, especially in the Amazon and Pacific. Some landscapes have been subject to strong human influence continuously for more than 500 years, whereas others have been transformed for less than thirty years. We discuss the relevance of a historical approach for guiding conservation goals, ecological restoration efforts, and research hypotheses. *Key Words: Colombia, environmental history, historical land use drivers, land cover change, regionalization.*

我们今日所观察到的景观改造程度及其空间形态，往往可以追溯到数百年或数千年来人类定居过程中所带来的变化。将这些历史形态加以分析和重造，有助于推动我们了解现今生态系统的动态与持续性。这篇文章将探讨这些重造的历史形态。我们识别和分析1500至2000年驱使景观变化的历史因素，并呈现历史性的土地利用现状图，来显示自然生态系统主要趋势和影响。在构造土地使用历史性地图的过程中，我们使用1998年的生态系统地图和一份生态系统“未清除前”的地图，并且利用以河流与公路的通达性，海拔高，坡度，湿度可用性和都市地区的数据，来限制面积转化的空间变化。我们估计面积转化从约1500年的15 Mha上升到至2000年的42 Mha。土地利用从1500年以放牧为种植为主，转化为2000年以放牧为主。驱动重大变化的因素包括殖民化对人口结构的影响，以及引进牛所带来的改变。不过，土地面积变化的速度和趋势有别于不同地区之间，以及不同时期之间。 最具深受影响的生态系统是安第斯和热带干燥森林。近期的趋势是潮湿的低地森林，特别是亚马逊河和太平洋流域森林的逐渐被砍伐殆尽。一些景观已受到连续500多年来强烈的人类活动影响，而另一些已被改造不少于三十年。另外，我们讨论了能够指导保护目标，生态修复工程和研究假说的历史研究法及其相关性。*关键词：哥伦比亚，环境史，驱使土地使用的历史因素，土地覆被变化，区域化。*

La extensión y los patrones espaciales de la transformación del paisaje que observamos en la actualidad, son el resultado del proceso histórico de asentamiento humano, que frecuentemente data desde hace cientos o miles de años. El análisis y la reconstrucción de esos patrones históricos ayudan a promover la comprensión de la dinámica y la persistencia de los ecosistemas actuales. En este artículo se explora esa reconstrucción identificando y analizando los impulsores históricos del cambio del paisaje durante siete periodos comprendidos entre 1500 y 2000, y presenta mapas históricos de uso del suelo que muestran las tendencias y los impactos en los ecosistemas

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naturales. Los mapas históricos de uso del suelo se crearon usando un mapa del ecosistema de 1998 y un mapa del ecosistema previo a su "desmonte", limitando el cambio espacial de las áreas transformadas con datos sobre la accesibilidad a ríos y carreteras, elevación, pendiente, disponibilidad de humedad y áreas de asentamiento. Calculamos que el área transformada se elevó de aproximadamente 15 Mha en 1500 a 42 Mha en 2000, y el uso del suelo cambió, de cultivo en 1500 a predominio del pastoreo en 2000. El impacto demográfico de la colonización y de la introducción de ganado fueron impulsores importantes en el cambio, pero la tasa y la tendencia del cambio de la cobertura del suelo cambiaron entre varias regiones y periodos. Los ecosistemas más afectados han sido los bosques andinos y los tropicales secos, siendo las tendencias más recientes el desmonte de los bosques húmedos de selva baja, especialmente en el Amazonas y en el Pacífico. Algunos paisajes han estado sujetos continuamente a una intensa influencia humana durante más de 500 años, mientras que otros han sido transformados en menos de treinta años. Discutimos la importancia de una estrategia histórica para orientar las metas de conservación, los esfuerzos de restauración ecológica y las hipótesis de investigación. *Palabras clave: Colombia, historia ambiental, impulsores históricos de uso de la tierra, cambio de la cobertura de la tierra, regionalización.*

Land use is the interaction between humans and the biophysical environment (e.g., Forman 1995). It cumulatively impacts on the structure, function, and dynamics of ecosystems at the local, regional, and global levels of ecological organization. In recent decades, land use and land cover changes have accelerated, driven by the rapidly increasing human population and consumption levels, becoming major forces of global environmental change (Vitousek et al. 1997; Foley et al. 2005). Wackernagel and Rees (1996) advanced the concept of the "ecological footprint" as an indicator of the human impact on the environment, which is defined as the amount of environmental resources required to support the consumption of a population, measured in terms of area per capita. However, the ecological footprint concept has not been applied in a spatially and historically explicit manner. Many regions have been settled for centuries or even millenniums, with the spatial extent and patterns of present-day ecosystems and landscapes shaped by historical settlement patterns and their varying cultural, socioeconomic, and political causes (Wardell, Reenberg, and Tottrup 2003; Lunt and Spooner 2005). The present-day ecological footprint, therefore, is the cumulative legacy of historical land uses, spatially imprinted on the modern biophysical landscape. Understanding these ecological footprints and the processes that shape them, therefore, requires a spatially and temporally explicit approach within a multidisciplinary framework. Landscape history analyzes the landscape as a product of multiple temporal events. It aims to determine the cumulative sequence of changes and interpret the resulting spatial patterns of natural and human-modified landscape elements (McIntyre and Hobbs 1999; Lunt and Spooner 2005).

The process of land cover change is often viewed as a linear process of increasing transformation from natural to transformed conditions (Forman and Godron 1986; Lambin, Geist, and Lepers 2003; Bürgi, Hersperger, and Schneeberger 2004). However, human transformation of natural ecosystems can also be interrupted by periods of reversal and ecological recovery as cultures decline or even collapse (Denevan 1992). Therefore, the magnitude of the cumulative long-term effects of landscape change is variable (Bürgi, Hersperger, and Schneeberger 2004; Lunt and Spooner 2005), and the impacts will depend on the level of disruption of ecological self-regulating processes operating within the landscape (McDonnell and Pickett 1993). Recent concern over global ecological change has stimulated the study of human-induced land cover and landscape change, but the time frames addressed are often short, a few decades at most (Geist and Lambin 2001). An increasing number of studies are adopting a long-term historical perspective of landscape transformation; for example, in the U.S. (Black et al. 1998; Foster, Motzkin, and Slater 1998; Ramankutty and Foley 1999; Bürgi, Russell, and Motzkin 2000), Latin America (Houghton, Skole, and Lefkowitz 1991), Europe (Williams 2000; Cousins 2001), Australia (Bowman 2001; Butzer and Helgren 2005; Lunt and Spooner 2005), or globally (Houghton 1994; Klein 2001; Ramankutty, Foley, and Olejniczak 2002). Although these studies have primarily focused on describing and explaining the temporal trends of landscape change, they also incorporate the spatial dimension, and are increasingly recognized as a valuable tool for defining relevant contexts in land use planning processes (Marcucci 2000; Lunt and Spooner 2005). The preceding makes an integrative knowledge of the physical, biological, and social sciences, including history and archaeology, crucial for environmental history studies.

Lambin, Geist, and Lepers (2003) advocate a narrative perspective to help deepen the understanding of the land cover and landscape change processes through historical analysis and interpretation. However, Marcucci (2000) argues that if landscape history is to capture and uncover the patterns and causes of landscape change it needs to be geographically specific, holistic in approach, and able to reveal key processes that shape the landscape over multiple time frames. The outcome should be a synthesis of the ecological stages and cultural periods linked with key underlying processes and drivers. Because environmental history also views historical landscapes as a cultural legacy (Nassauer 1995; Marcucci 2000), it might encounter conflicting interpretations derived from different value systems, such as those that arise from the tensions of historical aboriginal-colonist conflicts in many parts of the world (Sluyter 2001; McNiven and Russell 2005). Future studies need to address this issue. Sluyter (2001) presents a framework for colonialism-related processes and their effects in the Americas, introducing the "colonial triangle" among natives, nonnatives, and landscape, which is relevant to landscape history. He advances ideas such as the "obscuring of cultural landscapes," arguing that concepts such as the pristine wilderness myth resulted from overlooking the effects of the demographic collapses and subsequent depopulation of colonial conquests that led to natural vegetation regeneration, especially in forests. Internationally, the history of settler and postcolonial societies has emerged as a topic of major comparative significance in the new environmental history (e.g., Griffiths and Robin 1997).

Geographers and environmental historians are concerned with measuring the rate and spatial extent of landscape change (e.g., Etter, McAlpine, Pullar, and Possingham 2006; Seabrook, McAlpine, and Fensham 2006). This requires multitemporal maps that depict historical sequences of landscape change. The approach employed to generate such maps depends on the available data, spatial extent, and purpose of the analysis. Cousins (2001) used existing detailed cadastral data maps and aerial photography, whereas Ramankutty and Foley (1999) used historical agricultural census data and preclearing vegetation maps to produce multitemporal land cover maps. Etter and van Wyngaarden (2000) used indirect data such as settlement foundation dates and current transformed ecosystem maps applying interpolation techniques to produce a map with transformed areas sliced by historical period. Because of the long time frames involved in historical studies of landscape change, environmental historians often rely on both quantitative and qualitative data and a combination of scientific and narrative approaches (Turner and Butzer 1992; Bray 1995). Endfield and O'Hara (1999), in a study of Michoacán in Mexico, analyzed and discussed the difficulties of using archival sources, highlighting the importance of considering the socioeconomic context in which the archives were produced. Use of historical data is often limited by uneven quality and quantity, changes in political and census boundaries, along with variation in the spatial accuracy, which can imply high levels of uncertainty (Leyk, Boesch, and Weibel 2005). Several studies have, however, illustrated the power of integrating spatial data (maps, remote sensing) with narrative and temporal data (e.g., Black et al. 1998; Bürgi and Russell 2001; Wardell, Reenberg, and Tottrup 2003). Wardell, Reenberg, and Tottrup (2003), in a study of historical footprints of colonialism in West Africa, demonstrated the impact of different colonial events in shaping the regional and local landscape, and the importance of considering these events in understanding past and present landscape patterns.

In Colombia, the arrival of the Spanish in the early 1500s had major long-term consequences for the indigenous population and the ecosystems. As in many other tropical and Southern Hemisphere regions, colonization meant a clash of indigenous and European cultures, in terms of values, economy, social structure, laws, and technology. From an environmental perspective, the introduction of cattle, sheep, and goats had a major and long-lasting impact on Colombian ecosystems, with the expansion of cattle grazing continuing today in agricultural frontier regions such as the Amazon and Magdalena. The environmental history of Colombia since Spanish settlement has been addressed from a descriptive and mainly aspatial perspective (Patiño 1977; Bray 1995). More recently, Etter and van Wyngaarden (2000) constructed a broad spatial settlement history for the last 500 years using foundation dates of settlements, and a more detailed cross-disciplinary analysis for the last 150 years was conducted by Palacio (2001). Despite these recent advances in the study of Colombian landscape history, there remains a lack of more comprehensive and spatially explicit synthesis of human-induced landscape change occurring over the past 500 years that can help explain current transformation patterns and the extent and intensity of human impacts on ecosystems.

From a biodiversity conservation perspective, the history of landscape change in Colombia is particularly important because it is recognized as a biologically megadiverse country (Hernández et al. 1992; Chaves and Arango 1998). This rich biodiversity is under threat from the cumulative impacts of human settlement, and the ongoing expansion of the agricultural frontier (Etter, McAlpine, Phinn, et al. 2006b), driven by a human population of 40 million people growing at 1.5 to 2.0 percent per year (Departamento Administrativo Nacional de Estadistica 1993). This further highlights the need to investigate the history and the underlying causes and processes of landscape change to understand the pressures on Colombian ecosystems and help develop ecologically sustainable land use management.

In this article we present a regionalized spatially explicit landscape history of Colombia since the arrival of the Spaniards in the 1500s by spatially reconstructing the extent and major impacts of human land use on the nation's landscapes and ecosystems. The focus is on the national (million km^2) and regional levels (10,000s km^2). First, we define meaningful periods for recent Colombian landscape history from a socioeconomic, political, and cultural perspective. We then identify and analyze the main drivers and impacts of landscape change for each period. We construct a series of historical maps of the spatial extent of human-induced landscape change by broad land use types, and identify the major historical trends and impacts on natural ecosystems. Finally, we discuss the relevance of a historical approach to the study of human–landscape interactions as a useful starting point for establishing conservation goals, ecological restoration efforts, and research hypotheses.

Study Area

The land area of Colombia is approximately 1.1 million km^2, and comprises five major regions: Andean, Caribbean, Pacific, Eastern Amazonian, and Eastern Orinoco plains (Figure 1). The Andean region can be conveniently subdivided into the Andean Ranges, the Magdalena and Cauca Valleys, and Catatumbo. The total human population in 2000 was approximately 40 million, with 75 percent living in urban areas. However, the presence of humans dates back to at least 14500 BP (van der Hammen 1992; Bray 1995). Historically, the Caribbean and the Andean regions have supported high population densities, and hence have been more heavily transformed (Melo 1998; M. Herrera 2000). Similar regional differences have also occurred in other Latin American countries such as Costa Rica, where human settlement has been historically concentrated in the central plateau and dry forests of the west, and less in the humid Atlantic lowlands (Pfaff and Sanchez-Azofeifa 2004).

Methods

A common obstacle to the analysis of human–landscape interactions is the varying precision and spatial reference units of historical data and political boundaries, which compromise temporal comparability and analysis (Black et al. 1998; Bürgi, Hersperger, and Schneeberger 2004). For example, the present-day political boundaries of Colombia are the result of multiple modifications over the last 500 years, with important implications for the analysis of historical data, where multiple adjustments need to be made to data (e.g., demography, agricultural production, cattle) to a uniform and comparable spatial extent. Another difficulty, for example, is taking into account important regional variations in the rates of population decline or growth in colonization areas as shown by Cook (2004) for Peru, which had important implications for ecosystem transformation. Such difficulties need to be overcome, as by slicing the temporal extent of analysis into convenient historical periods in which such aspects can be better controlled.

Definition of Historical Periods

A sound historical analysis of human-induced landscape change and the associated environmental impacts first requires defining historical periods that adequately reflect the changes in the drivers and patterns of landscape change. With this in mind, we reviewed previous historical studies of Colombia (Ocampo 1987; Zambrano and Bernard 1993; Tovar, Tovar, and Tovar 1994; M. Herrera 1996, 2000; Melo 1998; Colmenares 1999; Etter and van Wyngaarden 2000; Langebaek 2000; Palacio 2001) and identified seven historical periods based on distinguishing socioeconomic and political characteristics. The main criteria used to define these periods were human population dynamics and trends, land and resource use, patterns of economic activity, and the change in political and social institutions:

Pre-Spanish (Before 1500). 1500 marks the average date of rupture of Amerindian history with the beginning of colonization. Although human occupation of Colombia dates at least from14500 BP, it was from 2000 BP that increasingly complex societies with well-differentiated cultures accompanied by agricultural intensification became established, especially in the Andes and Caribbean regions (Reichel-Dolmatoff and Reichel-Dolmatoff 1977; Melo 1998). The existing archaeological records show that from around 2000 BP there was a strong increase in human population with a

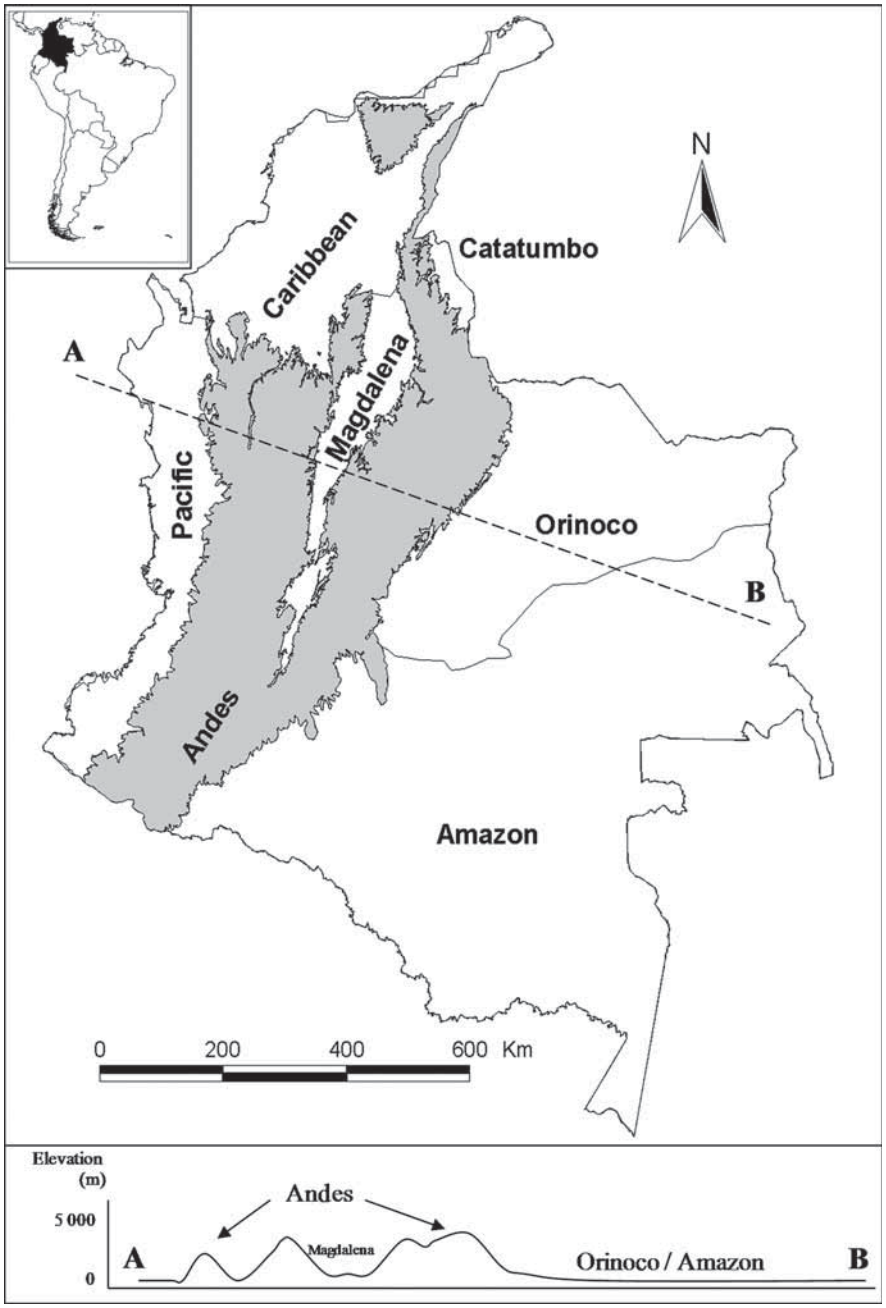

Figure 1. Location of Colombia showing the seven regions, and a schematic cross-section highlighting the Andean region.

steady increase in forest clearance for the cultivation of crops (Bray 1995). Nevertheless, land occupation did not always follow a steady increase in area and intensification, as some areas experienced population collapses with partial land abandonment, such as the disappearance of the Zenú "amphibian culture" around 650 BP. The Zenú culture developed sophisticated agricultural systems through the use of irrigation and raised field techniques, reaching estimated population densities of more than 1,000 inhabitants/km^2 (Plazas and Falchetti 1981). The estimates of the population size in Colombia at the arrival of the Spanish remains controversial (Denevan 1992; Melo 1998). Estimates vary between 1.5 million and more than 10 million; we used a total population estimate of 4 million people for 1500 (Melo 1998; see Table 1), which is probably on the conservative side. It is known that several areas of the Andes (such as the Sierra Nevada de Santa Marta, Sinú Valley, the Sabana de Bogotá, the Cauca Valley, and the Southern Highlands) had high population densities supported by more intensive forms of agriculture prior to colonization (Broadbent 1987; Bray 1995;

Table 1. Population by region for the dates marking the beginning and end of historical periods

Region	1500[a]	1600[a]	1800[b]	1850[b]	1920[b]	1970[b]	2000[c]
Andes	3,300,000	1,000,000	1,050,000	1,700,000	5,000,000	17,500,000	30,000,000
Caribbean	500,000	60,000	180,000	285,000	750,000	4,400,000	7,600,000
Rest of lowlands	200,000	200,000	130,000	150,000	250,000	1,105,000	2,700,000
Total	4,000,000	1,260,000	1,360,000	2,135,000	6,000,000	23,005,000	40,300,000
% Urban	0	2	15	22	31	61	75

[a] Melo (1998).
[b] Ocampo (1987).
[c] Departamento Administrativo Nacional de Estadistica (1993).

Melo 1998; Denevan 2001). Land use included different forms of agriculture (both intensive and extensive), fishing, and hunting. There is considerable archaeological evidence, as referred to in historical chronicles, for the existence of intensive agriculture, such as "raised fields" in swamp areas, supporting densely populated settlements, with some still functional at the arrival of the Spanish (Broadbent 1987; Denevan 2001). Shifting agriculture was also widespread, with fallows of varying rotation length, depending on fertility conditions and population pressure. However, Denevan (2001) argues that it must have been practiced by shortening of fallow periods and repeated clearing of young secondary forests with softer, easier to cut timber due to the technological limitations of stone axes. In regions with a strongly seasonal climates such as the Caribbean and the upper Magdalena, Cauca, and Chicamocha valleys, the use of fire was an important tool of landscape management (Tovar 1993a).

Conquest (1500–1600). The first part of the colonization process refers to the conquest of the territory. The major characteristic of this period was the rapid and substantial decline of the indigenous population, especially during the first fifty years of colonization (e.g., Denevan 1992; Melo 1998). Melo (1998) estimated the surviving indigenous population at the end of this period, based on tribute payment figures, to be around 1,260,000 people or 25 to 30 percent of the original population (Table 1). In Colombia, little is known about regional patterns of population decline apart from the fact that the impact was highest in the Caribbean lowlands (probably up to 90 percent decline), somewhat less in the Andes with an estimated 50 to 70 percent population decline, and a minor initial impact in less accessible regions such as the Amazon and Pacific. In Colombia this period was comparatively long due to the many independent power centers that had to be subdued. Although the initial motivation for colonization was the plundering and mining of gold and emeralds, this was increasingly paralleled by the gradual occupation and control of the indigenous lands. For this purpose the introduction of cattle, horses, and sheep was very important.

Colonial Period (1600–1800). In this period the population stabilized adjusting the demographic collapse of the conquest period (Table 1). To compensate for the decline of the indigenous communities, approximately 50,000 African slaves were brought to Colombia between 1580 and 1800, mainly to work in the gold mining industry (Ocampo 1987). The population experienced increased racial mixing, so that by 1800, 50 percent of the population was mixed race and this proportion was rising rapidly (Melo 1998; Figure 2). The cattle industry expanded rapidly into the Caribbean, Andean, and Orinoco regions (Table 2). Open range grazing was associated either with natural grasslands in savannas (Orinoco and Caribbean), or with seminatural grasslands and secondary regrowth of cleared drier vegetation (inter-Andean valleys and Caribbean). In the Andean highlands, cattle were part of a mixed land use associated with agricultural landscapes (Palacio 2001), where wheat joined maize and potatoes as an important crop. Land tenure was marked by ownership concentration of few families who owned extensivee *haciendas* (ranches), with smaller areas left as communal properties called *resguardos* (indigenous reserves) where the indigenous population was forced to concentrate, and which were linked to the haciendas. Haciendas usually occupied the more fertile lands, especially in the Andes (Fals-Borda 1982; Ocampo 1987; Melo 1998). There were also areas of smaller farms such as in parts of Antioquia, Nariño, and Santander (Ocampo 1987). Haciendas were mostly devoted to cattle, sugar cane, and cacao. Annual crops were preferentially produced in the resguardos and the smaller farms. Mining and

Table 2. Estimated size of cattle herd by region for the dates marking the beginning and end of historical periods

Region	1500	1600	1800	1850	1920	1970	2000
Andes	80 (?)	20,000	200,000	350,000	1,700,000	6,000,000	11,250,000
Caribbean		25,000	300,000	450,000	2,300,000	5,000,000	9,200,000
Amazon		—	—	—	10,000	250,000	1,100,000
Orinoco		5,000	100,000	100,000	900,000	3,200,000	5,400,000
Pacific		—	—	—	—	50,000	360,000
Total	1,000[a]	50,000[a]	600,000[a]	900,000[b]	4,900,000[b]	14,500,000[b]	27,000,000[b]

[a] Estimates based on Tovar (1992, 1993a, 1993b), Melo (1998), and Palacio (2001).
[b] Based on Ocampo (1987) and Palacio (2001).

commerce constituted the major economic activities. During the late 1700s, an "illustration period" began in Colombia with large expeditions such as the Real Expedición Botánica (1770–1800) and Humboldt's expeditions (1800–1810) conducted to survey Colombia's geography, and the biological and natural resources, also preparing for independence.

Independence (1800–1850). This period was predominantly marked by the political turmoil of the independence conflicts occurring between 1810 and 1820. While the economy slowed, the population grew to over 2 million by 1850 (Table 1) with mixed-race people becoming dominant (Figure 2). It also began a more liberal approach to the economy, and prepared the country for an export economy in the second half of the nineteenth century (Ocampo 1987). Also with independence, part of the public lands (*Baldíos*) slowly began to be handed over to peasants (Table 3). From a land use perspective, however, the area under grazing began to outgrow cropping and became a major source of land control and political power, and thereby a strong force shaping the landscapes.

Andean Recolonization (1850–1920). This period was characterized by an active reoccupation of the Andean slopes and parts of the lowlands, boosted by factors such as population growth, large investments in railway infrastructure, the internationalization of the economy demanding exports, and the increased opening of large areas of public lands (Table 3). The Antioquia Department had been quite isolated during colonial times, with mining the principal economic activity and low levels of agricultural development. However, after 1850, there was a strong increase in agricultural production stimulated by the international demand for products such as coffee and tobacco, and later bananas, and an increase in cattle production due to the introduction of wired fencing and African grasses (Ocampo 1987; Palacio 2001). This period is therefore also known as the *colonización Antioqueña*. Several internal conflicts of political origin, such as the Guerra de los Mil

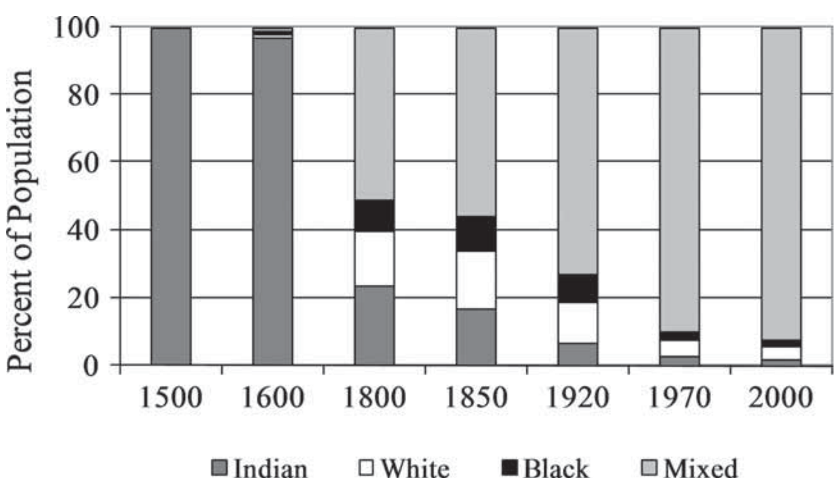

Figure 2. Changes in the racial composition of the Colombian population between 1500 and 2000.

Table 3. Baldíos (state lands) handed over to private owners for two historical periods by region

Region	Independence 1800–1850 (ha)	Antioqueño 1850–1920 (ha)
Andes	400,000	1,675,000
Caribbean	150,000	550,000
Amazon		90,000
Orinoco		420,000
Pacific		120,000
Total	550,000	2,700,000

Note: From Legrand (1988).

Dias at the turn of the century, heavily affected the economy. Nevertheless, during this period, the population continued to grow by a factor of three to reach 6 million people by 1920 (Table 1). The beginning was marked by an important event known as the Comisión Corográfica by Codazzi and Ancízar (1850–1860), a national mapping and surveying project that helped provide a better geographic understanding of the nation, its regions, and its resources, as there was no official mapping to guide land settlement and development. The economic development of Colombia during this period was marked by a liberalization trend, beginning with the presidency of Mosquera in 1845, which lasted several decades (Ocampo 1987). The United States exerted a growing economic and geopolitical influence during the 1800s, which led to the separation of Panama from Colombia and a growing foreign debt.

Early Twentieth Century (1920–1970). This period was marked by exponential population growth, technological changes in the agricultural sector such as increased mechanization and use of agrochemicals, rural–urban migration, recolonization of lowlands in Magdalena and Amazon, and the lack of export diversification with an increased dependence on coffee exports. Total population grew from 6 million to 20 million, and at the same time the proportion of urban population doubled from 30 to 60 percent (Table 1). During the early 1950s a political and social armed conflict also contributed to rural–urban migration trends. These factors all had important consequences for landscape change. Between 1925 and 1935, coffee plantations more than doubled to 360,000 ha (Ocampo 1987), with coffee accounting for more than 60 percent of exports. After 1930, oil also became an important export. Agriculture experienced growing technological change with mechanization and more productive agronomic techniques, including the use of fertilizers. There also were several largely unsuccessful attempts to carry out land reforms in the 1940s and 1960s to redistribute land, especially unfarmed or underused land, to poor and landless peasants.

Late Twentieth Century (from 1970). This period was marked by continued strong population growth, doubling in thirty years to over 40 million (Table 1). From 1970, several important factors changed the Colombian economy and therefore the human impacts on the biophysical landscape. First, there was the consolidation of the urbanization trend, which was further fueled by the increasing industrialization around the larger economic centers such as Bogotá, Medellín, Cali, and Barranquilla; urban population reached 75 percent. Second was a saturation of smallholder lands in the Andean region with a consequent increase in migration to lowland forest frontiers of the Amazon and lower Andes. Third, the development and steady growth of the illegal drug economy has progressively encroached on the agricultural frontiers. Fourth, an increased armed conflict was strengthened by the illegal economy. Fifth, parallel to these factors, a substantial change in policies toward the environment, such as the inception of the Colombian Natural Resources Code, the growth of the National Parks System, and the recognition of indigenous and African-American land rights occurred. The late 1980s saw a rapid increase in the allocation of public lands to the indigenous and African-American communities, especially in the Amazon, Pacific, and Orinoco regions. The National Parks System now covers more than 10 percent of the Colombian land area (Chaves and Arango 1998).

Data and Construction of Historical Land Cover Maps

The data used in this study included four main sources: contemporary maps, statistical data, historical synthesis books and maps, and firsthand transcribed chronicles (see Table 4 for a thematic summary). All data and information accessed were grouped according to the periods previously outlined. Where possible, data were cross-checked against at least two independent sources to minimize errors and bias.

A main aspect was to build spatial models to visualize and analyze the national and regional landscape change by comparing the patterns of land cover–land use maps for consecutive periods. Land cover–land use

Table 4. List of the data sources used in the production of the historical land use maps and their characterization

Theme	Sources	Units	Comments
Historical periods	Ocampo (1987), Zambrano and Bernard (1993), Bray (1995), Melo (1998), M. Herrera (2000), Palacio (2001)	Years	Criteria used: human population dynamics and trends, patterns of economic activity, changes in political and social institutions
Remnant ecosystems	Etter (1998), Etter, Fandino, and van Wyngaarden (1999)	Ecosystem type	Reclassified from sixty-four into twenty-one classes emphasizing forest ecosystems
Preclearing ecosystems	Instituto Geográfico Agustin Codazzi (1985), Etter (1998), Etter, Fandino, and van Wyngaarden (1999)	Ecosystem type	Explanation of method in text
Moisture availability index	International Water Management Institute	Continuous: Annual MAI	Resampled from 18 km to the 2 km grid, and smoothed with average on a 5 × 5 moving window
Population (total number, racial composition)	Ocampo (1987), Instituto Geográfico Agustin Codazzi (1992), Departamento Administrativo Nacional de Estadistica (1993), Tovar (1993a), Tovar, Tovar, and Tovar (1994), Melo (1998), Colmenares (1999), M. Herrera (2000), Instituto de Estudios Ambientales (2004)		Population data were extracted for the predefined historical periods, when possible by region
Land uses	Patiño (1977), Ocampo (1987), Bray (1995), Etter (1998), Melo (1998), M. Herrera (2000), Denevan (2001)	Categorical: Land use type	Six land uses defined
Economic activities	Ocampo (1987), Parsons (1996, 1997), Melo (1998), Ramos (1999), Palacio (2001)	—	Extracted resources, crops, exports
Social and political institutions	Fals-Borda (1982), Ocampo (1987), Legrand (1988), Chaves and Arango (1998), Melo (1998), Palacio (2001)	—	Includes land tenure, reserves, conservation areas
Elevation	Contour lines from the national topographic maps (Instituto Geográfico Agustin Codazzi, 2000)	M	
Distance to rivers	Instituto Geográfico Agustin Codazzi (2000)	Continuous: m	Resampled to the 2 km grid

Note: MAI = Moisture Availability Index (for calculation, refer to source).

maps were constructed for each period according to the procedure shown in Figure 3. The present-day map was derived from a simplified land use map based on the ecosystem map by Etter (1998). To capture and map the transformed areas for the remaining historical periods, we primarily used data and descriptions of location and size of population and settlements, cattle numbers, and types of agriculture. In this process, the transformed areas were spatially constrained using a reconstructed preclearing ecosystem map, the accessibility to rivers (and roads where applicable), elevation and slope, and a moisture availability index (Figure 3, Table 4). The generalized preclearing ecosystem map was constructed using a generalized version of the ecosystem map produced by Etter (1998). Ecosystems were grouped into nonforest including savanna, arid scrub, and Páramo vegetation; and six general forest types: dry tropical forest, subhumid lowland tropical forest, humid lowland tropical forest, and three (low, mid, and high belt) Andean forests. Ecosystems in the transformed areas were interpreted by combining the ecosystem map (Etter 1998) and the general agro-ecological map (Instituto Geográfico Agustin Codazzi 1985). We first cross-tabulated the ecosystem and agro-ecological map and established the major equivalences between both map codes, leaving out the small (<10 percent) coincidence values. Thereafter, we adapted the boundaries of the agro-ecological map within the transformed areas of the ecosystem map and assigned the equivalent generalized ecosystem map classification code. Each historical land

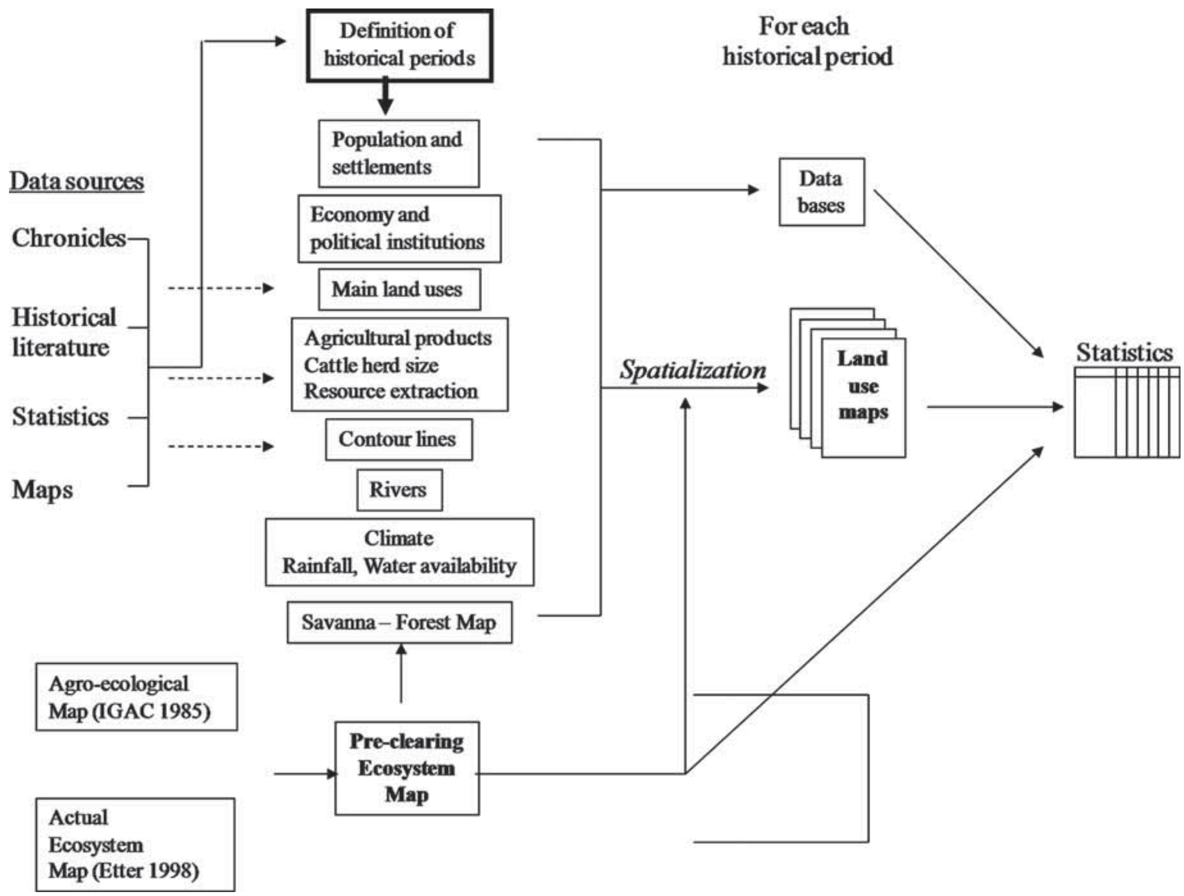

Figure 3. Schematic diagram showing the methodological sequence of input data, construction of historical maps, and generation of analytical outputs.

use–land cover map was then cross-tabulated with the preclearing ecosystem map to provide an overview of the impact on ecosystems for each period.

The land use–land cover maps were classified into the following seven land use classes:

- Natural landscapes (predominantly undisturbed)
- Extraction or burning in dry forests
- Nomadic hunting, gathering, or burning in savannas
- Shifting agriculture
- Permanent agriculture
- Grazing in cleared forest land
- Grazing in natural grasslands in savannas

Land Clearing Rates and Impacts on Ecosystems

We calculated the rates of deforestation for each forest type and historical period using the areas from the map cross-tabulations according to Puyravaud (2003). Because transformed landscapes always harbor a portion of remnant vegetation, we assumed that for the year 2000 in transformed landscapes 80 percent of the natural vegetation was cleared, with 20 percent remaining as scattered remnants. This figure was based on Etter, McAlpine, Pullar, and Possingham (2006), who found that the highly transformed forest landscapes in Colombia have between 10 and 20 percent of remnant natural forest ecosystems. However, according to descriptions in chronicles before the conquest and the introduction of cattle, the proportion of remnant vegetation was higher, with larger amounts of regrowth vegetation (fallow) present in the landscape. We assumed a value of 30 percent cleared in preconquest agricultural landscapes, increasing to 80 percent in 2000.

Results

Landscape Transformation Through the Historic Periods

A major shift in Colombian human–landscape interactions began with European contact in 1500, driven by

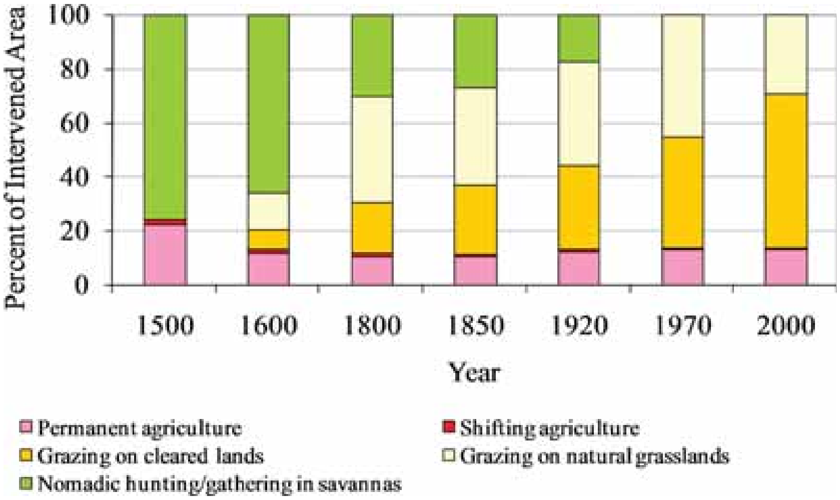

Figure 4. General changes in land use proportions in Colombia between 1500 and 2000.

major demographic, economic, and land use changes. The demographic impact consisted of three major processes (Table 1; Figure 2). The first was the collapse followed by a slow recovery of the indigenous human population in the period from 1500 to 1800. Second, centuries of racial and cultural mixing created a new racially and ethnically mixed population. Third, the introduction and the expansion of the cattle culture led to a gradual decrease in the proportion of land under crops and a corresponding growth in the area devoted to cattle grazing, to the extent that cattle now ranks as the dominant land use and driver of landscape change (Figure 4). The estimated overall annual rates of forest clearing rose from 0.02 percent in 1600 to 0.5 percent after 1970 (Table 5A). However, the spatial patterns of landscape change have varied according to the regions and main ecosystem types for the different historical periods (Figure 5), with the highest rates of forest clearing corresponding to Andean forests, especially since the 1800s (Table 5B).

These processes resulted in the initial contraction of the spatial footprint, followed by an expansion since 1800. Figure 6 shows an approximation of the agricultural spatial footprint of six land use categories for each period. The area of the agricultural spatial footprint in 1500 was approximately 7.5 Mha, dropping to 6.5 Mha in 1600, increasing to 12 Mha in 1850, and then exponentially increasing to 32.9 Mha in 2000 (Table 6). The main characteristics of land use and driving forces for each period on a regional basis are shown in the Appendix. Next we expand on the description and discussion of the spatial and temporal landscape transformation patterns for the seven historical periods.

Pre-Spanish Period (Before 1500). By 1500, all regions of Colombia already had some form of human occupation (Figure 6), although with varying population densities and land use types. The Andean and Caribbean regions were more densely settled, and the Orinoco, Amazon, and Pacific regions were less densely populated. The indigenous population of the Andean region was concentrated in the high plains of Bogotá and Cauca-Nariño, and the inter-Andean upper valleys of the rivers Magdalena and Cauca. Less populated were the Andean slopes, except for areas with rich volcanic soils located on the less steep slopes of the central Cordillera up to 2,400 m above sea level (L. F. Herrera, Drennan, and Piñeros 1989).

Our analysis estimates approximately 15 Mha used for agriculture in 1500, of which 7.5 Mha were effectively cleared (Table 6). The total agricultural area includes crops as well as fallow lands and remnants of natural vegetation located in the agricultural matrix. We speculate that the typical Andean and Caribbean agricultural landscape would have been between a variegated and fragmented state with 20 to 60 percent remnant native vegetation (McIntyre and Hobbs 1999). Agricultural land use was entirely devoted to crops (Figure 4), with the adjacent regrowth vegetation (fallow) and remnant areas also used for hunting and gathering natural products of forests and secondary vegetation. Bush meat was abundant according to chronicles, with wildlife probably favored by the heterogeneous mix of native vegetation, agricultural fields, and fallow areas (Patiño 1977). Historical chronicles also mention several forms of "semidomesticated" wildlife management using enclosures for animals such as deer

Table 5. Estimated annual rates of change of the transformed area of forest ecosystem types derived from Etter (1998) and the reconstructed potential ecosystem map

	1500–1600		1600–1800		1800–1850		1850–1920		1920–1970		1970–2000	
Ecosystem	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%
A												
Tropical dry forests	11,432	0.90	−693	−0.05	−5,024	−0.35	−4,206	−0.43	−5,670	−0.75	4,597	0.16
Tropical subhumid forests	1,540	0.14	−107	−0.01	−582	−0.06	−265	−0.03	−11,853	−2.16	−5,600	−2.67
Andean Forests	24,592	0.11	−4,326	−0.02	−19,910	−0.1	−25,888	−0.21	−40,742	−0.41	−171,189	−1.43
Tropical Humid Forests	9,756	0.02	−4,083	−0.01	−7,910	−0.01	−6,994	−0.03	−11,450	−0.03	−60,085	−0.14
Total	47,320	0.07	−9,210	−0.02	−33,427	−0.04	−39,753	−0.08	−69,716	−0.12	−232,277	−0.49
B												
Low Andean forests (<1,000 m)	7,364		−1,150		−5,779		−2,939		−11,174		−66,453	
Mid-Andean forests (1,000−2,000 m)	13,512		−2,346		−12,390		−12,014		−18,925		−55,520	
High Andean forests >2,000 m	3,716		−830		−1,741		−6,935		−10,643		−49,216	

(*Odocoileus virginianus*) and wild pigs (*Tajassu spp*.; Tovar 1993a). Fishing was an important source of protein, with fish especially abundant in lowland areas of Magdalena and Caribbean, but also in the Bogotá high plains (Patiño 1977; Tovar 1993a). Some of the landscapes were considered sacred such as the Páramos (high-altitude shrub and grassland vegetation), which were used for worship and rituals (Patiño 1977). The trade between tribal groups was very active (Tovar 1993a; Melo 1998), such as between the Muisca of

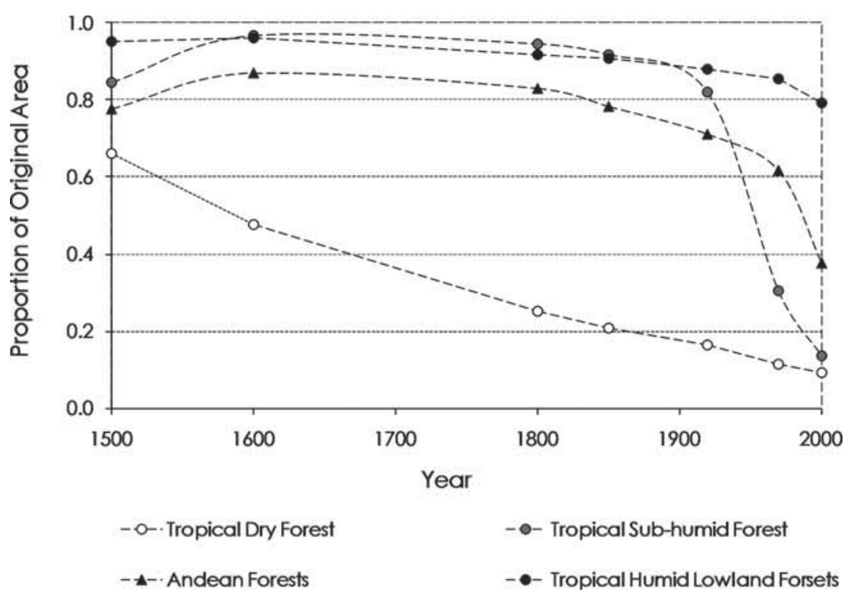

Figure 5. National aggregates of cover changes for general forest types between 1500 and 2000 in terms of proportion of original cover.

Table 6. Gross areas of total transformed land and estimated effectively cleared land for seven historical dates (measurement in hectares)

	1500	1600	1800	1850	1920	1970	2000
Transformed	15,400,000	13,000,000	17,500,000	20,200,000	24,200,000	28,900,000	41,390,000
Effectively cleared	7,500,000	6,500,000	10,500,000	12,150,000	17,000,000	23,100,000	33,000,000

the central Andean highlands and several groups in the lowlands of the Magdalena and Orinoco regions, or even the Malibú of the Caribbean (Reichel-Dolmatoff and Reichel-Dolmatoff 1977; Langebaek et al. 2000).

Although the agricultural technology was probably of low impact compared to present-day conditions, there is paleoecological evidence to suggest high-pressure levels of land use during pre-Spanish times, including erosion in the highlands around the Bogotá high plain and Andean slopes, and sedimentation in lowland areas such as the Magdalena Valley (Jungerius 1976) and the Patía Valley (Vélez et al. 2005).

Conquest (1500–1600). As a consequence of the demographic collapse and the abandonment of the land, many settled areas reverted to forest, especially in medium to high rainfall areas (Figure 5; Table 1). The area estimates derived from the constructed maps indicate that during this period the transformed area contracted by approximately 2.5 Mha (Table 6), with an estimated net annual forest regeneration of some 45,000 ha, occurring mainly on the slopes of the central Andean region and the humid and subhumid lowlands of the Caribbean (Figures 5 and 6; Table 5A). The rest of the landscapes would still have been predominantly of a variegated or fragmented type. Areas known to have been densely populated such as the Sierra Nevada de Santa Marta, the Upper Sinú and San Jorge rivers, Calima, and the Middle Magdalena Valley regenerated to dense forests decades after the conquest, as shown by archaeological and paleoecological records (Bray 1995; Denevan 2001). Some of these indigenous agricultural

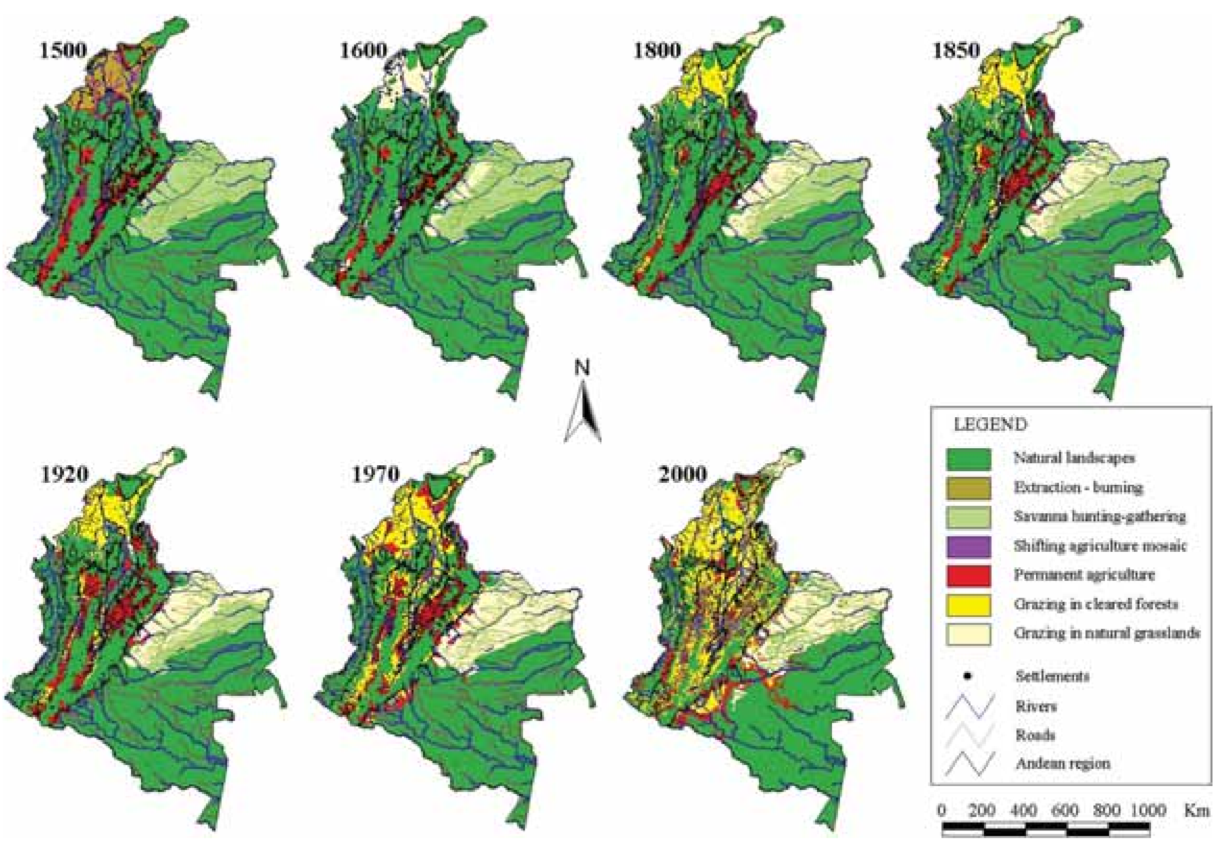

Figure 6. Historic land use maps of Colombia for the seven analyzed dates indicating the major land use types.

settlements in the Andes were uncovered by colonists in the Quindío and Risaralda districts in the late 1800s and early 1900s when they were recolonizing former agricultural lands that had been abandoned for centuries (Parsons 1997). Large areas of intensive agriculture such as the raised fields in the wetlands of the Bogotá Highlands were also abandoned and overgrown by forests for several hundred years after colonization (Broadbent 1987), although the population collapse was regionally less drastic and many surrounding areas remained settled.

Besides human depopulation, a major impact of the Spanish conquest on the environment was the introduction of grazing animals, especially cattle, sheep, and goats, which impacted on native vegetation, indigenous agricultural infrastructure and crops, and soil erosion. Initially, cattle were kept around settlements, but grazing of domestic stock expanded into the natural and seminatural grasslands of the Caribbean, Orinoco, and inter-Andean valleys where feral cattle populations became established and were later hunted (Figure 4).

Colonial Period (1600–1800). With the stabilization and the slow growth of the human population after 1600, the agricultural frontier slowly began to grow again. Forest clearing was concentrated mostly in the Andean region and some peripheral subhumid lowlands (Figures 5 and 6). We estimate the expansion of cleared land progressing at an average rate of 10,000 ha per year for this period (Table 5A). The cleared area reached some 17.5 Mha, with approximately one-third used for cattle grazing (Table 6). The impact of cattle increased steadily with the national herd reaching more than a half-million. By the end of this period, the landscapes slowly moved from a variegated state (>60 percent remnant native vegetation) to a more fragmented state (10–60 percent remnant native vegetation) especially on the more fertile soils of the highlands and the inter-Andean valleys. At the end of this period extraction of forest resources increased with the discovery of products such as quinine (*Cinchona officinalis*).

Independence Conflicts and the Forging of a New State (1800–1850). Landscape transformation paralleled the expansion of the cattle grazing industry, reaching an estimated total intervened area of 20 Mha (Figure 6; Table 6). We estimate that during this period more than 50 percent of the cleared land was devoted to grazing (Figures 4 and 6). According to the constructed maps (Figure 6), during the independence period more than 30,000 ha of forests were cleared annually (Table 5A), with approximately 20,000 ha occurring in the Andean region, especially the mid- and low-Andean altitude belts (Table 5B). Part of this clearing occurred on the released public lands or *baldíos* (empty lands; Table 3). Around the 1850s, the government continued to release public lands at an annual rate of greater than 20,000 ha to an expanding number of colonists willing to expand the agricultural frontier, mainly in the Andean region. However, according to Ocampo (1987), there were large additional areas colonized that remained outside state control.

Mining remained important up to 1840, especially in the Pacific region, contributing to more than 70 percent of exports, but its importance declined with the abolition of slavery in 1850 and the rise of other exports. Mining later shifted concentration to the Andes and was increasingly practiced by non-African miners (Ocampo 1987).

International Markets and the Neo-Andean Colonization Wave (1850–1920). We estimate the intervened area rose to over 24 Mha, and clearing of forests continued at an average rate of 50,000 ha per year (Figure 6; Table 5A) Our estimates indicate that more than 50 percent of the forest clearing occurred in the Andean region, especially in the 1,000 to 2,000 m belt (Table 5B). Due to the expansion of grazing, we speculate that at the end of this period, many Andean landscapes would already fall into McIntyre and Hobbs's category of fragmented landscapes, with less than 60 percent native vegetation remaining.

During this period, the cattle industry benefited from the introduction of exotic (mostly African) grasses, such as kikuyo (*Pennisetum clandestinum*) and puntero (*Hyparrhenia rufa*) among others. With fencing and improved pastures from more productive exotic grasses, the cattle industry began a rapid expansion with the herd size doubling to 2.1 M head between 1855 and 1875 (Table 2). Similarly, the area under grazing land use increased by approximately 60 percent during this historic period (Figures 4 and 6). However, the exotic grasses also invaded native grasslands and forests, with major, long-lasting effects for native biodiversity. The international markets also demanded natural products from the forests such as rubber (Amazon and Pacific), quinine (Andes), chiqui-chiqui palm fiber (Amazon), and plant ivory (Pacific), to mention a few. The extraction of quinine was particularly important between 1870 and 1890, when it accounted for up to 25 percent of exports. By the early 1900s, around 7,000 tons of plant ivory were exported annually from northwestern

Colombia to Europe, with the industry employing some 10,000 people in the collection of this product (Parsons 1996; see the Appendix).

Early Urbanization and Lowland Recolonization (1920–1970). The rapid population growth during this period accelerated the deforestation process, with clearing increasingly associated with a more spontaneous colonization process. The total transformed area reached 28 Mha by 1970. We estimate that over 2 Mha was cleared during this period in the Andean region alone (Figures 5 and 6), or approximately 7 percent of its original forest cover. The estimated national rate of clearing was around 70,000 ha per year (Table 5A), with 18,000 ha per year corresponding to the mid-Andean belt where coffee and other products continued to be grown (Table 5B). The clearing of lowland forests increased with large areas of subhumid and humid forests of the Caribbean that had regrown since the Spanish conquest, now being cleared at annual rates greater than 2 percent. The impact of the cattle industry continued to increase, with the herd size growing nearly threefold during this period and reaching 14.5 M head (Table 2). Of the 28 Mha of cleared land at the end of the period, we estimate that grazing accounted for more than 80 percent.

Industrialization and Metropolitization 1970–2000. The socioeconomic and policy changes that occurred during this period were paralleled by an increase in deforestation (Figure 5 and 6), at average annual rates in excess of 230,000 ha (Table 5A). The area of transformed landscapes exceeded 41 Mha, which was approximately 40 percent of the country (Table 6). The highest proportion of new clearing continued to occur in the Andean region, with 70 percent of the total national deforestation. However, there also was a shift to the lower Andean belt and to the humid lowlands of the Amazon and Pacific regions (Table 5B). Cattle grazing continued to expand at the expense of forests and cropping areas, accounting for almost 90 percent of all the cleared areas in 2000 (Figures 4 and 5). Natural savannas also were being transformed by replacement of introduced pastures and crops during this period (Figures 4 and 6).

During the 1990s, globalization impacted on the agricultural sector with smallholder agriculture declining as industrial agriculture such as oil palm and soybeans increased. The environment-friendly shaded coffee cultivation changed to high-input, intensive full-sun coffee cultivation. There also was a change in land tenure, with a trend toward concentration of lands in the control of fewer people, mainly due to drug barons investing in land. The area of exotic grasslands increased by approximately 50 percent, with *braquiaria* grass (*Brachiaria spp*), which was introduced in the early 1970s, dominating the pastures in the lowlands and lower Andean belt, paralleling the impact of kikuyo grass in the Andean highlands (above 1,500 m).

Historical Impacts on Ecosystems

According to our spatial models of landscape change (Figure 6), the total national rates of deforestation rose from an estimated 10,000 ha per year to more than 230,000 ha per year between 1500 and 2000. However, the historical trends of ecosystem transformation indicate some marked differences in the rates for the different ecosystems (Figure 5; Table 4). Dry forests show a continuous and steady decline; subhumid forests had an abrupt decline after 1900; and the humid lowland forests and Andean forests experienced a moderate decline between 1800 and 1950, and later a rapid decline from 1970.

Discussion and Conclusions

Overall, this study provides new insight into the environmental history of Colombia, which invites the formulation and testing of new hypotheses related to the impacts of human land use on ecosystems over a longer time frame. Binding a large amount of dispersed and disconnected socioeconomic and historical data to a spatial base enables the use of otherwise disconnected knowledge.

Synthesis and Drivers of Landscape Change

The present-day spatial footprint of human land use in Colombia is the cumulative result of historical processes spanning contrasting indigenous, colonial, and modern societies (Figure 6). After 1500, there was an initial contraction of this footprint, especially in the Caribbean and Andean regions, as a consequence of the demographic decline following the Spanish conquest (Bray 1995; Denevan 2001). However, after 1700, the spatial extent of the agricultural footprint began to increase steadily with population growth accelerating after 1900, resulting in the clearing of over one-third of the nation's forested landscapes. In this process, cattle grazing played a leading role in the way the footprint expanded, with cattle presently dominating over

75 percent of the transformed landscapes of Colombia. Therefore, the understanding of the processes and the impacts of the historical landscape transformation demands we first enhance our understanding of the ecological impacts of grazing on native species and ecosystems. Rifkin (1992) argues that Western culture and its historical impacts on the environment are heavily linked to the close and long-lasting relationship with cattle.

Although cattle raising has played a major and expanding role, there has been a succession of historical drivers over the last 500 years of Colombian history, with different land use drivers important at different times. During and after the Spanish conquest the decline of the indigenous population played a major role. From 1600 to 1850 the mining industry dominated the economy, with relatively little interest in expanding the agricultural frontier and limited capacity to do so. Cattle grazing mainly impacted the dry to subhumid ecosystems of the Caribbean and open savanna landscapes. Between 1850 and 1920, the opening of the economy to international markets stimulated the expansion of the agricultural frontier and the extraction of natural resources. The role of cattle also expanded after 1850 with the introduction of wired fencing and exotic grasses. From 1920 to 1970, population growth played an increasing role in land cover change. Since 1970 industrialization, urbanization, and globalization have increased the pressure to expand the agricultural frontier. The illegal drug economy began to trigger shifts in control of the land and land tenure with important consequences for land cover change within the expanding agricultural frontier and in more isolated areas.

Our results show large temporal differences in the extent and intensity the various types of forest ecosystems cleared for human land use. Some forest types have been cleared extensively and for a longer time. These include the tropical dry forests of the Caribbean and the inter-Andean valleys, and the belt of subhumid forest of the Caribbean. However, we show that large areas of the high Andean forest belt have also been heavily and constantly cleared over the last 400 years, with clearing accelerating to 1.4 percent per year during the second half of the twentieth century (Table 5A). These accelerating rates of landscape change in the Andes and more recently in other regions such as the Amazon are affecting the forest ecosystems remaining in Colombia, which are now less than 40 percent of their original extent. The tropical Andean and adjacent Amazonian ecosystems are recognized as major global biodiversity hotspots due to their high diversity, endemism, and threat levels (Myers et al. 2000; Orme et al. 2005).

Contemporary drivers of land cover change in Colombia are globalization, technological change, increased migration to urban centers, and the drug economy. This is making traditional peasant farming systems economically unsustainable due to labor shortage, cost of technology, and changing market demands. Therefore, in some ways, the recent trends in land use change in Colombia are not very different from those in other developing countries: high-input, intensified, highly mechanized cropping on the most suitable land, market oriented, and in the control of fewer land holders. Deforestation remains an important land cover change issue (Etter, McAlpine, Phinn, et al. 2006a; Etter, McAlpine, Wilson, et al. 2006), with large areas of economically less suitable agricultural lands increasingly being devoted to cattle grazing concentrated in large holdings, as areas of more marginal land are slowly being abandoned and left to revegetate, such as in the Chicamocha region (Cárdenas 2000).

Urbanization is also playing an increasingly important role, as the urban population continues to grow at the expense of the rural population. Around cities such as Bogotá, Medellín, and Cali, urban settlement is sprawling into the surrounding natural forest landscapes and the traditional peasant agriculture areas (A. Etter, personal observation), comparable to the urban sprawl processes described for the United States (e.g., Hammer et al. 2004).

Comparison with Other Studies

This study offers new insights with respect to previous studies such as Palacio (2001) and Etter and van Wyngaarden (2000). The maps we present have the advantage of: (1) addressing the processes of both deforestation and forest regrowth in a spatial and historical context; (2) using additional historical and biophysical contextual data to produce more detailed interpretation of historical land cover change; and (3) the interactive use of broad preclearing ecosystem type maps, settlement areas, distance to rivers (accessibility), and altitude to map historical land cover change. The inclusion of observations contained in chronicles and historical accounts helped to spatially constrain the mapping of the expansion and reduction of land use areas, resulting in more realistic maps. For instance, the clearing between 1970 and 2000 reported in Etter and van Wyngaarden (2000) was mainly concentrated in the Magdalena and Amazon regions. This work was limited due to gaps in settlement age data used in the interpolation process at that time. Our work also shows contemporary clearing in the lower Andean belts to be important.

However, as mentioned previously, our analysis was focused at the regional level, and ignored fine-grained effects of local topography, soils, and hydrology. A precise validation of historical maps was hampered by the lack of more accurate historical spatial data such as aerial photographs and satellite images, which are now readily available for monitoring contemporary landscape change. Despite this limitation, there are possible indirect approaches to validate and calibrate historical models of landscape change: assessing quantity of change irrespective of its location and assessing localized quality of change. The first involves comparing land cover change area estimates to data or estimates and trends from other land cover change studies similar in their context, or from demographic data and approximate figures of cleared land per person. For example, according to Houghton, Skole, and Lefkowitz (1991), the amount of pasture lands (nonnatural grasslands) in Latin America increased by a factor of 2.7 between 1850 and 1985, which is similar in order of magnitude to the increase of 2.9 we estimated for Colombia. For cropping lands, we estimated an increase of 2.26 (including fallow lands) and Houghton, Skole, and Lefkowitz (1991) estimated a similar value of 1.85 for crops and associated fallow lands. In all Latin America, between 25 and 30 percent of the original forest cover was lost between 1850 and 1985 (Houghton, Skole, and Lefkowitz 1991), whereas our estimates for Colombia are approximately 20 percent. Hence, our results are consistent with the general trends for Latin America.

The accuracy of our historical estimates of the extent and rate of land cover change are very difficult to validate, due to the lack of statistical land use data such as used by Ramankutty and Foley (1999), which would permit more precise mapping. Nevertheless, the aim of our study was to establish general trends in patterns and rates of landscape change, and identify major land use shifts to assess the historically most affected ecosystems. The spatial resolution used in our analysis provides a national and regional overview, but is too coarse to address local-level (100s km^2) patterns of landscape change. This will require spatially detailed studies of patterns of landscape change for individual regions that take into account the interaction of historical settlement patterns, cadastral data, soils, climate, and topography. However, with our results, it is possible to identify the historic land use effects on one or more ecosystem types. Based on our results, a map indicating areas with different lengths of occupation can be produced (e.g., areas subject to 500, 200, and thirty years of occupation). The effects of the differential occupation length could be tested, choosing biophysically comparable areas that show different length of occupation, and comparing the overall structure and composition attributes of natural ecosystems.

The spatial ecological footprint of human land use extends beyond strictly cleared land and should include different states of ecosystem degradation, such as those resulting from overgrazing or logging. The definition of degradation depends on the baseline condition of preclearing ecosystems. A study of relatively intact eucalyptus forests of the Southern Tablelands in New South Wales (Australia) concluded that erosion scars in present-day landscapes are not all a result of European settlement, but also resulted from previous indigenous fire disturbances that were mentioned in explorer and early settler descriptions (Butzer and Helgren 2005). The authors conclude that in the relatively intact forests occurring on marginal lands historically used for extensive grazing only small changes in the structure of forests were evident. By contrast, in Queensland (Australia; Seabrook, McAlpine, and Fensham 2006) and in the northwest United States (Black et al. 1998), the clearing of the natural ecosystems has been extensive with only low proportions of native ecosystems remaining. In Colombia little is still known about ecosystem transformation beyond land clearing, such as the impact of grazing in savanna and high Andean nonforested ecosystems.

The progression and importance of cattle as a driver of historical landscape change in Colombia is associated with the introduction and spread of exotic grasses, such as kikuyo above 1,500 m in the Andean region, and braquiaria in the humid areas below 1,500 m. These exotic grasses cover at present most of the cleared forest areas now under grazing in the subhumid to humid areas, producing important impacts on the native biodiversity and ecosystem integrity.

Approach and Limitations

Environmental history and historical ecology are promising fields for the study of long-term land cover change. A landscape-ecological and geographic perspective provides a much needed spatial and interdisciplinary perspective to historical studies. However, they must still deal with the limitations imposed by dissimilar historical data sources with different spatial and temporal resolutions and extents, and uneven levels of certainty. The data available for this study do not permit a spatially detailed land cover change analysis at the scale of individual landscapes (10,000s ha). However, our approach permits us to visualize the broad patterns of Colombian land cover change in a spatially explicit manner over a time frame of several centuries. It highlights the magnitude of landscape transformation and its broad impacts on ecosystems. An important consequence of landscape change that our study did not address is the cumulative effects of centuries of human land use on native biodiversity and ecosystem integrity. This will require more detailed studies for the more dynamic regions affected by historical landscape change, with special emphasis in their specific socioeconomic drivers.

Conservation Planning Implications

Colombia parallels many other countries in the increasing evidence of substantial and growing impact of humans on the global ecosystem (Foley et al. 2005). Importantly, however, we need to recognize that the state of ecosystems is a legacy of past land use. Expanding human pressure on the natural ecosystems of Colombia is at present not geographically uniform, but rather is concentrated in certain regions such as the Andean ranges and the western Amazon Basin in Colombia. Historically the patterns have varied as we show with the constructed maps, an aspect that should be taken into account in conservation planning. Also, in recent years, deforestation is occurring at faster speed and on larger spatial scales as a result of mechanized technology and demographic pressures. These regions are priority global biodiversity hotspots (Orme et al. 2005). Nevertheless, because of the temporal variation in land cover change pressures, the impact on different ecosystems varies and has also historically varied in space and time, with different effects due to the time lags involved. Regions with longer and more intense disturbance regimes such as the Andes should show stronger and larger impacts on native ecosystems and species. Empirical studies that help tie time since clearing or isolation with ecosystem condition are needed to feed the conservation planning process. Foster (2002) points to the importance of historical land use in determining the abundance and distribution of species in the New England landscape, indicating that modern landscapes are strongly conditioned by the history of human land use. A better understanding of the impacts of ecosystem transformation, therefore, needs to rely on a spatially explicit historical perspective of land uses and changes in land cover. Ecological history provides, through the long-term historic mapping of human disturbance regimes and intensities, important additional information useful for conservation planning. Good maps of historic land use can help improve the inclusion of the temporal dimension in conservation planning.

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Appendix. Major economic activities by historic period

Region	Pre-Spanish <1500	Conquest 1500–1600	Colonial 1600–1800	Independence 1800–1850	Antioqueño colonization 1850–1920	Early twentieth century 1920–1970	Late twentieth century 1970–2000
Andes	Intensive raised fields and shifting agriculture	Intensive and shifting agriculture	Mining, intensive agriculture, grazing, quinine	Intensive agriculture, sugar cane, grazing, quinine extraction	Coffee, sugar cane, mining	Coffee, sugar cane, coal mining	Coffee, flowers, dairy farming
Caribbean	Shifting, and localized intensive agriculture, fishing	Shifting agriculture, grazing, fishing	Grazing and shifting agriculture	Grazing and shifting agriculture	Grazing and shifting agriculture	Grazing	Grazing, industrial mining (coal, nickel), agriculture (cotton, rice)
Amazon	Localized intensive agriculture in black-earth areas, shifting agriculture, fishing	Localized intensive agriculture in black-earth areas, shifting agriculture, fishing	Localized intensive agriculture in black-earth areas, shifting agriculture, fishing	Shifting agriculture, fishing	Shifting agriculture, fishing and rubber	Rubber, palm fibers, shifting agriculture, commercial fishing	Cattle grazing and illegal crops, timber, gold mining, commercial fishing
Pacific	Shifting agriculture, fishing	Mining, shifting agriculture, fishing	Mining, shifting agriculture, fishing	Mining, shifting agriculture, fishing	Shifting agriculture, fishing, plant ivory (7,000 tons/year), reduced mining	Timber, mining, shifting agriculture, fishing, industrial mining	Timber, shifting agriculture, aquaculture, oil palm
Orinoco	Hunting/gathering with localized permanent and shifting agriculture, fishing	Hunting/gathering with localized permanent and shifting agriculture, fishing; first cattle in savannas of Andean foothills	Grazing expanding east into savannas, hunt-ing/gathering with localized permanent and shifting agriculture, fishing	Grazing, shifting agriculture, fishing	Increased grazing, shifting agriculture, fishing	Consolidated cattle grazing with intensification trends; colonist agriculture in forest areas along rivers	Intensified grazing with pasture planting, agriculture (irrigated rice, cotton, oil palm), oil fields
Magdalena	Shifting agriculture, fishing	Shifting agriculture, fishing, mining	Grazing	Grazing	Intensive agriculture (tobacco), grazing	Oil fields, intensive agriculture, grazing	Grazing, intensive agriculture (soya, oil palm), oil fields
Catatumbo	Shifting agriculture	Shifting agriculture	Shifting agriculture	Shifting agriculture	Shifting agriculture	Shifting agriculture, oil fields	Cattle grazing and illegal crops, timber