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Colombia and the prospect of peace:

Is there hope for a slowdown of deforestation in the foothills of the Amazon? An analysis of deforestation patterns and potential preventive measures

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CIAT	International Centre for Tropical Agriculture
CIFOR	Center for International Forestry Research
DANE	Departamento Administrativo Nacional de Estadística
DIRAN	Dirección de Antinarcóticos
DNP	Departamento Nacional de Planeación
EPI	Environmental Performance Index
FAO	Food and Agricultural Organization of the United Nations
FARC	Fuerzas Armadas Revolucionarias de Colombia
FRA	Global Forest Resources Assessment
GFW	Global Forest Watch
GHG	Greenhouse Gas
GIS	Geographical Information Systems
Guidos	Graphical User Interface for the Description of image Objects and their Shapes
IAvH	Instituto de Investigación de Recursos Biológicos Alexander von Humboldt
IDEAM	Instituto de Hidrología, Meteorología y Estudios Ambientales
IPCC	Intergovernmental Panel on Climate Change
LUCC	Land use and land cover changes
MinAmbiente	Ministerio de Ambiente y Desarollo Sostenible
MinMinas	Ministerio de Minas y Energía
MSPA	Morphological Spatial Pattern Analysis
PNN	Parques Nacionales Naturales
PNNAFIW	Parque Nacional Natural Alto Fragua Indi Wasi
PNNSC	Parque Nacional Natural Serranía de los Churumbelos

REDD+	Reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries
RFPCARM	Reserva Forestal Protectora de la Cuenca Alta del Río Mocoa
RS	Remote sensing
SDMT	Species Distribution Modelling Tools
SIMEC	Sistema de Información Minero Energético Colombiano
Simci	Sistema Integrado de Monitoreo de Cultivos Ilícitos
SINAP	Sistema Nacional de Áreas Protegidas
SINCHI	Instituto Amazónico de Investigaciones Científicas
WRI	World Resources Institute

1 Introduction

Being located in the transition zone between the two major ecosystems of the Andes and the Amazon, Colombia's southern Andean-Amazonian foothills comprise unique biological, eco-systemic and cultural values. This ecological corridor plays a significant role in hosting a diverse range of plant and animal species that are partly endemic to the region (Rico Baez and CI Colombia, 2015, p.7; Etter et al., 2006a, p.241). It is an important element of the hydrological system of the Amazon, as rivers originating in the Colombian foothills feed into the Amazon drainage basin (McClain and Naiman, 2008). In fact, the area is far from being completely understood and researched by the scientific community. And yet, this ecological treasure is at the risk of profound and possibly irreversible damage: the Andean-Amazonian foothills are among the most pressing deforestation hotspots in Colombia with alarming annual rates of forest removal (IDEAM, 2015c, p.63).

The accelerated landscape transformation in the region visualizes the conflictive history that has been coined by a nearly uncontrolled exploitation of its wealth of natural resources. The presence of petroleum, minerals of different kinds, precious woods and large unoccupied forested areas not only imply a strategic importance for the Colombian state and a business opportunity for companies of the extractive industry. It has also contributed to the fact that the Andean-Amazonian foothills have historically been one of the regions in Colombia with the persistent presence of armed combative groups, outbursts of violence, migration waves and a highly dynamic and productive system regarding the cultivation of coca and drug trafficking (Ávila, 2014, p.5; Vargas Valencia, 2013, pp.58–59; Observatorio del Programa Presidencial de DH y DIH, 2014, p.1). Forests have been an inseparable element in the course of this conflict: as a potential space for the cultivation of illicit crops that represent a major source of income for the guerrilla, as a place of retreat for armed actors and as life-sustaining space for expelled communities and settlers in search of new land for subsistence (Walsh et al., 2008, p.67; Álvarez, 2003, p.57).

With the ongoing peace negotiations between the Colombian government and the FARC, the country is now heading towards a historical moment. The post conflict scenario implies not only the challenging reconciliation between parties and the establishment of social peace after more than six decades of armed conflict, but it also entails the territorial reorganization of areas that have been subject to war and abandonment by the state. For the Andean-Amazonian foothills, the peace agreement could imply the stimulation of a local economy that favors alternative and more sustainable production systems while preserving the forests (cf. Aguilar et al., 2015, p.4). However, a peace agreement could also bring about the risk of relentless exploitation of the remaining natural resources if there is no strict regulation on land use put into place, as it has been the case before in various countries after they had achieved the settlement of long-time internal conflicts (SINUC, 2014, p.1).

There is a growing consciousness on the political level for deforestation as a pressing problem that needs to be addressed. In fact, the Colombian government has expressed the intention of decreasing deforestation and achieving zero net deforestation of the Colombian Amazon by 2020 (MinAmbiente, 2015). However, research on deforestation in Colombia and particularly regarding the Colombian Andean-Amazonian foothills is still incipient in comparison to other Latin American countries. The first official report that quantifies deforestation in Colombia on an annual basis is available from 2013 onwards (MinAmbiente, 2014). For an adequate territorial reorganization in the post conflict that guarantees the incorporation of local stakeholders and particular on-site conditions, a targeted analysis of the situation at the local level is required.

This thesis represents an interdisciplinary approach for assessing the impact, the spatial distribution and the causes of deforestation in the southern Andean-Amazonian foothills of the department Putumayo near the border of Colombia with Ecuador. The analysis is based on data of the Global Forest Watch project which covers the period from 2001 to 2014. It is complemented with 25 semi-structured interviews that have been realized with locally and regionally engaged stakeholders. Based on the analysis of the spatial evolution of deforestation patterns and the explanation of the direct and indirect drivers of the phenomenon, the thesis suggests measures in order to slow-down deforestation rates in a post conflict scenario.

1.1 Deforestation: causes and consequences

The FAO (2012, p.5) defines deforestation as the conversion of forested land to other types of land use or the permanent reduction of the tree canopy cover below a 10 percent threshold. As such, deforestation represents a type of land use and land cover change (LUCC) that is often rooted in a combination of “underlying” and “proximate” causes or drivers (Lambin and Geist, 2007). Underlying or indirect causes often operate more diffusely and describe more complex regional or even global factors that ultimately influence LUCC locally, such as commodity markets, new technologies or international policies (Lambin and Geist, 2007; cf. Etter et al., 2006). Proximate or direct causes tend to explain direct influences of human activities on the local level (Lambin and Geist, 2007). The most common proximate deforestation drivers include agricultural expansion both for subsistence and commercial purposes, urban expansion, the harvest of timber for fire wood and the production of derived commercial products, infrastructure and mining (Keenan et al., 2015, pp.13–14; d'Annunzi et al., 2015, p.124; Hosonuma et al., 2012, p.3). A number of studies stress that agricultural expansion for cropland and pastures is by far the most important direct deforestation driver, particularly in tropical regions where agricultural expansion causes more than 70 % of deforestation (d'Annunzio et al., 2015, p.124; Nepstad et al.. 2008, p.1739). Besides human-induced causes, deforestation may also have natural causes, such as droughts, fires, storms and pathogens (Keenan et al., 2015, pp.13–14).

Deforestation represents a major global concern as forests play a key role in the maintenance of the ecological balance and the provision of fundamental human needs. Ecosystem services provided by undisturbed natural forests include carbon sequestration, the maintenance of biodiversity in terms of flora and fauna, the conservation of water resources and water quality, the maintenance of the water cycle and atmospheric circulation particularly in the case of tropical forests, the prevention of soil erosion and landslides, the reduction of downstream sedimentation and the provision of recreational, cultural or spiritual spaces and livelihood for local communities (Miura et al., 2015, p.36; FAO, 2015a; Nepstad et al., 2008, p.1737). The conversion of forest land puts these ecosystem services at risk. According to the IPCC, deforestation causes emissions of CO_2 into the atmosphere and an increase of the surface albedo, both of which contribute to the warming of the earth's atmosphere (cf. IPCC, 2007). Despite the fact that global forest cover loss has slowed down by approximately 50 % between 1990 and 2015, deforestation still represents a major threat for biodiversity as most of it occurs in areas with particularly high degrees of biodiversity and endemic species (Morales-Hidalgo et al., 2015, p.69). Furthermore, the eradication of forest cover may contribute to desertification and salinization of soils and increases the risk of erosion (Miura et al., 2015, p.36). Deforestation also implies a threat for the livelihoods of local communities, as it may cause reduced water quality, diminishing water bodies and the destruction of spaces with high cultural, spiritual and recreational values for local communities (cf. Miura et al., 2015).

1.2 Deforestation in Colombia

Regular national forest cover assessments for Colombia are mainly conducted by the IDEAM (Instituto de Hidrología, Meteorología y Estudios Ambientales) and the IAvH (Instituto de Investigación de Recursos Biológicos Alexander von Humboldt).[1] Furthermore, the FAO uses and adjusts IDEAM data for the use of its own standardised international forest assessment (FAO, 2013; Sánchez-Cuervo et al., 2012, p.3). Until 2010, forest cover assessments were provided every five years. The IDEAM recommended using a constant annualized deforestation rate for 1990 to 2010, but in the context of Colombia's membership in the REDD+ readiness program, the institute moved to bi-annual forest cover reports in 2012 (REDD desk, 2015).

In 2015, 52.7 % of Colombia's land area was covered by forests (FAO, 2015b, p.4). According to the IDEAM (2015c, p.57), in 2013 67.2 % of the country's forests were located in the Amazon, followed by 17.2 % in the Andean region, 8.9 % in the Pacific region, 3.7 % in the Orinoquía and 3 % in the Caribbean. Given its historical relevance as the economic centre of the country, the Andean region has experienced high deforestation rates throughout the past centuries and is still undergoing a systematic transition following a pattern of croplands, pastures and secondary vegetation replacing one another (cf. Rodríguez Eraso et al., 2013; Etter et al., 2006, p.375). However, current deforestation hotspots mainly concern the western part of the Colombian Amazon, several areas close to the Pacific and several areas in the central north of the country (IDEAM, 2015c, pp.63–64). According to the Colombian ministry of the environment and sustainable development (MinAmbiente) and the IDEAM, the average annual deforestation rate between 1990 and 2010 amounted to 310,349 ha, implying that 5.4 % of the country's territory was affected by deforestation within that period (MinAmbiente, 2016).[2] For 2013 and 2014, the IDEAM estimates that 120,934 ha and 140,356 ha were deforested in these years, representing an increase by 16 % between

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[1] Their products are regional and national thematic maps based on Landsat and MODIS sensors without ground-based forest inventory information (Sánchez-Cuervo et al., 2012, p.3).

[2] Note that an average rate is suggested by the MinAmbiente and IDEAM as forest cover assessments were done for the periods from 1990 to 2000, from 2000 to 2005 and from 2005 to 2010. Hence, potential peaks and annual fluctuations of deforestation cannot be explained with these data sets.

these years (IDEAM, 2015a). 45 % and 24 % of the overall national deforestation occurred in the Amazon and the Andean region respectively (IDEAM, 2015a).

The Colombian government has declared that it aims at decreasing deforestation and achieving zero net deforestation of the Amazon by 2020 (MinAmbiente, 2015). Its two main objectives are tackling direct causes and creating incentives for local communities in order to protect and use forests sustainably, as well as improving the governance and the capacities of the responsible authorities (MinAmbiente, 2015). The respective measures will be financially supported by the means of result-based payments by a partnership of Norway, Germany and Great Britain (MinAmbiente, 2015; KfW and GIZ, 2015).

1.3 Deforestation in the Andean-Amazonian foothills

In terms of LUCC analysis of the Amazon, deforestation in the Brazilian Amazon has been the main research target, particularly since the international community has started to regard the Brazilian "Arc of Deforestation" as a matter of international concern in the context of current global challenges such as biodiversity loss and climate change (Fearnside, 2007; cf. Durieuxet al., 2003). Research on deforestation in the Colombian Amazon in general and the Andean-Amazonian foothills in particular is comparatively scarce and incipient.

Armenteras et al. (2006, pp.354–355) stress that ecosystem diversity and deforestation patterns in the Colombian Amazon are "totally different" from the one reported for Ecuador or Brazil and that a deeper understanding of the human dimension in the deforestation of the Colombian Amazon is much needed. Sierra (2000, p.6) analyzed deforestation patterns in the Napo region of the Western Amazon belonging to Colombia, Peru and Ecuador and found evidence that deforestation between 1986 and 1996 was relatively concentrated near the Andean foothills in Putumayo on the Colombian side of the study area, and that it advanced faster than in the Ecuadorian sector. Armenteras et al. (2006, p.359) found that out of five pilot study areas in the Colombian Amazon, the Alto-Putumayo region near the Andes experienced the highest annual rate of natural ecosystem loss (3.73 %) between 1985 and 2000.

In more recent official reports, the two neighboring departments in which the Andean-Amazonian foothills are mainly located accounted for the highest deforestation rates in the country: Caquetá and Putumayo ranked 1st and 4th in terms of deforestation rates at the departmental level with 20.84 % and 7.91 % of national deforestation respectively in 2014 (IDEAM, 2015a). In the second half of 2014, Putumayo was the department with the highest number of early deforestation alerts, especially due to high deforestation rates in the municipalities Puerto Guzmán and Puerto Asís in the surroundings of the rivers Mandur and Putumayo (IDEAM, 2015c, p.63 and 65). Against this background, the Andean-Amazonian foothills in the department Putumayo have been identified as one out of eight major deforestation hotspots in Colombia (IDEAM, 2015c, p.63).

1.4 The role of protected areas

The concept of protected areas was defined by the Colombian legislation with the law 165 in 1994, when the country ratified the UN Convention on Biological Diversity (Aldana and Mitchley, 2013, p.16).[3] Since then, numerous protected areas were created with lacking specific standards or criteria and so these areas were left out of legal protections schemes, mostly due to shortcomings in legislation and incorrect use of recognized protection categories (Ponce de Leon and IAvH, 2005, p.129). This problem was targeted with the decree 2372 in 2010, which regiments the consolidating role of the National System of Protected Areas (SINAP) and the legal categories of protected areas in Colombia (Decreto 2372 de 2010). Since then, protected areas can be managed in three ways: publically, either at the national level by the MinAmbiente or at the regional level by regional environmental agencies; and by private landowners (Aldana and Mitchley, 2013, p.17). There are six sub-categories for publically managed protected areas.[4] However the only category that implies full and unlimited protection is the National Natural Park System Areas category (PNN) (Aldana and Mitchley, 2013, p.17). The Colombian constitution states that the subsoil is state property and thus, any piece of land for which oil deposits or other subsoil minerals have been proven is subject to a governmental decision regarding exploitation on behalf of the state or

[3] The Colombian legislation adopted the following definition: “Área definida geográficamente designada o regulada y administrada a fin de alcanzar objetivos específicos de conservación”. The definition is equal to the one in the Convention on Biological Diversity (Gasca Álvarez and Torres Rodríguez, 2013, p.35; Aldana and Mitchley, 2013, p.16).
[4] The decree 2372 lists the following sub-categories: las del Sistema de Parques Nacionales Naturales, las Reservas Forestales Protectoras, los Parques Naturales Regionales, los Distritos de Manejo Integrado, los Distritos de Conservación de Suelos, las Areas de Recreación (Decreto 2372 de 2010).

private entities, with PNN as the only perpetual exception to this procedure (Aldana and Mitchley, 2013, p.17).

As a number of protected areas have been a continuous subject to human interventions of various types and the institutional capacity for supervising these areas has been deficient in numerous cases in the country, some authors have come to the conclusion that the actual effectiveness of protected areas has been insufficient (Daniel Nepstad et al., 2013, p.22; Aldana and Mitchley, 2013, p.23). However, Dávalos et al. (2011, p.1225) have found evidence that protected areas have decreased the risk of forest conversion in Colombia even in non-remote regions and suggest that protected areas should be extended and integrated into schemes that support the development and livelihoods of existing local communities.

Effective conservation of biodiversity is of particular importance in Colombia as it has been identified as one of the mega-diverse countries in the world that hosts more than 10 % of the earth's plant and animal species (Convention on Biological Diversity, [no date]). A large proportion of the country's richest areas in terms of biodiversity and endemic species is hosted by the Andean ecosystems and the Amazonian rainforests (Convention on Biological Diversity, [no date]). The Andean-Amazonian foothills represent an important ecological corridor that connects these two highly diverse ecosystems and are acknowledged for an exceptionally high diversity of species and endemism (Rico Baez and CI Colombia, 2015, p.7; Etter et al., 2006a, p.241). According to the WWF (2014, p.2), 85 % of the surface of the Andean-Amazonian foothills are covered with natural vegetation hosting 977 bird species, 254 mammal species, 101 reptile species and 105 amphibian species. It is worth mentioning that there is a consensus among authors and corresponding environmental institutions on lacking quantitative and qualitative assessments of the biodiversity richness in the region, which implies that the actual impact of landscape transformation on biodiversity loss remains unknown (cf. IDEAM, 2015b, p.63; Martínez, 2007, pp.22–23; cf. Armenteras et al., 2006, p.354). There are several categories of protected areas in the Andean-Amazonian foothills of the departments Putumayo, Cauca and Caquetá, the most important ones in terms of coverage being PNN and forest reserves (cf. Rico Baez and CI Colombia, 2015, p.5). Conservationists and environmental NGOs emphasize the need for more effective conservation regarding endangered plant and animal species and the threatened habitats for ancestral local communities (Rico Baez and CI Colombia, 2015, p.9; cf. WWF, 2014).

1.5 The role of natural resources in the context of colonization and land use change

Colombia is very rich in natural resources and has experienced several booms of different export-driven commodities throughout the past century, such as petroleum and coal, and studies found evidence for patterns of the so-called Dutch disease[5] in the economy (Campo R. and Sanabria P., 2013, p.18). Regarding the Andean-Amazonian foothills, authors have identified a series of booms of various commodities and important natural resource uses in recent history that have driven migration in the region and stimulated the development of road infrastructure and social services and thus, the transformation of forested land.

Whereas the Southern Andean-Amazonian foothills of today's departments Putumayo and Caquetá remained practically untouched until the late 19th century, the extraction of quinine and rubber during the so-called rubber boom, the "fiebre del caucho", brought about the first non-indigenous colonization of the territory by the early 20th century (Brücher, 1970, p.100). The inflow of migration in the region increased steadily since then and was mainly driven by the poverty of subsistence farmers and the dissolution of indigenous reserves in the Andean regions of the department Nariño (Ramírez M., 2010, p.54; Brücher, 1970, p.104), but also by the conflict with Peru in the 1930s (Fajardo et al., 2012, p.21). However, immigration augmented sharply when the exploitation of one of the country's most important oil deposits was initiated in the department Putumayo in Puerto Asís in 1963 (Brücher, 1970, p.104). The extraction of petroleum incentivized colonization in the region for an additional reason besides the fact that it offered work opportunities: as it triggered road infrastructure, remote and formerly inaccessible areas became subject to settlements of subsistence farmers and small but quickly growing villages (Domínguez, 1999, pp.42–43). When oil companies started to pay taxes to municipalities in 1969, this stimulated urbanization, territorial reorganization and the establishment of the service sector in urbanized areas (Domínguez, 1999, pp.43–44). By

[5] The Dutch disease or the natural resource curse refers to a paradox according to which countries that are rich in natural resources experience high exportation rates of these resources but stagnation or recession in other economic sectors and thus, slower growth than other countries with less natural resources (Campo R. and Sanabria P., 2013, p.18).

1975, the extraction of crude oil in the nearby oil fields of Orito alone represented 27 % of Colombia's oil production at that time and state policies strongly supported the establishment of the industry in the department Putumayo (Ramírez M., 2010, p.49). In the following years, both the volume of oil extraction and the size of newly discovered oil deposits have decreased overall in the departments Putumayo and Caquetá, but national and multinational oil companies have remained in the region and continue with explorative assessments of oil deposits (Ramírez M., 2010, p.49). Also, the infrastructure of oil pipelines was extended by the state company Ecopetrol and several US and Canadian companies between 2003 and 2008 by creating a net of pipelines in the lower Bota Caucana and the center and southern Putumayo that merges in Orito for storage and transport towards the Pacific (Ramírez M., 2010, p.49). Between 2009 and 2012, the sector experienced a new upswing as oil production increased by 61 % within this period, making Putumayo the 6th largest oil producing department of the country (Ávila, 2014, p.52). Ramírez (2010, p.69) has detected numerous hazardous environmental effects of the exploitation of petroleum in the oil fields of Orito, such as spills of contaminated waste material of oil fields, inadequate disposal of toxic waste, deforestation and fragmentation of tropical forests, alteration of water sources, contamination of precipitative surface water that flows into nearby rivers and adverse effects on land and water species.

Another important boom in the region that has had strong impacts both on the social and the environmental level is the cultivation of illicit crops, mainly coca and marihuana. It initiated towards the end of the 1970s and followed the decline in the production of petroleum, failed state policies for managing uncontrolled colonization processes and a semi-permanent state of crisis of the agricultural sector (Ramírez M., 2010, pp.54–55; Walsh et al., 2008, p.28). Domínguez (1999, pp.48–49) states that the cultivation of coca represented a "maná salvador", the salvation for thousands of settlers that had lived in misery for several decades and suffered from low returns of their land, low prices for their products and thus, poor livelihood. The extraordinarily high prices along the value chain of coca production represented a profitable working opportunity that led to a high population inflow into the region and had strong effects on the rest of the regional economy: as the income of the involved actors along the value chain increased, prices for services and gasoline increased accordingly. Legal agriculture was basically driven out of some areas as its yields were unable to compete with the high revenues generated by the coca crop (Domínguez, 1999, p.49). The Colombian government started with massive aerial fumigations of Coca plantations in 1996, a measure that later became part of the US-supported Plan Colombia and persists until today (Ávila, 2014, p.9). Repressive measures have not managed to eliminate coca plantations in the region: the area from the southern Andean-Amazonian foothills to the Ecuadorian border is one of the major coca-producing regions in the country that has been under a constant influence of the crop in the past decade (UNODC, 2015, p.22). The history of the coca crop in the Andean-Amazonian foothills is inseparably linked with the armed conflict and social tensions in the region, which is explained further in detail in subsection 1.6.

An overview on the most important natural resources in the region would not be complete without mentioning cattle ranching. It has always been an important land use type throughout the history of the colonization of the Andean-Amazonian foothills as the possession of bovines represents a symbol of power and a type of investment that can be relocated and transferred to cash easily (Fajardo et al., 2012, p.22). Although the occupation of territories has principally been initiated by extractive activities, cattle ranching has continued this process and significant forested areas were cleared in order to convert them into pastures (Fajardo et al., 2012, p.22). Despite the low efficiency of extensive cattle ranching, the phenomenon has been very intense in Caquetá for which cattle ranching is the most important economic activity, and the number of animals has also increased continuously in Putumayo (Fajardo et al., 2012, p.22; Calderón, 2007, p.39). Armenteras et al. have identified cattle ranching as one of the main deforestation drivers that has caused dramatic changes in the landscape of the Alto-Putumayo since the 1980s (Armenteras et al., 2006, p.365). Besides deforestation, the homogenization of the landscape and soil erosion, extensive cattle ranching has also had adverse effects on the Amazonian ecosystem due to the contamination of water sources with organic waste and increased emissions of CO_2 and methane (Fajardo et al., 2012, p.23).

Besides petroleum, another, yet in comparison still minor part in the extractive sector is mining. Small-scale mining in the Andean-Amazonian foothills has experienced relative continuity since the beginning of colonization, but as most of it has taken place informally and without official mining licenses, there has been little to no detailed information on its actual qualitative and quantitative extent (cf. Martínez, 2007, p.33; cf. Calderón, 2007, p.43). However, there have been indications in recent years that the informal mining sector is growing, particularly regarding the small-scale mining of gold (FIP, 2014, p.13). Furthermore, the allocation of mining licenses to multinational companies has increased dramatically in the context of national development plans that foster the establishment of a mining industry in the Amazonian region (Ávila, 2014, p.52).

As has been shown, authors agree that the presence of natural resources in the Andean-Amazonian foothills have attracted several migration waves throughout its recent history. The extraction of these resources and the use of the land have had negative implications on ecosystems, especially regarding deforestation, biodiversity loss and the contamination of water resources. Several studies describe how the wealth of natural resources in the region, particularly petroleum and coca, have also contributed to a militarization and an intensification of the armed conflict in the area and to social tensions in the context of land use conflicts (Ávila, 2014, p.5; Vargas Valencia, 2013, pp.58–59; Observatorio del Programa Presidencial de DH y DIH, 2014, p.1).

1.6 The role of the armed conflict

For several decades, the southern Andean-Amazonian foothills have been affected by a violent armed conflict that has had dramatic impacts on the population.[6] The region has been affected by militarization on behalf of the FARC, paramilitary groups, illicit armed groups related to drug trafficking and the armed forces of the government; and it has gone through several waves of violence in the form of military attacks and massacres that have resulted in massive displacements of the population (cf. Ávila, 2014). Putumayo and Caquetá have played an important role in Colombia's armed conflict for the following reasons: firstly, the region has been of strategic importance for generating income for the FARC. There is a temporal and local coincidence between the expansion and the increasing influence of the FARC and the expansion of coca cultivations in the 1980s in these departments which is rooted in a profitable taxation scheme on coca growing farmers and a clear division of roles between the FARC and big drug traffickers (Consejería Presidencial para los Derechos Humanos, 2014, p.158). Similar patterns of income generation have been observed regarding the paramilitaries that were important militant players in the regions in the 1990s until their demobilization in 2006 (Consejería Presidencial para los Derechos Humanos, 2014, p.161; Observatorio del

[6] By April 2012, 25,764 victims of the armed conflict were reported for the department Putumayo (cf. UARIV, 2012, p.9). The most frequent reported incidents were homicides and forced disappearance, followed by injured persons, kidnapping, torture, illegal recruitment of children and adolescents and sexual violence (cf. UARIV, 2012, p.9).

Programa Presidencial de DH y DIH, 2014, p.2). In the course of the conflict, Putumayo and Caquetá have become important political and military bastions and zones for retreat of the guerilla (FIP, 2014, p.2). Also, the presence of petroleum has contributed to the conflict: the guerilla has frequently attacked oil pipelines and executed pressure on oil companies by extortions and kidnappings of their employees in order to generate further financial resources (FIP, 2014, p.4; cf. Ávila, 2014). In addition, communication roads in the region are of strategic importance for the transport of in- and outputs of the oil industry and the coca economy, for the connection with the Ecuadorian border and for trespassing towards the Pacific (Ávila, 2014, pp.9–10; cf. Observatorio del Programa Presidencial de DH y DIH, 2014, p.1).

Given the strategic importance of the region, Putumayo became the first department for which the Plan Colombia was implemented in 2000 and the southern Andean-Amazonian foothills have remained in its focus (Ávila, 2014, pp.9–10).

1.6.1 Violence and deforestation

There is the perception that the armed conflict has had a somewhat ambiguous effect on natural ecosystems in Colombia: on the one hand, ecosystems have suffered from the expansion of illicit crops, the devastation caused by landmines and by attacks on oil pipelines and illegal mining (SINUC, 2014, p.1; cf. Álvarez, 2003). On the other hand, there is the perspective that the conflict has kept some forested areas with high degrees of biodiversity isolated from the impact of colonization and socio-economic development (Aguilar et al., 2015, p.5; SINUC, 2014, p.1) and that the guerilla has protected some forested areas of strategic importance by forced coercion, including the installation of landmines (Álvarez, 2003, p.57).

Yet, whereas the socio-economic impacts of the armed conflict have been captured by numerous academic studies and institutional reports, the direct impact of the armed conflict on the environment and deforestation has for a long time received comparatively little to no attention in academic research (Álvarez, 2003, p.49). According to a recent study on deforestation drivers in the Amazon that has been conducted by the Amazonian Center of Scientific Investigation (SINCHI) and the WWF for the period between 2002 and 2012, more than 90 % of deforestation in the Amazon has taken place in areas that have been temporarily or constantly affected by the armed conflict[7] (2016, p.51). Álvarez (2003) has concluded that the armed conflict has had an impact on the use of natural resources and is a major cause for various environmental threats in rural areas, but that these relationships are sometimes difficult to trace and to evaluate with valid tests. The identified environmental threats include: the expansion of cattle ranching and related deforestation in areas conquered by paramilitaries that were mercenaries for cattle ranchers, the relentless and accelerated extraction of natural resources in conflict areas that are out of reach of environmental authorities and NGOs and the impaired reach of national and international funding regarding social development and conservation in conflict areas (Álvarez, 2003).

1.6.2 Illicit crops and deforestation

It has been estimated by the Colombian Antinarcotics Directorate that for each hectare that is cultivated with coca, producers have to destroy three hectares of forest (Walsh et al., 2008, p.67). According to the United Nations Office on Drugs and Crime (UNODC)[8], 290,992 ha were deforested directly for the purpose of coca cultivations in the whole of Colombia between 2001 and 2014 and furthermore, the overall tree cover loss in that period was mainly concentrated in departments with the highest proportions of coca cultivations (2015, p.24). These results coincide with the findings of Dávalos et al., who showed that coca cultivation increased the likelihood of deforestation in the northern Andes and Chocó, and that changes in population density determined deforestation rates in these regions (Dávalos et al., 2011, p.1224).

In 2001, 42 % of the total area of 145,000 ha used for coca plantations in Colombia were located in Putumayo and Caquetá (UNODC, 2015, p.33). The overall extent of coca cultivations was decreased in the following years but experienced an increasing trend from 2010 to 2014, with an increase of 68 % from 2013 to 2014. In Putumayo, the highest densities of coca cultivations are located in the south of the department towards the border with Ecuador, but the phenomenon has also gained particular importance in the foothills (UNODC, 2015, p.33).

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[7] The study states that 78 % of deforested areas are located in areas of temporal conflict, 14 % are located in areas of permanent conflict, 7 % are located in conflict-free areas and 0.7 % in areas with settled conflicts (SINCHI and WWF, 2016, p.51).
[8] Data on the extent of coca cultivation in Colombia is provided by the Integrated Illicit Crops Monitoring System (Simci) and the Anti-Narcotics Directorate (DIRAN), which tend to deviate from each other (Walsh et al., 2008, p.45). The official report is provided by the UNODC and is based on data by Simci.

In order to fight illicit crops and drug cartels, the Colombian state implemented the Plan Colombia with the support of the US government in 2000. The program mainly consists of the aerial fumigation of illicit cultivations and the support of alternative production systems and has been celebrated by the Colombian government as successful in decreasing the overall area in the country that is occupied by coca plantations (Rincón-Ruiz and Kallis, 2013, p.60). However, the effect of forced eradication has been fiercely debated: not only have authors partly questioned the presumed overall decreasing trend of coca cultivations and the figures and methods used in official reports (Rincón-Ruiz and Kallis, 2013, p.76; cf. Walsh et al., 2008). Depending on the applied study designs, authors have also concluded that forced eradication has only had a small effect on illicit crops (Davalos, 2016, p.8) or even an unintended stimulating effect on the area under coca cultivation as coca production is not eradicated by fumigations but displaced to other regions and diffused in the territory (Rincón-Ruiz and Kallis, 2013, p.61; Walsh et al., 2008, p.67). According to these studies, more communities, often the least developed and most vulnerable ones (Dávalos et al., 2011, p.1225), and more primary forest and biodiversity hotspots are affected by coca production due to forced eradication (Rincón-Ruiz and Kallis, 2013, p.61; Walsh et al., 2008, p.67).

Furthermore, aerial fumigations have been heavily criticized for the use of the herbicide mixture called Roundup Ultra, a Monsanto product that contains glyphosate whose effects on the environment and the health of local populations have been heavily debated in Colombia (Rincón-Ruiz and Kallis, 2013, pp.70–71; Walsh et al., 2008, pp.63–67). Fumigations have also been associated with the increased displacement of communities (Rincón-Ruiz and Kallis, 2013, p.61).

1.7 Expectations from the post-conflict

More than six decades of armed conflict have paralyzed development in large parts of Colombia’s rural areas and have produced substantial harm to social capital and ecosystem services (Aguilar et al., 2015, p.4; Daniel Nepstad et al., 2013, p.vi). The transformation of ecosystems in Colombia has been dramatic, but the dimension of the political and social implications of the conflict have used up the capacity of the Colombian society to respond to environmental risks (Álvarez, 2003, p.47). A peace agreement between the Colombian government and the FARC would represent a historical moment for gradual national recovery, with substantial chances for ecological restoration if it is recognized as an important part of socio-economic and political planning (Aguilar et al., 2015, p.4).

However, there is also the risk of accelerated deforestation rates and the degradation of ecosystems in a future post-conflict scenario due to large-scale uncontrolled exploitation (Aguilar et al., 2015, p.5; SINUC, 2014, p.1; Álvarez, 2003, p.64). Unfortunately, this phenomenon has occurred in other countries in the past, such as Guatemala and Angola, which have been affected by intense environmental degradation after settling their armed conflicts (SINUC, 2014, p.1). Aguilar et al. (2015, p.5) argue that ecological restoration in the post-conflict will depend on governmental effectiveness in enforcing environmental laws, enhancing ecological planning and considering ecological restoration as a “unifying theme and an important engine for job creation” instead of regarding it an opponent factor to fighting poverty and creating work opportunities.

1.8 What we still need to understand and what motivated this project

The ongoing peace negotiations between the Colombian government and the FARC have not only made a post-conflict situation and an official peace agreement a scenario that is both likely and welcomed by many stakeholders. The advances of the negotiating parties have also raised questions on how a peace agreement will affect the country’s future development in social, economic and ecological terms. Particularly regions such as the Andean-Amazonian foothills that have undergone strong transition processes in the past decades face high uncertainty in the near future. Accelerated migration rates with uncontrolled colonization and the occurrence of different economic booms related to the extraction of natural resources have caused some of the highest deforestation rates in the country and have had severe negative impacts on the ecosystem in the region. Thus, expectations are high that in a situation with peace, actions for a more sustainable land use will be taken and that conflicting interests related to land use will be settled and channeled towards a sustainable development and a slow-down of deforestation.

The motivation for this project originates from the belief that adequate measures for preventing deforestation can only be developed based on an understanding of deforestation patterns and the relationship between the underlying direct and indirect drivers. Detailed research on annual fluctuations of deforestation and links to its influencing factors is still incipient in the area but of high importance when it comes to the reorganization of territorial management in the Andean-Amazonian foothills. In the quest for a balance between social and economic development and conservation, further insights are needed regarding the effectiveness of existing protected areas in the region. Given the rapid transformation processes in the area, the need for adequate and effective measures for consolidating the different needs and interest of stakeholders is pressing.

1.9 Objectives and methodology

The overall aim of this thesis is to quantify and to understand deforestation in the Andean-Amazonian foothills in the south of Colombia and to offer suggestions for preventive measures for slowing deforestation in that area. The thesis pursues four objectives. Firstly, deforestation shall be quantified on an annual basis within the period from 2001 to 2014 for the overall study area and separately for the territory of protected areas. Secondly, the spatial distribution of deforestation trends in the study area shall be described. Thirdly, the underlying drivers of deforestation and their relationships shall be explained. And fourthly, potential measures for counteracting deforestation shall be presented.

In order to achieve these objectives, a combination of both quantitative and qualitative methods is applied. The quantification of annual deforestation is determined with a geographical information system (GIS) and by the means of multi-temporal datasets provided by the Global Forest Watch (GFW) project. The spatial analysis of deforestation trends in the study area is realized through a Morphological Spatial Pattern Analysis, a tool provided by the Joint Research Centre of the European Commission, and the calculation of selected fragmentation indicators. In order to understand the underlying direct and indirect drivers of deforestation, 25 semi-structured interviews with locally and regionally engaged stakeholders have been conducted. Suggestions for preventing deforestation in the future are based on the conclusions drawn from the analysis of the semi-structured stakeholder interviews and the quantitative findings of this thesis.

2 Materials and methods

The methodology chosen for this thesis is based on the assumption that studying and analyzing deforestation is a task that requires interdisciplinary methods and thinking. This assumption has the following reasoning: although the role of remote sensing (RS) imagery and Geographic Information System (GIS) techniques for LUCC studies is significant, they may not deliver sufficient explanations for the depicted changes and dynamics. For that purpose, researchers have recognized the potential benefits of linking spatial data with ground-based socio-economic information[9] in order to understand the underlying drivers of the spatially observed changes (Sohl and Sleeter, 2012, p.235; Crews and Walsh, 2009, p.438). Despite some challenges that still exist concept-wise and in terms of practicability, the combination of remotely sensed and socio-economic data also plays an increasingly important role for the development of future scenarios and spatially explicit LUCC projections (Sohl and Sleeter, 2012, p.235). Such scenarios and projections may serve as useful tools for decision making over policies affecting land use and land management.

The research design in this thesis is an approach of methodological triangulation that combines quantitative and qualitative elements. The quantitative part aims at the determination of annual deforestation rates in the study area in the southern Andean-Amazonian foothills of Colombia and the description of the spatial distribution of deforestation trends. The qualitative part consists of data collection by means of 25 semi-structured interviews with local and regional stakeholders and the triangulation of these data with secondary literature on corresponding socio-economic factors.

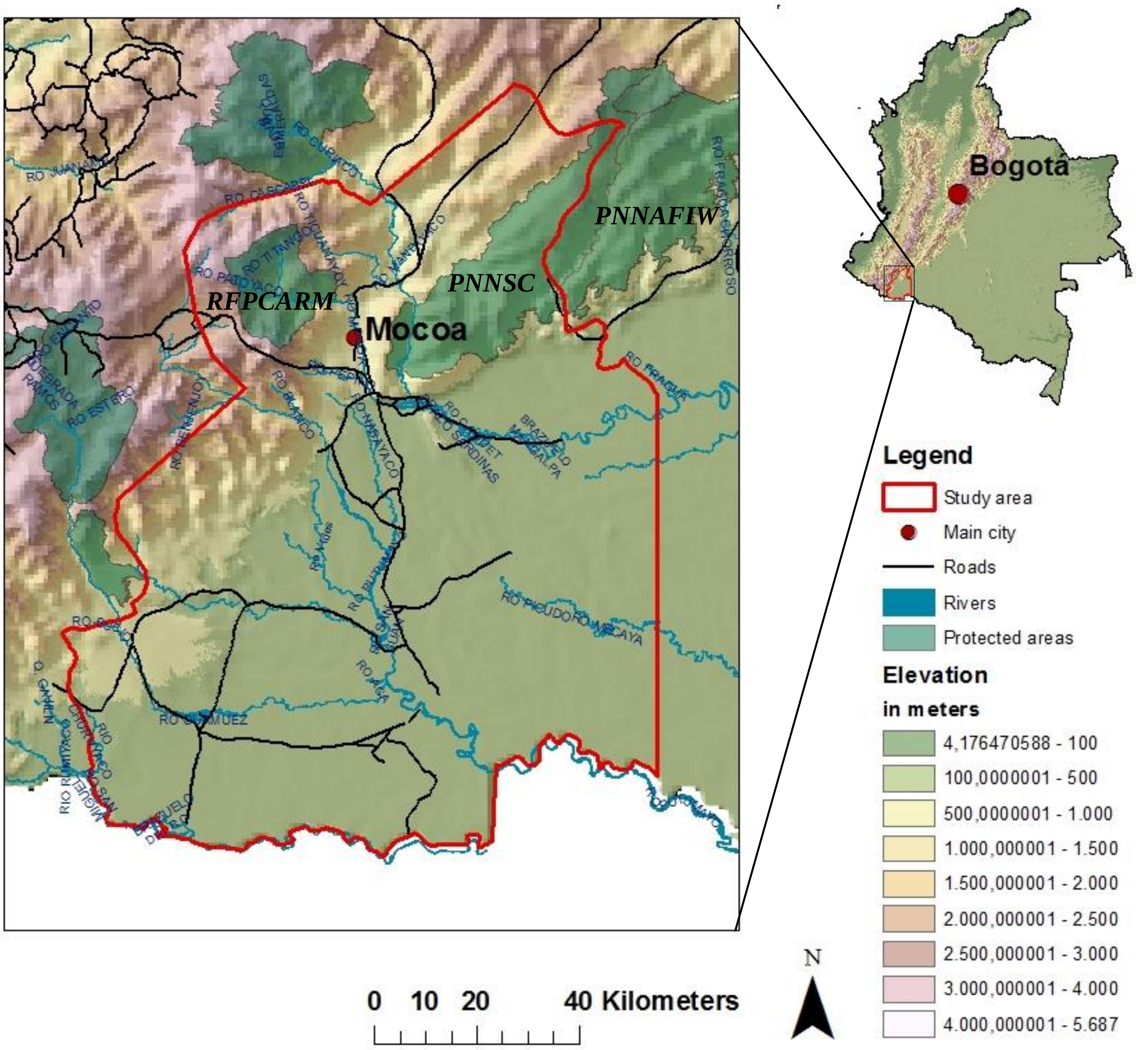
2.1 Description of the study area

The study area is located in the Amazon region near Colombia’s south-western border with Ecuador. It is mainly situated in the department Putumayo, with northern parts of the area in the departments of Cauca and Nariño[10], and its total size amounts to 1,209,277.87 ha. Overall, the area is characterized by a high degree of biodiversity, including endemic and a number of endangered species regarding both flora and fauna, and a wealth of natural resources of different kinds.

9 Examples for ground-based socio-economic data may include census data and information on households, the distribution of income, policies, the presence of businesses and value chains and other factors.

10 Note that there is a map of the study area and administrative boundaries of departments and municipalities in Appendix1.

Figure 1: The study area



Source: author's own

Three main types of landscapes can be distinguished: first, the Cordillera Oriental, which is the Andean mountain range in the north and the west of the study area with an elevation of 900 m up to more than 3500 m above sea level; second, the foothills representing the transition between the Andes and the Amazon plains at an elevation between 300 m and 900 m above sea level; and third, the Amazon plains below 300 m above sea level in the south and the east of the region (cf. Martínez, 2007, p.25). According to Thornthwaite's climate classification system, the climate in the study area varies from mesothermal perhumid-humid in the mountain ranges of the Andes in the west, to megathermal perhumid in the foothills and the Amazon plains (Martínez, 2007, p.20). Mean annual temperatures in the Cordillera are approximately 15 °C and 25 °C in the foothills and the Amazon plains, and precipitation is relatively constant throughout the year with overall levels of 1,747 mm, 3,728 mm and 3,007 mm in the respective regions (Martínez, 2007, p.20).

Both the vegetation and the fauna in the study area vary according to the different elevation levels and climatic conditions. In the Andean and Sub-Andean forests, at elevations of 2400 m to 3800 m and 1000 m to 2400 m, small-leaved and deciduous trees, mosses and epiphytes prevail (Martínez, 2007, p.22). Vegetation below an altitude of 1000 m can be generalized as evergreen tropical rain forest with extensive river systems and an abundance of tree species, palms, hygrophytes, epiphytes, orchids and ferns, among others (Martínez, 2007, p.22). Wildlife is particularly diverse in the tropical parts of the study area, which concerns bird species, mammals, reptiles and insects (cf. INCOPLAN S.A., 2008, pp.30–31). It is worth mentioning that Martínez (2007, pp.22–23) criticizes a lack of studies regarding the biogeography, densities and current states of populations in the region, and thus a scarcity of information that inhibits the development of comprehensive quantitative and qualitative assessments of wildlife in the area. There are several publicly managed protected areas: the forest reserve “Reserva Forestal Protectora de la Cuenca Alta del Río Mocoa” (RFPCARM), large parts of the national park “Parque Nacional Natural Serranía de los Churumbelos” (PNNSC) and a fraction of the neighboring national park “Parque Nacional Natural Alto Fragua Indi Wasi” (PNNAFIW). The mentioned protected areas account for approximately 8.81 % of the study area and fall into the jurisdiction of the environmental authority Corpoamazonia in the case of the RFPCARM, whereas the PNNSC and PNNAFIW are managed within the framework of Colombia’s System of National Natural Parks.

The area with the highest population density in the study area is Mocoa, the capital of the department Putumayo. It is estimated that currently, 341,034 people or 48 % of the population of the department lives in Mocoa (DNP, 2014, p.1). The overall population density in the department is 13.70 per km^2 (DNP, 2014, p.1). Various ethnic groups live in the area, including indigenous and afro descendant communities (cf. Martínez, 2007, p.26). According to governmental information, 67 % of the overall population of the department live in conditions under which the basic human needs are met (Gobernación de Putumayo, 2016).

The land use and economic activities in the study area are related to bio-physical conditions and the presence of natural resources. There is small-scale mining in the northern mountainous areas for gold and precious minerals, especially along the river Caquetá, but also for silver, copper, zinc, platinum, molybdenum and limestone

(INCOPLAN S.A., 2008, p.18; Martínez, 2007, p.33). The allocation of mining licenses in the foothills of the study area to multinational companies has increased in the past years as part of national development plans that foster the establishment of a mining industry in the Amazonian region (Ávila, 2014, p.52). As has been described in section 1.5, the exploration and exploitation of oil fields in Orito and La Hormiga in the south of the study area have played an important historical role in the socio-economic development of the region and continue to do so. Small-scale agriculture and extensive cattle ranching both for meat and milk production are among the most important economic activities in the region (Gobernación de Putumayo, 2016; cf. Fajardo et al., 2012). Cultivated crops include corn, bananas, pineapple, yucca, sugar cane, peach palm fruit, rice, yams, beans and vegetables (Gobernación de Putumayo, 2016). Further local and small-scale activities include fishing and timber production (Martínez, 2007, pp.33–34). The territory has been continuously subjected to the cultivation of illicit crops, mainly coca, but also marihuana and poppy (cf. Salgar Antolínez, 2014; cf. Martínez, 2007). The study area comprises the areas with the highest densities of coca cultivations in the department Putumayo (cf. UNODC, 2015, p.33).

Despite the wealth of resources in the primary sector, the secondary and tertiary sectors face incipient social and economic infrastructures. Thus, these sectors are rather limited to the manufacturing of basic construction materials, the processing of crude oil, wood and milk and the provision of services such as transport, local commerce, banking, hospitality and construction work (Martínez, 2007, pp.34–35). Whereas governmental agencies and administrative bodies account for a large part of employment in urban areas, academic activities and research are mainly carried out by external scholars and research groups (Martínez, 2007, p.35).

2.2 Quantitative analysis

The following sub-sections describe the procedure by which data of the Global Forest Watch project is used to quantify annual deforestation rates in the study area in general and in protected areas in particular. Afterwards, there is an explanation of the approach that is used in this thesis for describing the spatial distribution of deforestation trends through a Morphological Spatial Pattern Analysis and the calculation of selected fragmentation indicators.

2.2.1 Quantification of deforestation with data sets provided by the Global Forest Watch project

For the purpose of analyzing changes in forest structures in the study area, data sets[11] provided by the GFW project, more precisely by Hansen et al. (2013a), are used.

Data source

Hansen et al. (2013a) have established a global data set and a high-resolution map that is available online, free to use and that enables the monitoring of changes in the world's forest cover within the period from 2001 to 2014. The data is based on Landsat imagery, for which the spatial resolution of the selected 10 x 10 degree tile[12] is one arc-second per pixel or approximately 30 m per pixel at the equator (Hansen et al., 2013a). Table 1 gives an overview about the datasets that were applied.

Hansen et al. (2013) use a layer depicting the percentage tree cover per pixel for the year 2000 as the base layer for assessing changes in the forest cover in the following years. Forests are specified as vegetation taller than five meters in height with a tree density of more than 50 % per pixel as a threshold, without discriminating trees that are part of intact forests or cultivated plantations (Hansen et al., 2013a).

Table 1: Dataset details of Hansen et al.

Data Set	Period	Content	Classification
Tree canopy cover for the year 2000	2000	Tree cover in the year 2000, defined as canopy closure for all vegetation taller than 5m in height	0 (no loss) 1 (loss)
Year of gross forest cover loss event	2001-2014	Forest cover loss disaggregated to annual time scales	0 (no loss) 1-14 (representing loss in the respective years from 2001 to 2014)
Global forest cover gain	2000-2012	Forest cover gain during the overall period	0 (no gain) 1 (gain)

Source: author's own, based on Hansen et al., 2013a

Forest cover loss is defined as "(…) a stand-replacement disturbance, or a change from a forest to non-forest state", while forest cover gain implies "(…) the inverse of loss, or

[11] Datasets have been downloaded from the website of earthenginepartners.appspot.com, which is one of the partners in the GFW project and powered by Google Earth Engine: http://earthenginepartners.appspot.com/science-2013-global-forest/download_v1.2.html
[12] The selected tile is the granule with the top-left corner at 10N, 80W. See: http://earthenginepartners.appspot.com/science-2013-global-forest/download_v1.2.html

a non-forest to forest change entirely within the study period" (Hansen et al., 2013a). The data provided by the researchers is pre-processed, including image resampling, the conversion of raw digital values to top of atmosphere reflectance, cloud/ shadow/ water screening, quality assessment, image normalization and classification with decision tree methodology (Hansen et al., 2013a). Hansen et al. (2013b) also conducted an internal accuracy assessment based on an independent data set with overall results for the entire period. For the tropical biome, producer's accuracies are stated as 83.1 % for loss and 48.0 % for gain, and user's accuracies are 87.0 % and 81.9 % respectively (Hansen et al., 2013b, p.16).

Data processing and methodology

Despite the fact that the datasets are pre-processed, there is still a critical decision to be taken regarding the further analysis of the data, which concerns the occurrence of both loss and gain for the same pixel within the respective layers ("year of gross forest cover loss event" and "global forest cover gain"). This problem has also been described by Mitchard et al. (2015): whereas the incident of loss is clearly assigned to a particular year in the respective layer, the incident of gain cannot be assigned to a specific year because the corresponding layer only indicates pixels for which a gain in tree cover has occurred *at some point* within the period from 2000 to 2012. Consequently, it is impossible to know which event has predated the other one. These conditions do not allow the calculation of annual net deforestation, as this could only be done for the period from 2000 to 2012 and even then with uncertainties due to overlapping pixels with both loss and gain. Hansen et al. do not provide any suggestions on how to deal with this issue. There is the possibility that pixels for which both gain and loss occur are plantations and not forests, or that errors are involved. For that reason, these pixels have been neglected in the calculation of deforested areas in the analysis in this thesis.

The procedure that is applied to determine the respective rates of forest loss in terms of hectares is executed in ArcGIS according to the method that is suggested by Paz-Garcia and Coca-Castro (2014) in the Terra-i project[13] for analyzing transition processes in Latin America. The method basically comprises the following steps: projecting the

[13] The Terra-i project is currently operated by the International Center for Tropical Agriculture for the entire Latin American continent. It detects human-induced changes in land cover in near-real time with updated information every 16 days (CIAT, 2016). For further reference, see: http://www.terra-i.org/terra-i.html

layers provided by Hansen et al. into the correct projection that is used within the entire analysis, extracting the target area with a mask of the study area and calculating the changed area, which in the case of this thesis is done with the tool “Zonal Geometry as Table” in ArcGIS. The area that has been affected by forest loss between 2001 and 2014 is calculated for each year in the entire study area. In a second step, a separate calculation is made for the foothills in the northern part of the study area and for the flatter terrain in the south of the study area. For that purpose, 800 meters were chosen as the dividing line between these two areas. This decision was made based on several statements of local and regional stakeholders on the distribution of land use types that are present in the study area[14]. The separate calculation shall provide insights into possible differences of deforestation rates depending on the altitudinal gradient in the Andean-Amazonian foothills.

2.2.2 Relation between deforestation and protected areas

The impact of deforestation on protected areas is analyzed separately for the forest reserve RFPCARM and the joint areas of the neighboring national parks PNNSC and PNNAFIW that are located in the study area. The applied methodology for the calculation of deforested areas in terms of hectares involves the datasets and methods specified in section 2.2.1. The calculation is done for the territory of the mentioned protected areas and also for a 5 km buffer zone around them. The calculation of forest loss within the protected areas and in the corresponding buffer zones are expected to give insights into the impact of deforestation in protected areas and whether or not there has been an increasing trend of forest loss in their vicinity.

2.2.3 Spatial analysis of deforestation trends

In order to describe the spatial pattern of deforestation within the study area, the Graphical User Interface for the Description of image Objects and their Shapes (Guidos) Toolbox (Vogt, 2016) and the statistical package R (R Core Team, 2015), making use of the SDMTools package (VanDerWal et al., 2014) are applied.

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[14] Stakeholders indicated that some of the most determining land use types in terms of direct and indirect impacts on deforestation have taken place up to 600 meters or 1000 meters above sea level.

Guidos[15] has been developed by the Forest Resources and Climate Unit of the Joint Research Centre of the European Commission and provides several generic image processing tools that can be applied to raster data. In this thesis, the tool called Morphological Spatial Pattern Analysis (MSPA) is applied. The tool analyses the geometry and connectivity of the foreground area of binary images and can be used in any application field. Possible binary images for the MSPA include forest/non-forest masks, grassland/non-grassland masks and masks displaying other vegetation types. As described on the corresponding website of the Joint Research Centre, the key features of MSPA comprise the detection of connecting structures, the detection of holes, the detection of deviations from a pre-defined thickness and a user-defined analysis scale (Vogt, 2016b). The output of the MSPA consists of seven possible mutually exclusive classes, which are core, islet, loop, bridge, perforation, edge and branch. The meaning of each class is described in Table 2.

Table 2: MSPA classes

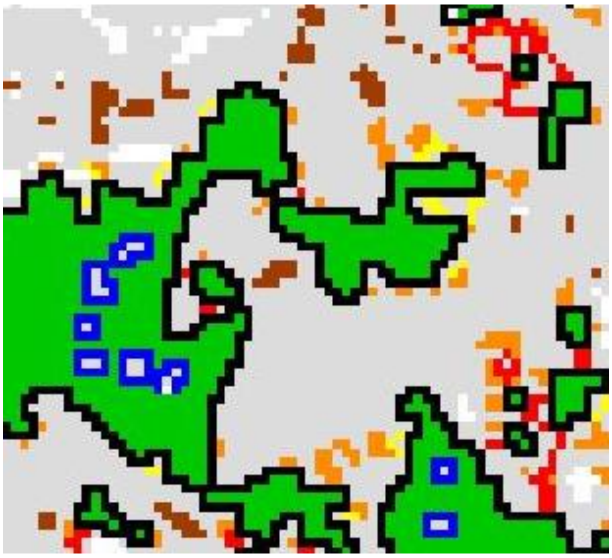
MSPA class	Color	Meaning
Core		Interior foreground area excluding foreground perimeter
Islet		Disjoint foreground object and too small to contain core
Loop		Connected at more than one end to the same core area
Bridge		Connected at more than one end to different core areas
Perforation		Internal foreground object perimeter
Edge		External foreground object perimeter
Branch		Connected at one end to edge, perforation, bridge or loop

Source: author's own, based on Vogt, 2016

Before applying the tool for analyzing deforestation patterns in the study area, 14 images were prepared with a binary structure in R by the means of the "Raster" package (Hijmans, 2015): those pixels displaying annual deforestation have been classified as "foreground area", thus as the category of pixels that is relevant to the MSPA. The remaining pixels, hence pixels for which no deforestation was detected or pixels that were excluded from the analysis for reasons that were explained in section 2.2.1 are classified as background area. Furthermore, the images are prepared for each year in such a way that the pixels displaying deforestation from the previous years were added to the image of the current year. For instance, the image of the year 2004 contains pixels of deforestation from 2001, 2002, 2003 and 2004.

[15]See: http://forest.jrc.ec.europa.eu/download/software/guidos

Figure 2: Example of the MSPA output within the study area



Source: author's own

Consequently, each image displays aggregate deforestation from 2001 onwards including the respective final year, which shall enable the MSPA tool to detect the evolvement of spatial deforestation patterns through time. The MSPA parameters in the analysis are set as follows: 8-connectivity for the connectivity of the foreground-pixels, one pixel for the edge-width of non-core boundary classes, and both transition pixels for intersections between different classes and the intext function are switched off. The MSPA tool is run for each of the 14 images displaying aggregate deforestation from 2001 to 2014. Figure 2 provides an example of the MSPA output within the study area as displayed in ArcGIS.

The MSPA output is then read back to R in order to calculate the areas of the respective MSPA classes for each year from 2001 to 2014. The objective of the procedure is to detect potential differences in the occurrence of each class in order to draw conclusions on how deforestation has spread in the study area in spatial terms. For instance, the case of a dominating "core" class would imply that deforestation has occurred in a concentrated way. In contrast, high proportions of the "islet" class would indicate that deforestation has occurred in a dispersed way that affects rather small areas respectively.

In a further step, the Landscape Class Statistics function of the SDMT package is used in R in order to calculate additional indicators of the deforestation pattern in the study area. The tool allows for the calculation of various class statistics for patch types, thus for deforested areas in the raster data in the case of this thesis. The background value for which statistics are not calculated consists of all those pixels that do not indicate deforestation within the raster data. The indicators that have been chosen in order to provide meaningful additional information on top of the MSPA output and the respective meaning of each indicator are presented in Table 3.

Table 3: Indicators of patch types

Indicators of patch types	Meaning
Number of patches	The number of patches affected by deforestation
Mean patch area	The average area of patches affected by deforestation
Effective mesh size	Equals 1 divided by the total landscape area (m^2) multiplied by the sum of patch area (m^2) squared, summed across all patches in the landscape

Source: author's own, based on McGarigal, 2015

Besides the number of patches and the mean patch area, the effective mesh size was chosen as an indicator of general fragmentation. In this thesis, it is applied at deforested areas instead of forest patches, which requires a different interpretation of the indicator than when applied to forest patches or other types of ecosystems (cf. Jaeger et al., 2007). In this case, it measures the probability that two randomly chosen deforested pixels in the study area may be connected and not separated by barriers represented by non-deforested areas. Hence, the greater the effective mesh size, the higher the probability that the two deforested pixels are connected and the higher the fragmentation of forests. It is worth mentioning that the indicator is only calculated for forest fragmentation from 2001 onwards. Hence, the actual effective mesh size of the study area may be a different one if deforested areas before 2001 were taken into account. However, it is assumed that the calculation of the effective mesh size with the available data for 2001 until 2014 may still serve as an indicator for the change of ecological connectivity in the study area.

The choice of the aforementioned indicators provided by the MSPA output and the indicators of patch types has been made as to provide an insight into the evolvement of deforestation pattern within the study area. In order to take potential deviations of deforestation patterns related to differing levels of elevation into account, the analysis has not only been run for the entire study area, but also separately for the plains and elevated terrain with the dividing line at 800 meters of elevation[16].

2.3 Qualitative analysis

The qualitative part of this thesis pursues two main objectives: firstly, providing insights into the direct and indirect drivers of the deforestation that is observed in the study area within the period from 2001 to 2014. And secondly, providing the basis for proposing measures to prevent deforestation in the future, taking the scenario of post conflict into account. The approach to achieve these objectives consists of semi-structured interviews with local stakeholders in Mocoa and regional stakeholders in Bogotá and a triangulation of these results with the obtained information from the quantitative analysis and, if applicable, corresponding socio-economic data and secondary literature about the region. The research approach of this thesis is best described as abductive matching, which is moving back and forth between data sources, theory and analysis that as such could not be done with a merely deductive or inductive approach (cf. Paavola, 2014).

The following subsection explains the choices of the research design, the structure of the interview guide, the selection of participants, the interview procedure and the corresponding data collection, data analysis and the management of quality criteria in the course of this research.

2.3.1 Semi-structured interviews with local and regional stakeholders

The purpose of the interviews is to obtain an understanding of the observed deforestation rates and patterns in the study area and to collect recommendations for potential preventive measures.

Data collection

In qualitative research, interviews represent one of the most common approaches for data collection (Roulston et al., 2003). The approach has been chosen for this thesis because the subject of the study is a local, on-site phenomenon that might be best understood by the help of insights, experiences and perceptions of stakeholders who are

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[16] The decision for setting the dividing line at 800 meters of elevation has been explained in section 2.2.1.

either directly affected by the phenomenon of deforestation in the Andean-Amazonian foothills or engaged in the issue in different ways. The three existing types of interviews are unstructured interviews, semi-structured interviews and structured interviews (Myers and Shaw, 2004, p.195; Berg, 2001, p.68 ff.), of which semi-structured interviews were selected as the most appropriate type for the purpose of this thesis. Semi-structured interviews comprise a set of pre-determined questions which serve as a guideline for the interview, but which allow for specific follow-up questions and the inclusion or deepening of topics that might not have been anticipated in that way, and which could not be included when choosing the structured interview approach (Berg, 2001, p.70).

The selection of participants

As for the selection of participants for the semi-structured interviews, purposeful sampling has been used as a sampling method. Purposeful sampling implies that the researcher may choose suitable "cases" (or interviewees, in the case of this thesis) from the population according to the researcher's judgement on what is important and relevant to the subject (Berg, 2001, p.32; Guba, 1981, p.86). This sampling method was chosen as it ensures that certain stakeholder groups with attributes that are considered relevant in the context of deforestation are included in the analysis.[17]

It is worth mentioning that in five cases, interviewees identified other useful informants on the subject of deforestation in the course of the interview or even introduced the researcher directly to the other informant. This process has been described as snowball sampling in qualitative research and has the advantage that it allows for a good introduction of the interviewer to populations which might otherwise be hard to reach (cf. Noy, 2008; Berg, 2001, p.33).

Regarding the selection criteria for participants in the study, at least one of the following criteria had to be fulfilled for identifying suitable informants: (1) local[18] engagement in concrete practices of land management, e.g. land tenure, agriculture or

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[17] For instance, local communities of peasant and indigenous groups are considered as relevant stakeholder groups in the context of deforestation in the Andean-Amazonian foothills, and purposeful sampling enabled targeting these specific groups of interest.

[18] Local engagement refers to activities within the polygon of the study area.

management of protected areas, (2) local or regional[19] engagement in administrative activities that influence or concern land management, (3) engagement in scientific studies or projects on land management or deforestation in the Andean-Amazonian foothills.

In total, 25 interviews were conducted within the period from February 15th to February 25th 2016. Most of the interviews (17) were held within the study area, mainly in Mocoa and its vicinity, and another part of the interviews was conducted subsequently in Bogotá. The selected interviewees represent local and regional stakeholders with differing cultural, educational and professional backgrounds. Table 4 provides an overview on the participants in the interviews.

[19] Regional engagement refers to activities in the Amazonian region beyond the scope of the study area. However, the study area should still fall into the reach of the respective activity.

Table 4: Participants in the interviews

Nr	Represented stakeholder group	Profession	Relation to study area	
			Local	Regional
1	NGO	Biologist		X
2	NGO	Coordinator (Amazon region)		X
3	Farmers	Farmer, activist	X	
4	Farmers	Farmer, activist	X	
5	Local administration	Employee, consultant	X	
6	NGO	Program officer	X	
7	Protected areas	Project assistant (communities)	X	
8	Protected areas	Director	X	
9	Protected areas	Technical expert	X	
10	Protected areas, indigenous people	Project assistant (communities)	X	
11	Protected areas	Technical expert	X	
12	Local administration	Consultant	X	
13	Local environmental authority	Professional	X	
14	Indigenous people	Leader	X	
15	Tourism and entrepreneurs	Manager, activist	X	
16	Indigenous people	Leader	X	
17	Indigenous people	Member, consultant	X	
18	Independent consultant	Director		X
19	International cooperation agency	Regional coordinator		X
20	National environmental authority	Professional, analyst		X
21	University	Professor, researcher		X
22	Governmental research institute	Researchers (2)		X
23	NGO	Anthropologist		X
24	NGO	Biologist		X
25	NGO	Biologist		X

Source: author's own

Out of 25 interviewees, 15 people are local stakeholders who both live and work within the study area, whereas the remaining 10 stakeholders are regionally engaged and work mainly in Bogotá. Table 5 gives an overview on the representation of stakeholder groups in the interviews in descending order.

Table 5: Representation of stakeholder groups

Stakeholder group	Number of interviewees
NGOs	6
Protected areas	5
Indigenous people	3
Researchers	2
Farmers	2
Local administration	2
Local environmental authority	1
Tourism and entrepreneurs	1
National environmental authority	1
International cooperation agency	1
Independent consultant	1

Source: author's own

As can be seen, the most represented groups of stakeholders are NGOs, members of the local management of protected areas and indigenous people. This is partly explained by the facilitated introduction of the interviewer to these stakeholder groups by other interviewees. Another reason is practicability: given the relatively short amount of time that was available during the field trip, not every potential informant was able to take part in the interviews. Regarding the stakeholder groups of NGOs, protected areas and indigenous people, the interviewer had the chance to participate in meetings of existing environmental projects and to address potentially useful informants who were present during these meetings. It was more difficult to arrange meetings with regionally engaged professional stakeholders, as some of them were on field trips in other regions of the country or on conferences during the period when the interviews were held.

The interview guide

The 15 questions of the interview guide have been developed based on the background information presented in the sections 1.1 to 1.9 and the findings of the quantitative analysis. The questions are open-ended questions that belong to six subsequent thematic groups, which are the following: (1) basic information and relation of the interviewee to the study area, (2) land use change, (3) deforestation patterns, (4) conflicts and problems related to land use, (5) land use in the future and (6) the possibility to draw conclusions or add further aspects to the interview. The full interview guide can be found in Appendix 5.

The interview procedure

The first contact with the interviewees was made either via email one to two weeks before the interview or by phone during the field trip. The interviews were held in 2016 from February 15th to February 25th. Depending on the availability and the schedules of the informants, one to five interviews were held per day. All of the interviews were conducted face-to-face by the same interviewer. During eight interviews, a research assistant who is familiar with the interviewees and the research area was also present in order to facilitate the process of trust and credibility building between the interviewer and the respective interviewee. In five of these cases, a member of the management of PNNSC who is responsible for the collaboration with local communities was also present, as this person had established the initial contact between the informants and the interviewer. Since both the research assistant and the member of PNNSC were known to the interviewees through several years of collaboration in various projects, the atmosphere was friendly and the presence of additional people during the interviews did not exert pressure on the interviewees. The interview with researchers of the governmental research institute is the only one in which two interviewees were present at the same time. The interview was originally scheduled with one of the researchers, who spontaneously invited his colleague to the conversation. Despite the fact that this is a group interview, albeit a small one, it is included in the analysis of this study as it provides valuable insights into the perspective of a governmental research institute. The interview enters into the analysis by representing one stakeholder, given that only the original contact person responded to all of the questions and the interviewees had agreeing points of view.

Every interview started with an introduction of the interviewer that was either done by herself, by the research assistant or by the member of PNNSC, depending on the situation and the way in which the interviewer had made contact with the informant. In the following, the purpose of the research project was explained by the interviewer to the interviewee. Also, questions and doubts about the research project, the purpose of the interview and the use of the obtained information were answered by the interviewer. Careful attention was paid within this introduction phase in order to create a friendly atmosphere, trust and credibility with the interviewee. Afterwards, the actual interview started. All participants agreed to the recording of the interviews, some of them explicitly uttered the wish that their name should not be mentioned in the analysis. The interviews were carried out in Spanish and lasted between approximately 30 and 100 minutes each. There was no rush during most of the interviews, as the participants had scheduled enough time for answering the questions, with the exception of two cases in which the interviewees had to end the interview rather abruptly in order to attend another appointment. Given that most of the interviews took place in the offices or homes of the interviewees, some interviews had to be paused due to brief interruptions by phone calls, colleagues or family members of the interviewees. Apart from one exception, all the interviews were finished afterwards. It is worth mentioning that in the majority of the cases, the interviewees were very willing to share their experience and personal perception on the raised questions and beyond.

Data recording and analysis

The 25 interviews resulted in approximately 22 hours of recorded voice. Shortly after the field trip, the interviews were transcribed. There appears to be a consensus among authors that despite the fact that transcriptions are a powerful tool in qualitative research, there is no particular ideal way for transcribing interviews; and thus, the applied technique should be chosen carefully according to the purpose and the context of the respective study (cf. Oliver et al., 2005; cf. McLellan et al., 2003). In the case of this thesis, the interviews were transcribed directly from Spanish to English. This approach was chosen as a suitable compromise that allows for a highly detailed transcript of the interviews at the one hand, and the avoidance of spending even more time with written translations on the other hand. In the case of this thesis, the risk of errors through direct translation while transcribing can be considered very small for the following reasons: the interviewer took notes during the interviews in addition to the recording; and the interviewer was also the same person that carried out the transcription of these interviews. Substantial effort has been put into the detailed word-by-word transcription and translation of the interviews. Remarks on the quality, unclear words or noteworthy incidents during the interviews have been included in parenthesis with capital letters. Furthermore, all the interviews have been anonymized in order to respond to the wish of some of the interviewees, which is an important element when adhering to research ethics (cf. Berg, 2001, p.57 f.). The original names of the interviewees and the respective institutions have been replaced with generalized indications in square brackets. The complete transcriptions of the interviews can be found in the Appendix 6.

In order to handle a large amount of data in qualitative research, authors have recommended working with different categories that enable the structured analysis of the obtained information (Berg, 2001, p.245 ff. Brink, 1993, p.37). The categories for the analysis of the interviews were established based on the objectives of this thesis that have been outlined in section 1.9. There are four core categories: deforestation drivers, regional features of deforestation, preventive measures and stakeholders' expectations for the future. As each of these core categories still represents a wide field, different subcategories have been established in order to handle the answers of the informants more efficiently. Table 6 shows the combination of core categories and the corresponding sub-categories. In order to facilitate the process of coding, the program MAXQDA was used.

Table 6: Code categories

Core-categories	Sub-categories
Deforestation drivers	Direct drivers
	Indirect drivers
	Relationships between drivers
	Evolution of deforestation drivers through time
Regional features of deforestation	Foothills
	Plains
	Protected areas
Preventive measures	Alternative sectors and land use types
	Government-driven measures
	Community-driven measures
	Protected areas
	Other measures
Stakeholders' expectations	Opportunities
	Risks

Source: author's own

In MAXQDA, each sub-category was divided into further sub-categories. In the following, that data was unitized: answers of different interviewees were grouped in MAXQDA according to the corresponding sub-categories. Each group was scanned for overlapping, contradicting or complementing answers, taking the differing backgrounds and contexts of stakeholders into account. In a further step, the answers were summarized, which provides the base for the presentation of the results in the sections 3.2, 3.3 and 3.4.

As for the discussion of these results in section 4, the obtained results from the interviews are triangulated with information obtained from the analysis of the deforestation pattern that are presented in section 3.1 and, if applicable, other sources of data on political, social and economic features in order to sustain, question or debate features that have come up within the conversations with stakeholders. Sources that have been used for this purpose include governmental information, the reports of NGOs, official statistics and other types of secondary literature.

Trustworthiness and quality criteria

Several quality criteria have been taken into account in order to ensure trustworthiness during and after the collection of data, which are credibility, transferability, dependability and confirmability (Guba, 1981, p.79).

As for credibility, several de-briefings were done with the supervisors of this thesis and the research assistant in order to contextualize the obtained information. Furthermore, data triangulation has been chosen in order to enrich the findings of the interviews with existing perspectives within academic literature (cf. Berg, 2001, p.6; cf. Guba, 1981, p.85). Consequently, comparisons were made as far as possible between the findings of the interviews and various other sources, such as official statistics on deforestation, coca production or indicators of conflict.

In terms of transferability it ought to be mentioned that this thesis follows the assumption that there are no universally applicable truth statements, but that social or behavioral phenomena are context-bound (Guba, 1981, p.86). The transferability of this study is partly limited due to the fact that the names and contact details of the participants of the interviews are anonymized. However, background information on the type of participating stakeholders is provided. Furthermore, the interview guide is attached in the annex, which ensures a satisfying degree of transferability of this study.

Dependability was ensured in this study through the use of overlapping methods. A so-called “multi-operations” inquiry (Guba, 1981, p.86) was used in the sense that the quantitative GIS approach, semi-structured interviews and the comparison of data with secondary literature complement each other and increase the stability of the presented findings.

Regarding confirmability, several measures are taken in order to ensure investigator-free findings. As has already been outlined in the aspect of credibility, data triangulation has been practiced in different ways. Furthermore, there is a thorough description of how the interviews have been transcribed; and the complete transcriptions can be found in Appendix 6 of this thesis in order to allow the reader to cross-check the findings of this thesis and to follow the conclusions that are derived subsequently.

3 Results

The following sub-sections present the results of the aforementioned analysis of deforestation patterns and deforestation drivers in the study area from 2001 to 2014. After that, potential preventive measures and stakeholders' expectations for the future are described.

3.1 Deforestation pattern

The deforestation pattern in the study area is described through the quantification of annual deforestation rates for the entire study area and a discriminated quantification of deforestation for mountainous areas and areas at lower elevations. In addition, the impact on protected areas and the spatial distribution of deforestation trends are presented.

3.1.1 Quantification of deforestation

Deforestation affected 67,530.16 ha within the period from 2001 to 2014, which is equal to a proportion of 5.58 % of the overall study area and 6.14 % of the total forested area in relation to the base year 2000. Figure 3 displays the annual fluctuations of

Figure 3: Annual deforestation in the study area

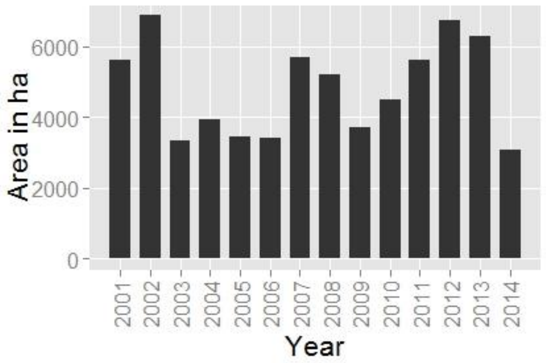
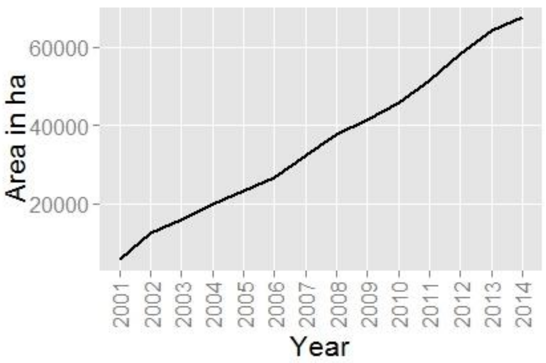


Figure 4: Cumulative deforestation in the study area



Source of Figure 3 and Figure 4: author's own deforestation within that period. The data fluctuate in a cyclical pattern: there are distinct peaks for the years 2001 and 2002, 2007 and 2008 and for 2012 and 2013. It is noteworthy that deforestation rates declined by more than 50 % after the peaks of 2002 and 2013. The most stable period with comparatively low deforestation rates was between 2003 and 2006. The average annual deforestation rate was 0.44 %. Figure 4 displays cumulative deforestation for the entire period. Cumulative deforestation has increased steadily between 2001 and 2014, and there is no indication for a flattening-out of the curve during the investigated period.

Figure 5: Deforestation in areas below 800 meters above sea level

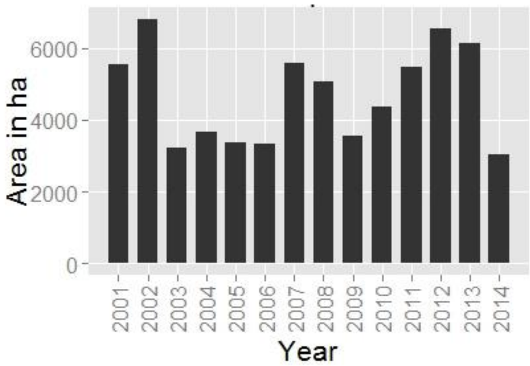
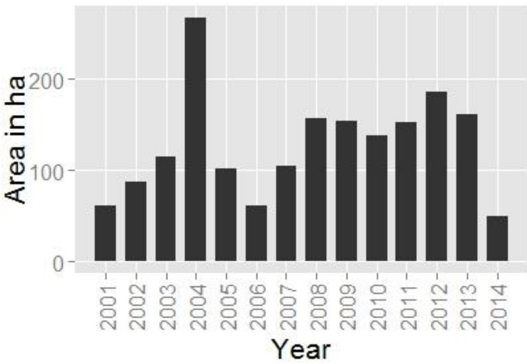


Figure 6: Deforestation in areas above 800 meters above sea level



Source of Figure 5 and Figure 6: author’s own

Figure 5 and Figure 6 show the differences in deforestation in areas below 800 meters of sea level, which is equal to 68.95 % of the entire study area, and above 800 meters of sea level, which corresponds to a proportion of 31.05 % of the study area. 97.34 % of the deforestation in the total period occurred in those areas located below 800 meters of sea level, whereas mountainous areas accounted for the remaining 2.66 % of deforestation between 2001 and 2014. The fluctuations of deforestation in the plains are therefore highly similar to the overall deforestation rates in the study area, with deforestation peaks in the corresponding years. As for deforestation rates in the mountainous areas, there is a remarkable deforestation peak in 2006 and a slowdown from 2005 to 2007, followed by an increasing trend between 2008 and 2013. The average annual deforestation rate for mountainous areas amounted to 0.04 %, whereas it was 0.63 % for those areas below 800 meters above sea level.

3.1.2 Relation between deforestation and protected areas

Figure 7 to 10 display that the protected areas and their buffer zones coincide in an increasing trend of deforestation for several years with different peaks between 2008 and 2013, which are followed by lower deforestation rates towards the end of the study period. There are slowdowns of deforestation in 2006 and 2014 which occur in each of the time series.

Figure 7: Annual deforestation in PNNSC

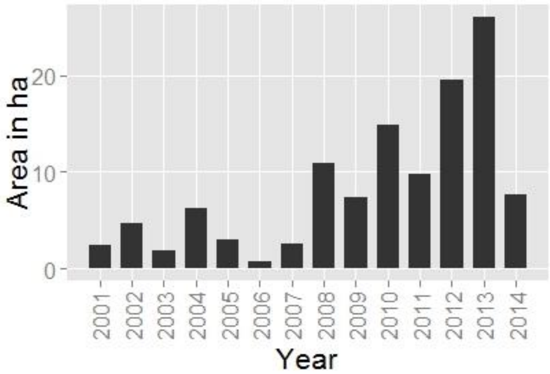


Figure 8: Annual deforestation in the buffer zone of PNNSC

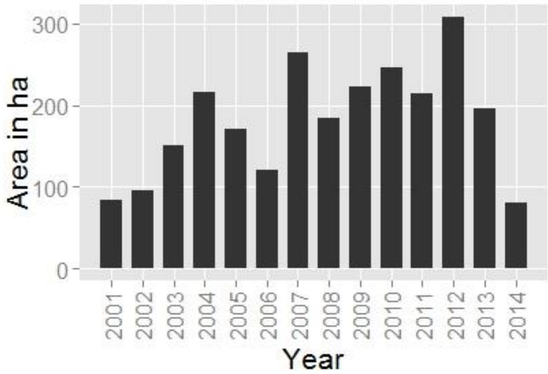


Figure 9: Annual deforestation in RFPCARM

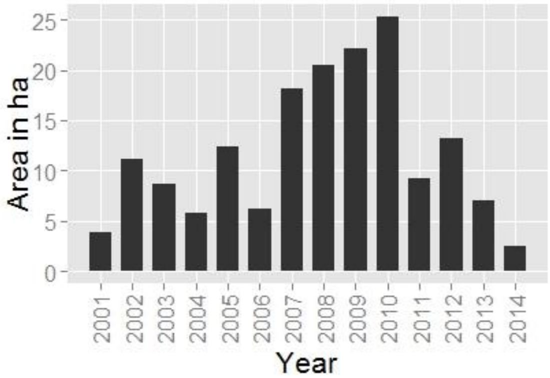
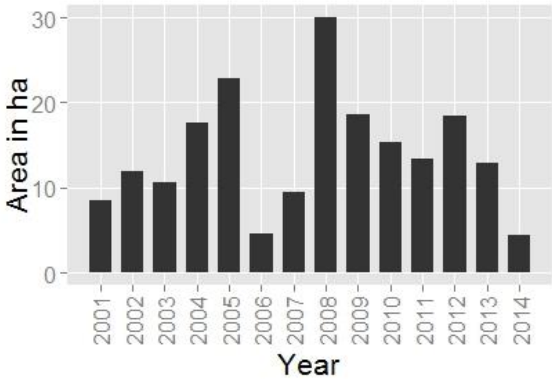


Figure 10: Annual deforestation in the buffer zone of RFPCARM



Source of Figures 7 to 10: author’s own

The PNNSC is the least affected area both in relative and in absolute terms with 0.16 % forest loss between 2001 and 2014. The opposite is the case for its buffer zone, in which 4.40 % of forested areas were affected by forest loss between 2001 and 2014. As for the RFPCARM, deforestation amounted to 0.57 % within the protected area and 0.46 % in its buffer zone.

3.1.3 The spatial distribution of deforestation trends

As has been shown in section 3.1.2, the largest proportion of deforestation occurred in areas below 800 meters above sea level, which corresponds to the south-east, the south and the south-west of the study area. In those regions, deforestation took place in dispersed patches.

Figure 11: The evolution of deforestation patches below 800 meters above sea level

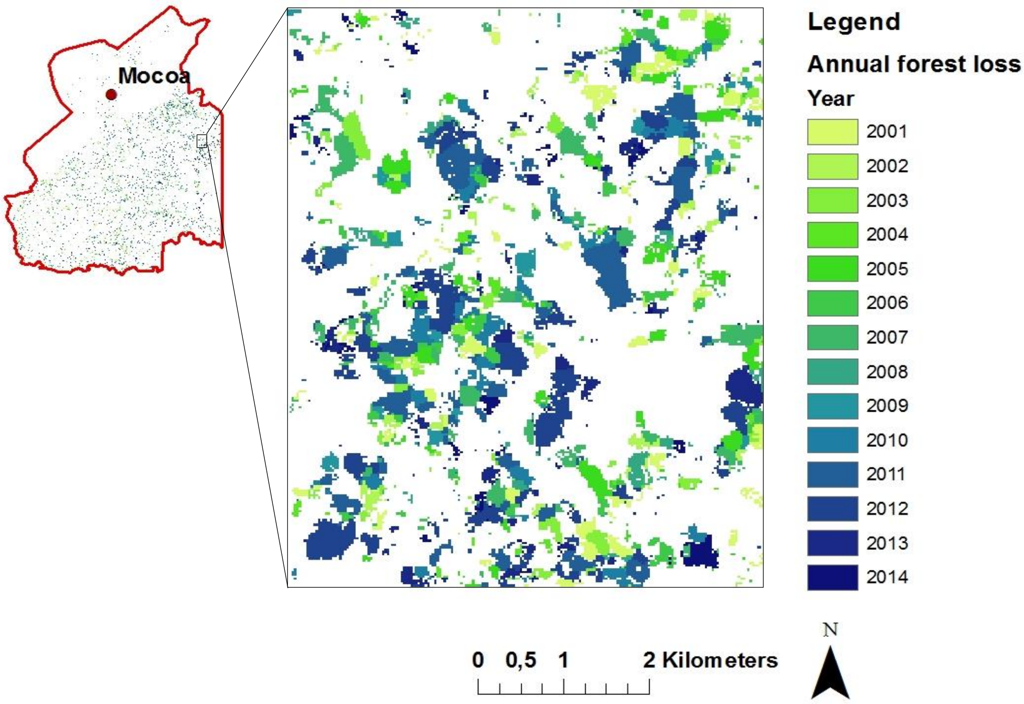
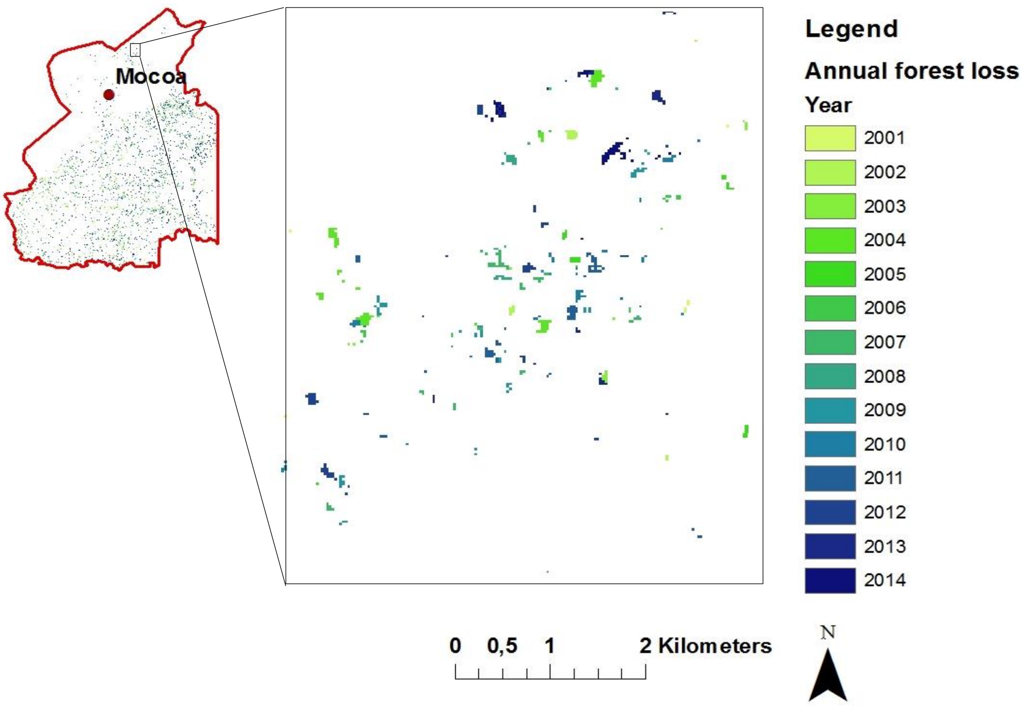


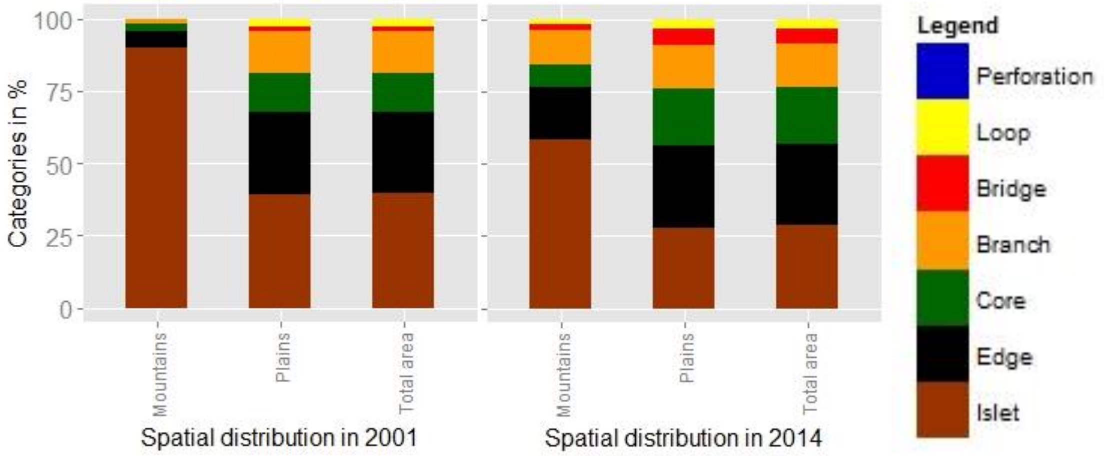
Figure 12: The evolution of deforestation patches above 800 meters above sea level



Source of Figure 11 and Figure 12: author's own

Figure 11 shows an example of the spatial evolution of deforestation in the east of the study area, where some of the largest deforested patches have been detected. Deforestation in areas located at 800 meters above sea level or higher typically occurred in smaller and more dispersed patches, which is exemplified by Figure 12. This visual impression that is obtained when looking at the data in ArcGIS is supported by the results of the MSPA as shown in Figure 13.

Figure 13: The change of MSPA categories in 2001 compared to 2014



Source: author's own

In 2001, the most dominant MSPA category within the total area and both for mountainous and flatter terrain was the islet category, which accounted for 90.19 % and 39.27 % in elevated and flatter areas respectively. The categories edge and core summed up to more than 41 % both for the total area and the plains but accounted for less than 8 % in mountainous areas. By 2014, the proportion of islets decreased for all area types and accounted for 58.35 % and 27.97 % respectively in mountainous and flat terrain. Whereas the category edge only incurred minimal changes in the total area and in the plains from 2001 to 2014, all of the remaining categories increased for all area types, including the bridge category that implies an increased connectivity of deforested patches. The strongest gain occurred for the core category.

Table 7 shows the increasing values for the indicators of patch types for the total area, the mountainous area and for areas below 800 meters above sea level. Although the absolute majority of the number of patches is located in areas below 800 meters of sea level, the relative increase of the number of patches has been the highest in mountainous areas. The average patch area is 0.75 ha for the overall study area and 0.77 ha for the plains, which is approximately twice the size of the mean patch area in mountainous areas. The increase of the mean patch area has occurred with a factor of 1.6 from 2001 to 2014 both for mountainous and flat terrains.

Table 7: Results of indicators of patch types

	Nr of patches		Mean patch area in ha		Effective mesh size	
Type of area	2001	2014	2001	2014	2001	2014
Total area	11574	90213	0.48	0.75	97.72	9196.61
Mountains	276	5142	0.22	0.35	0.83	118.43
Plains	11298	85071	0.49	0.77	141.35	13279.31

Source: author's own

The effective mesh size has increased for deforested areas in all area types, which indicates the increasing connectivity of deforested areas in the landscape. Particularly those areas located below 800 meters of sea level have been affected by an increased connectivity of deforested areas.

3.2 Drivers of deforestation

The interviewees identified a range of direct and indirect drivers that influence each other to varying degrees. Whenever there have been noteworthy differences regarding the opinions or experiences among or within different stakeholder groups, they are mentioned in the respective subsection of each driver.

3.2.1 Direct drivers

The identified direct deforestation drivers that are most relevant within the study area according to the interviewees are illicit crops, cattle ranching, the extraction of wood for different purposes, small-scale agriculture, petroleum and infrastructure. Mining has also been indicated but was said to play a comparatively small role as a direct deforestation driver.

Illicit crops

23 out of 25 interviewees identified illicit crops as a major or even the most important cause of deforestation in the study area, due to the fact that coca is one reason through which the agricultural frontier has expanded into the Amazon by the logging of primary forest. Those who identified illicit crops as a deforestation driver also stressed the regional differences of the impact of coca cultivations: whereas it has caused deforestation on a large scale in the plains in the south of the study area, its impact has

been smaller in mountainous terrain in comparison. The most affected areas that have been mentioned repeatedly are the regions of Puerto Caicedo, La Hormiga and Puerto Asís. However, representatives of the management of protected areas have stated that illicit crops are also present in the PNNSC, where an area of approximately 60 ha with coca plantations has been identified in a recent assessment.

Small-scale farming

18 interviewees noted that small-scale farming is a direct deforestation driver in the study area. They referred to settlers and farmers and partly also to indigenous people who have migrated into or within the study area between 2001 and 2014, and who have cleared parcels mainly for subsistence agriculture and, if possible, the selling of surpluses. Small-scale farming has been identified as the driving force in the process of expanding the agricultural frontier and cutting primary forests. Small-scale farmers are also linked to the cultivation of illicit crops, as a big part of coca growers consists of subsistence farmers who grow coca in addition to subsistence crops in order to generate an actual income. Farmers and settlers have been described as a very mobile and responsive factor within the study area, as they are sensitive to numerous external influences causing them to abandon their parcels and relocate themselves in order to occupy and clear new plots of primary forests.

Cattle ranching

In general, there is a consensus among stakeholders that cattle ranching is more important in Caquetá than in Putumayo, and that cattle ranching influences the south-eastern plains of the study area moving west-wards into the territory from Caquetá. The municipalities Villagarzón, Puerto Caicedo and Puerto Guzmán have been named for being under a particular influence of cattle ranching. However, to a lesser degree, cattle ranching is also present in the RFPCARM and in areas bordering the PNNSC that are sufficiently even to allow for the activity. The prevailing type of cattle ranching in the study area is extensive cattle ranching which is characterized by low degree of technological inputs, a large area that is used per animal[20] and hence, low efficiency and low profitability.

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[20] Stakeholders indicated that one animal occupies approximately one to one and a half hectares of pasture land.

However, there are different perceptions among stakeholders with regards to the actual impact of cattle ranching on deforestation. Three stakeholders, two of them being among the interviewees with the longest experience in the area, have stated that cattle ranching does not play an important role in terms of deforestation, especially in comparison to the strong impact of coca. In contrast, 18 stakeholders have identified cattle ranching as a major and historical type of land use in the study area; and nine of them, both local and regional stakeholders, have stated that cattle ranching is a major direct driver of deforestation particularly in the center, the south and the south-east of the study area. It is also worth mentioning that there are different perceptions among stakeholders regarding the type of impact of cattle ranching on deforestation. The majority of local and regional stakeholders have stated that there is logging with the explicit purpose of establishing pastures. Yet, two stakeholders have stressed that they do not consider cattle ranching a direct deforestation driver as it mostly moves into areas that were formerly used for small-scale agriculture and that have been abandoned or sold due to diminishing harvests. Two stakeholders stated that cattle ranching causes both types of impacts in the study area: the logging of primary forests for the establishment of pastures and the occupation of land that had been used for cropping, including coca. Cattle ranching was also repeatedly mentioned in the context of the speculation on land: interviewees described the existence of a non-transparent process of land accumulation on behalf of wealthy landowners that do not live in the area, but who steer local processes by contracting local agents for land clearing and the accumulation of pasture land. This process is hard to overview according to the interviewees and strongly related to problems and deficiencies in land governance.

Wood extraction

17 interviewees have identified the extraction of wood as an important type of land use in the study area that contributes to deforestation. The wood is extracted for specific purposes and not burned, as it is often the case when converting forested land for other purposes, such as establishing cropland or pastures. The most important uses of wood according to the results obtained from the interviews are the extraction of wood for the construction of housing in the context of human settlements and small-scale agriculture, selective extraction of precious woods, the selling of wood along nearby roads, the use of wood for the production of charcoal that is being sold in the villages, and the use of firewood for the production of limestone. The interviewees agreed that the extraction of

wood for these purposes takes place illegally in the majority of the cases. Several local stakeholders mentioned the existence of illegal wood cartels and the transport of wood on the rivers Putumayo and Caquetá, together with illegal wood from outside of the study area from the south-eastern Putumayo and Peru.

It is noteworthy that no particular locations have been indicated in which this phenomenon prevails, but it has rather been described as an activity that is generally present close to human settlements or roads within the study area. However, it has been mentioned that several tree species that are considered as "precious woods" practically do not exist anymore in certain areas and that wood traffickers have started to move into the PNNSC where these species can still be found.

Petroleum

19 stakeholders identified petroleum as a booming resource in the past decades and hence, as an important land use in the study area with major implications for local communities, interregional migration, other economic activities and the course of the armed conflict in the study area.

According to the representative of the local environmental authority, petroleum tends to be extracted at 300 m above sea level or at a maximum elevation of 600 m above sea level in the study area, implying that it is concentrated in the south towards the border with Ecuador. Petroleum is mainly extracted by the state-owned company Ecopetrol and a number of multinational companies. It is the only commodity that is exported to other regions and has represented a significant source of income for the central government. Direct deforestation for the reason of drilling for crude oil is comparatively little, even if the deforested safety buffers around these sites are taken into account.[21] A bigger concern was uttered regarding the contamination of water bodies and gorges through the discharge of toxic substances that result from processes related to the exploitation, handling and processing of crude oil. It is especially local communities consisting of farmers and indigenous people who suffer from the contamination of water resources. The leader of an indigenous association indicated to know of communities in La Hormiga facing problems to obtain potable water and the contamination of fish that

[21] A local stakeholder has described how oil companies deforest a surrounding buffer of approximately 5 km around the sites with oil extraction in order to prevent possible intruders and to detect potential attacks on behalf of the guerrilla.

used to be caught by the community. Both local and regional stakeholders have stated that neither municipalities nor local communities have been compensated to a sufficient degree for the environmental damage that they are facing.

Despite these direct impacts of the industry, the most frequently mentioned problem related to petroleum was the construction of road infrastructure. According to the interviewees, petroleum has been the main, if not the only driver of the construction of roads in the south of the study area in recent times. Roads are indispensable for the transport of equipment and machinery to the extraction sites, and for the oil trucks to transport petroleum through Mocoa and further northwards into the center of the country. Oil companies and roads have attracted the migration waves of workforce, farmers and settlers who provide various services in these areas. Consequently, human settlements are established nearby the extraction sites of petroleum, with related activities such as the extraction of wood and logging and burning for the establishment of small farms and pastures. In addition, two stakeholders holding managing positions have stated that petroleum has not only had an impact on social factors in its surrounding areas, but that it has distorted the entire economic scenario in the region. Given that the state has mainly focused on the promotion of this industry, it has neglected investments into the development of other sectors; and petroleum has become the driving socio-economic force.[22]

According to several stakeholders, petroleum has also intensified the armed conflict in the study area. Pipelines have been a frequent subject to blow-ups by the guerrilla, which has also blackmailed oil companies and kidnapped employees in order to extort financial resources. Furthermore, one regional stakeholder has stated to have knowledge about the past affiliation of oil companies with paramilitary groups in the study area in order to obtain protection against guerrilla attacks.

Infrastructure

As has been mentioned in the context of petroleum, stakeholders have considered roads as an important deforestation driver. Whereas the deforestation taking place directly for the construction of roads is comparatively little, the impact on migration and the

[22] For instance, stakeholders mentioned that a slowdown of the extraction of crude oil increases the pressure on wood extraction and mining, as affiliated laborers and settlers opt for alternative sources of income.

establishment of human settlements and the provision of services is considered significant, as roads provide access to formerly untouched areas. Stakeholders described how the construction of roads leads to speculation on future economic opportunities, and how the surrounding land gains value immediately. Furthermore, stakeholders explained that the presence of roads increases the likelihood of wood extraction as it can be transported more easily or sold directly along the roads.

In the south of the study area, the topography of the road network is determined by the oil industry. In areas that are outside of the spatial scope of the industry, road infrastructure is scarce. The lack of roads in these areas has been mentioned as a reason for which local commercial food production has not been developed in the study area, as there is no way of transporting agricultural products such as platano to populated areas and bigger cities. Several stakeholders have mentioned how this fact favors the cultivation of coca, as coca leaves can be transported easily in bags and do not necessarily require any vehicles or pack animals.

Three stakeholders have also mentioned the role of rivers in terms of infrastructure for transporting extracted wood between locations and for reaching remote areas. According to these interviewees, areas close to rivers are more prone to deforestation processes.

Mining

14 stakeholders mentioned mining as a type of land use that has had comparatively small implications for deforestation to the present day in the study area. The interviewees stated that gold is the most important mineral, followed by copper and molybdenum. Most of the mining was found to be informal, partly traditional small-scale mining that is considered illegal by the state. Furthermore, two interviewees stated that mining is related to armed groups in some cases, and that trying to exercise control in affected areas can be dangerous and even life-threatening.[23] Locations identified by the interviewees as being affected by mining in terms of deforestation are in the foothills in the north of Mocoa and along the rivers Putumayo, Puerto Asís, Cauca, Caquetá and Puerto Guzmán. Interviewees agreed that the impact of mining has

[23] One representative of an indigenous reserve reported on the presence of illegal mining within the territory of the reserve and the killing of one community leader in 2005 in the context of the conflictive land use interests within the reserve.

increased throughout the past years as heavier machinery has been introduced in the respective sites.

3.2.2 Indirect drivers

Stakeholders have mentioned a wide range of underlying deforestation drivers, the most important ones being the armed conflict, poverty, the Colombian state and its institutions, cultural habits and a lack of knowledge.

The armed conflict

21 interviewees stated that they believe that the armed conflict, hence the armed actors engaged in it and the violence that has come along with it, has had a significant impact on the environment in the study area. Both local and regional stakeholders stated repeatedly that the area is among the most affected regions in the entire country, and that the guerrilla forces in the area belong to the most combative groups of the FARC. However, stakeholders have disagreed regarding the type of impact of the armed conflict on the environment.

17 interviewees described how the armed conflict has fueled deforestation in the study area mainly for two reasons: firstly, because both the guerrilla and paramilitary groups have promoted the presence of illicit crops in order to generate income through fees charged on coca growers. Secondly, because the violence linked to the armed conflict has caused the displacement of entire communities within the study area, but also the inflow of people who had been expelled through violence from regions outside of the study area.[24] Furthermore, two members of indigenous communities mentioned that the presence of armed actors engaged in illegal mining in their reserve has prevented the community from protecting the forests in the area[25] and a representative of the local environmental authority mentioned that the presence of the guerrilla has inhibited the development of sustainable forest management in various areas.

There have been ten locally and regionally engaged stakeholders who were convinced that the presence of the guerrilla has protected various forested areas from deforestation,

[24] One representative of an NGO who is responsible for the engagement with local communities explained that most people that migrate into the study area are originally from the departments Cauca, Huila and Caquetá.

[25] Both representatives of the indigenous reserve explained that one of their leaders was killed by illegal groups in 2005 and that families of the community were attacked with gunshots.

particularly in mountainous terrain. The interviewees explained their view by stating that the guerrilla groups are known for exercising control in their areas of influence by determining which parts of the land may be used by farmers and which forested areas have to remain untouched, and that communities respect these rules as they would face high risks such as landmines and attacks in these areas. Also, the protective role of forests for hiding plantations of illicit crops has been mentioned as a reason for the guerrilla to maintain forests in areas that are under their control.

Two regionally engaged stakeholders explicitly disagreed with this point of view: according to them, the FARC has not only promoted illegal types of land use, but also accumulated cleared land in order to reflect their wealth.

Poverty

13 stakeholders mentioned poverty as an underlying driver for activities that cause deforestation: people in rural areas lack alternatives that would allow them to survive in a way that does not entail the degradation of the environment through the extraction of wood, mining or subsistence agriculture. According to the interviewees, the non-existence of a noteworthy local production of commercialized agricultural products or any other merchandise explains why illicit crops represent the only economic alternative, especially in regions with scarce or no infrastructure. Furthermore, the majority of the population in rural areas lacks access to credits according to an interviewed representative of the local environmental authority.

Culture and lacking knowledge

A total of 19 stakeholders indicated cultural and educational reasons for deforestation in the study area. Eight stakeholders stated that forests as such have no economic or cultural value for the population in the study area, and that a forest culture is non-existent among settlers and farmers. Instead, the influence of Andean cultures is strong in the region, a culture that has been described as closely linked to the concept of wealth being reflected mainly in the property of pastures and cattle. Hence, the conversion of forests to pastures is understood as the valorization or the improvement of land, and the development of a region is understood as a process of colonization and logging for the establishment of cattle ranching – a way of thinking that is wide-spread among settlers and farmers, but also among local and regional governors. Five stakeholders believed that a lacking sense of belonging among settlers and farmers is a problem in the region, which they said is rooted in the high degree of immigration from different departments, the diverse range of cultural backgrounds and thus, the perception of the environment as a place of work or a temporary space for living. Stakeholders described how these conditions support short-term thinking and interests into the maximization of monetary benefits from the exploitation of natural resources. They also stated that the insecure situation due to war and fumigations hampers long-term planning. Three local stakeholders described how local indigenous cultures that used to be closely linked to the sustainable use of tropical forests in terms of subsistence farming and the use of medical plants are disappearing due to the mentioned increasing external influences and short-term interests. On the one hand, this development has caused the displacement of indigenous communities, but on the other hand, some indigenous communities have started to also engage in short-term related activities such as coca cultivation and wood extraction.

In addition, five local stakeholders indicated that there is a general lack of environmental education in the study area, implying that especially peasant communities are not aware of the environmental damage that is linked to deforestation and cattle ranching. Furthermore, stakeholders described how communities with differing cultural backgrounds lack knowledge on local food crops and medicinal plants, and also on how to adapt agricultural practices to tropical conditions. This implies that communities maintain their traditional agricultural practices and accelerate the degradation of tropical soils, which leads to the necessity of logging more forest for new agricultural parcels.

The state

Without any exception, stakeholders stressed the role of the state as a major underlying factor contributing to deforestation in a number of different ways, which can be summarized by the following key factors: the lacking sovereignty of the state, a centralized political system and conflictive political interests regarding natural resources, the non-implementation of environmental laws, short-term environmental policies and missing alliances with other stakeholders in the process of political decision making.

Regarding the lacking state sovereignty, stakeholders mostly referred to the abandonment of certain areas[26] due to the presence of guerrilla groups which replace functions of the state in these areas and exercise control, including the recruitment of new members and decisions on land use. In addition, the study area used to be categorized a “red zone”, implying the strong presence of illegal armed groups, drug production and violent attacks and thus, very little control by the state and few investments into public services such as health care and education. Stakeholders uttered that the non-existent authority of the state has enabled the importance of coca in the region and the establishment of a wide-ranging informal sector that is linked to drug trafficking, wood extraction and mining – partly even in protected areas. Six regional stakeholders stressed the weakness of institutions in the region and gave examples on how their capacity in terms of personnel, technology and budgets is insufficient to react adequately to deforestation alerts. The representatives of an NGO and of an international cooperation agency gave examples for situations when they were asked for help by environmental authorities. In addition, the representatives of indigenous communities claimed that the state does not defend local communities in cases of illegal land use on their territory, which is why they feel abandoned by the state.

17 stakeholders indicated that the centralized political system and its focus on policies that favor extractivism translates into environmental problems at the local level. Stakeholders indicated that royalties of oil companies represent an important source of income for the central government and practically the only element that is of strategic importance for the central government in the region. Consequently, stakeholders described how petroleum-related projects with so-called national interests override environmental policies such as the status of forest reserves and the rights of local communities, a process which is generally justified with the argument that the subsoil is state property according to Colombian law. Consequently, the stimuli for conservation and local projects that promote sustainable production practices are low. Furthermore, one representative of entrepreneurs described negative first-.hand experiences regarding disproportionately high administrative obstacles for obtaining official licenses for alternative production systems.

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[26] La Hormiga, Orito and Puerto Asís were named as regions that have historically been under the control of the FARC.

Another six stakeholders have criticized the general short-term character of previous institutional policies or projects that were supposed to prevent deforestation and promote alternative local production systems. Frequently, such projects are subject to a maximum of the four-year presidential period and stakeholders claimed that they lack post-project follow-ups or monitoring. In addition, the collaboration between governmental institutions and NGOs, research bodies and other agencies is hampered by the cyclical replacement of staff in administrative bodies. Four regional stakeholders with contacts at the political level claimed that the lacking cooperation and coordination between researching entities, territorial entities and political decision makers is a problem that is rooted in lacking technological capacity for processing and preparing real-time information, the non-existent culture to cooperate across entities and the habit of decision makers to use aggregated macroeconomic data as the most important base for decision making.

Land governance

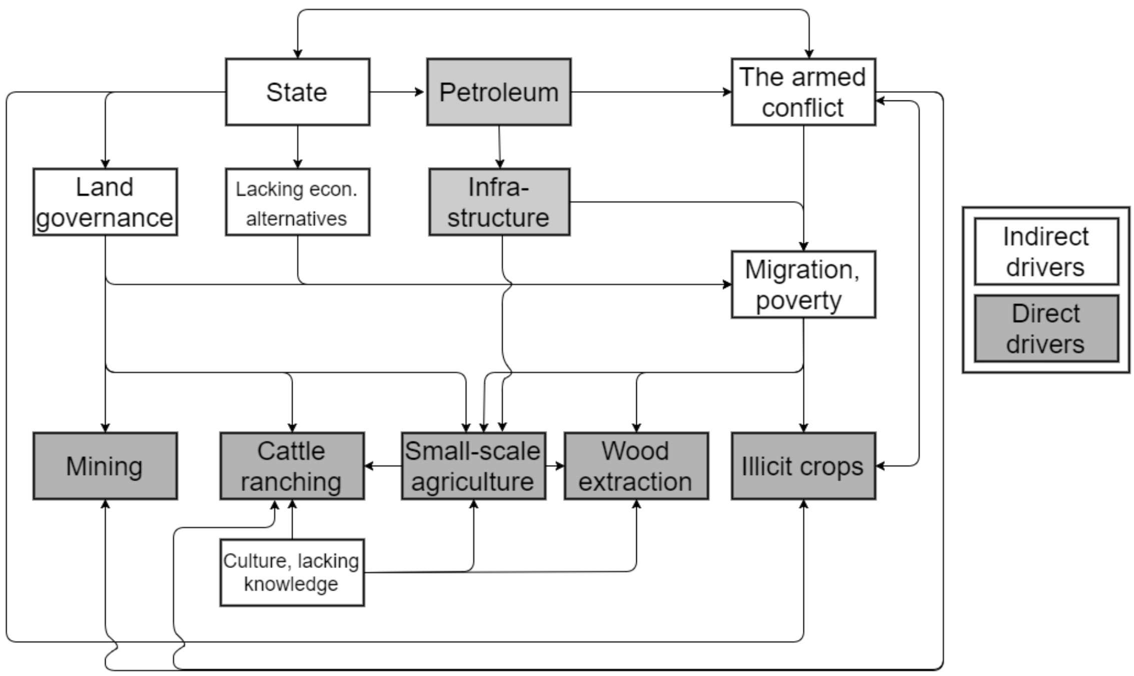
Nine stakeholders stated that the situation of land governance contributes significantly to the problem of deforestation as it actually implies an incentive for land clearing. Stakeholders described how titles of ownership are only allocated if potential landowners prove that at least two thirds of the area of interest is productive in the sense of cattle ranching or agricultural production. One entrepreneurial stakeholder explained that the production of forest-related outputs such as resin, butterflies or honey is not accepted as a type of production that would allow for land ownership. Consequently, titles of land ownership are only allocated if the majority of the land is cleared and used for cultivation or cattle ranching.

Furthermore, there is no clearly defined regulation of land allocation regarding many forested areas on behalf of the state. Land is cleared without any official permits and speculatively in order to valorize and sell it to future land owners who accumulate land and apply for land ownership. Stakeholders described in this context how land is cleared and converted to meadows even without the establishment of cattle ranching, but merely for valorizing and selling the land. One local and politically engaged stakeholder claimed that this process not only benefits potential land owners, but also the local government which has an interest in land clearing and the allocation of land titles as it obtains cash flows from property taxation.

3.2.3 The relationship of direct and indirect drivers

The interviewees have described how direct and indirect deforestation drivers influence each other, and how there are also impacts within the group of direct and indirect drivers respectively. Figure 14 attempts to display the relationships between the most relevant drivers according to the perspective of the interviewees.

Figure 14: The relationship of direct and indirect drivers in the study area



Source: author's own

The scheme of the relationship between drivers resembles a network, as each driver is under the influence of at least one other factor. The analysis of the interviews has led to the identification of three core nodes in the category of indirect drivers: 1) the state and its failure to provide long-term and continuous stimuli for the establishment of fruitful local productions systems that would prevent poverty and migration. Related to this aspect is also the state's land governance which has incentivized clearcutting, the establishment of meadows and speculation on land; 2) the state and the promotion of the oil industry, and the resulting stimulation of oil-related road infrastructure especially in the south of the study area. This aspect has contributed to a militarization of the armed conflict and has caused migration waves within the region, resulting in deforestation originating from roads and infrastructure; 3) the armed conflict that has caused forced displacement and poverty and which has promoted the increased mobility of the coca economy.

With respect to direct drivers, illicit crops may have generated the largest impact on deforestation. Illicit crops have been promoted by three main agents: 1) migration waves and poor communities who lack alternatives or for which coca represents the only means to leave subsistence agriculture and generate and actual income; 2) the armed conflict, as armed actors benefit from coca as one of their most important source of income; and 3) the state, which has invested considerable efforts and funds into the eradication of illicit crops and thus has contributed to the disperse distribution of cultivations into more remote areas and to a high degree of mobility of coca growers. There is an entire parallel economy evolving around the production of cocaine, and the profitability of the value chains has increased the capacity of environmental destruction in the study area given the ability of coca growers to afford technological inputs[27] and the financing of the armed conflict. Small-scale agriculture and wood extraction are direct drivers that are fueled by the mentioned migration, poverty and lacking economic alternatives, but also by lacking knowledge regarding sustainable agricultural practices in the tropics. Small-scale agriculture is also related to cattle ranching, as ranchers tend to move into areas that have been abandoned by small-scale farmers. Cattle ranching is supported by a strong influence of the Andean culture, for which cattle are more valuable than crops or forests and easily transferrable to cash. Cattle ranching is also used as a method to accumulate and appropriate land, which is supported by the land governance of the state. In addition, cattle ranchers have been said to associate with illicit armed actors for the protection of their land, and that armed actors have an interest reflecting their assets in pasture land. Mining has been said to still play a comparatively small role. Depending on the agent realizing mining activities, it is supported by the state in the case of international or medium-sized companies, but it is also associated with armed actors.

3.2.4 The evolution of the importance of drivers

The interviewees were asked about their perceptions regarding possible changes in the importance of direct and indirect deforestation drivers through time and especially with regards to overall deforestation rates in the study period from 2001 to 2014 as shown in Figure 3 in section 3.1.1. The results are summarized in Table 8.

[27] E.g. chainsaws.

Ten interviewees recommended linking the deforestation rates of the overall study area to the course of the armed conflict and related state policies, especially the Plan Colombia and the fumigations of illicit crops. In general, interviewees preferred making rather general statements on the evolution of deforestation drivers and were hesitant to assign concrete events or developments to deforestation trends within the study area.

Table 8: The impact of deforestation drivers from 2001 to 2014

Period	Deforestation trend in the study area	Mentioned development of direct and indirect drivers
2001-2002	Deforestation peak	Strong expansion of coca cultivation Displacement of communities
2003-2006	Slowdown of deforestation	DMG gains momentum and paralyses remaining sectors
2007-2008	Deforestation peak	End of DMG causes an upswing of other activities Coca cultivation Cattle ranching Mining
2009-2011	Gradual increase of deforestation)	Coca cultivation Woodwork People start to return to abandoned places Cattle ranching Mining
2012-2013	Deforestation peak	Cattle ranching Coca cultivation Small-scale agriculture
2014	Slowdown of deforestation	No explanations offered

Source: author’s own

However, there were some noteworthy exceptions: Nine stakeholders were convinced that a strong expansion of coca plantations caused a deforestation peak in 2001 and 2002, and another four stakeholders said that massive displacements of local communities related to the armed conflict in those years contributed to accelerated deforestation rates.

The most frequent explanation for the slowdown of deforestation rates from 2003 to 2006 was the establishment of the fraudulent investment scheme of the Colombian company DMG and its wide-ranging influence on the local economy. Interviewees described how the establishment of DMG[28] in Putumayo motivated people to abstain

[28] DMG’s business model offered customers the opportunity to buy pre-paid cards and that could be used to buy consumer electronics and appliances form retailers. After a period of several months, customers

from work, to abandon agricultural activities, and even to sell their belongings in order to invest as much money as possible into DMG’s financial schemes. The paralysis of numerous economic activities implied a slowdown of deforestation according to the interviewees. From 2007 onwards, the interviewees’ explanations for deforestation rates and the evolution of the importance of deforestation drivers are less consistent. As for the deforestation peak from 2007 to 2008, the interviewees suggested that the cultivation of coca, cattle ranching and mining might have experienced an upswing in the territory after the elimination of DMG. Regarding the gradual increase of deforestation rates between 2009 and 2011, explanations included that coca cultivations and woodwork gained more importance, that cattle ranching continued to spread in the territory and that the armed conflict began to settle to an extent that allowed people to return into rural areas and to resume activities related to agriculture and woodwork. Regarding the deforestation peak from 2012 to 2013, the majority of interviewees expected cattle ranching and illicit crops to be the main reasons for increased deforestation rates. However, it is worth mentioning that there were contradicting statements of interviewees, as two stakeholders argued that illicit crops are still present but do not play an important role anymore in the study area according to official reports. For the slowdown of deforestation in 2014, interviewees had either no explanation or expressed their doubts about an actual downwards trend in that year.

3.3 Potential preventive measures

Without any exception, all interviewees had suggestions and ideas for measures to slow down deforestation. The recommendations made by the interviewees may be grouped into the following categories: alternative types of land use and production systems, government-driven measures, community-driven measures and alliances between stakeholder groups. Furthermore, interviewees were asked explicitly to state on their

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would receive a return of 150 to 300 % on their initial investment in addition to the purchased consumer goods, and customers would also become salesmen for promoting the reach of DMG (Carvaja et al., 2009, pp.36–37). The system relied heavily on the constant recruitment of new customers, as returns to already engaged customers were paid through the cash inflow of new customers instead of actual investments.

DMG was founded in Putumayo and spread throughout Colombia and further to other Latin American countries. It was prohibited by the Colombian state in 2008, after four million citizens had invested more than one billion USD and banks warned that they may collapse if withdrawals of savings continued at the same pace (Carvajal et al., 2009, p.40).

attitudes towards the effectiveness of the establishment of further protected areas in order to prevent deforestation.

Improvements and alternatives for production systems and land use types

The majority of the interviewees (20) considered that improved and alternative kinds of land uses compared to the existing ones could make a major contribution to the prevention of deforestation in the future. Table 9 summarizes the suggestions of stakeholders, which can be grouped into measures for the improvement of current productions systems and the establishment of alternative sectors and land use types.

Table 9: Alternative production systems and land use types

1) Improvement of current production systems	
Production system	Examples for improvements
Small-scale agriculture	Replacement of traditional non-tropical crops with local crops Mixed cultivations Crop rotation
Cattle ranching	Intensive cattle production in barns Grass-cutting on meadows for animal feeding Silvo-pastoral systems
2) Establishment of alternative sectors and land use types	
Sector	Examples for initiating the sector
Food production	Production of local food crops and fruits
Production of local commodities	Mixed cropping systems and plantations for the production of fruits, coffee, cocoa, spices, resin, honey and other products
Certified forestry and woodworking industry	Establishment of a value chain for commercial wooden products consisting of tree plantations, sawmills and woodworking companies Agroforestry
Pharmaceutical industry	Commercial use of medicinal plants and trees of the Amazon Medicinal and pharmaceutical research
(Eco-)Tourism	Observation of animals, e.g. bird watching Trekking and guided tours to waterfalls, gorges and viewpoints in- and outside of protected areas Cultural tourism Research tourism
Recycling and reprocessing plants	Processing of solid wastes, particularly plastics Production of furniture from recycled materials

Source: author’s own

Most of the suggestions entail land use types or activities that adapt to the particular conditions and the potential of the Andean-Amazonian foothills instead of imposing traditional land use types from the center of the country onto tropical regions, which is the case for improved small-scale farming, local food production, the local production of commodities, the establishment of a pharmaceutical industry and tourism. Several stakeholders emphasized the necessity to replace the imports of food products with local food production, given that many activities related to deforestation are rooted in the necessity to generate money for buying food and other imported products. These interviewees argued that a local and less import-oriented economy would provide the necessary base for replacing current activities related to deforestation with the legal production of local food products and other commodities. Furthermore, the interviewees emphasized that mass-production and monocultures with regards to agricultural commodities should be prevented.

Government-driven measures

Approximately half of the interviewees (12) stressed the role of the state as a fundamental actor for preventing deforestation in the future. The most important identified governmental responsibilities were 1) continuous and long-term guidance in the establishment of alternative land use types, particularly regarding alternative types of subsistence farming for communities and the establishment of new strategies for conservation schemes; 2) the alteration or adoption of normative conditions so that communities are enabled to develop legal alternative production systems; 3) the allocation of an increased amount of funding within the Andean-Amazonian foothills into public social services, agricultural training and the stimulation of the local economy; 4) the strengthening of the governability and capacities of local environmental entities and authorities; 5) the promotion of participative decision making at the local level and the decriminalization of indigenous and peasant communities; 6) the strict implementation of the existing environmental regulation and more environmental control; and 7) the establishment of new adequate thresholds and limits on the extraction of resources and land use types by taking into account biodiversity hotspots and ecosystem services.

Five interviewees emphasized the role of the state in the so-far reluctant implementation of environmental compensations schemes: despite the fact that according to the current legislation, companies have to compensate for environmental damage that they cause for instance through reforestation or restoration, implementing this measure has been inadequate or has not been realized at all according to representatives of an NGO, an international cooperation agency, the local administration and a governmental research institution. According to these interviewees, compensation schemes would entail a considerable potential for reforestation and the protection of forests, and stated that the state had to assume its responsibility for putting existing legislation into practice.

Education and cultural recovery within communities

Twelve interviewees considered the strengthening of peasant and indigenous communities a necessary prerequisite to slow down deforestation in the study area. The interviewees mentioned environmental education, the empowerment of communities with access to information and knowledge about ecosystem services in their territories and self-coordination as important elements of the process of strengthening communities. Furthermore, all representatives of farmers and indigenous communities stressed the necessity of communities to recover their former cultures and related sustainable agricultural practices. As for indigenous communities, traditional farming systems that combine the cultivation with food crops and medicinal plants were mentioned as a sustainable way of indigenous subsistence agriculture that has been displaced by other external land use practices related to deforestation in the study area.

Alliances between stakeholder groups

Eleven interviewees stressed the necessity to create alliances between stakeholder groups in order to promote adequate sustainable land use types and binding agreements between stakeholder groups. Interviewees mentioned indigenous communities, peasant communities, the local administration, the local environmental authorities, NGOs, the scientific community and entities of the central government as the most relevant stakeholder groups that need to establish alliances for joint decision making on land use. Three of those interviewees stated that improvements in land management can only be established by a bottom-up approach, hence through local and very targeted initiatives and local decision making that is derived through a participative process, and that local indigenous and peasant communities need to be well organized internally for negotiation processes.

Protected areas

It is worth mentioning that the interviewees were asked explicitly whether they consider the establishment of new protected areas a useful measure to prevent deforestation. 16 stakeholders, including all representatives of indigenous communities and all representatives of the management of protected areas, had a positive attitude towards the establishment of new protected areas. Ten of these stakeholders who agreed on the necessity of establishing new protected areas added that several conditions would have to be fulfilled in order to guarantee effective conservation of forests in these areas: the process of determining, establishing and managing the target area would have to be an inclusive and participative one that ensures the involvement of local stakeholders, the promotion of environmental education and the possibility of combined systems of conservation and sustainable food and wood production within protected areas. Four members of an NGO, the tourism sector, the management of a protected area and the national environmental authority claimed the necessity of establishing non-negotiable, hence untouchable zones within protected areas in order to prevent biodiversity loss and to safeguard ecosystem connectivity.

Nine interviewees, including the representative of the local environmental authority, had a negative attitude towards the current concept and management of protected areas and the establishment of further ones in the future. According to them, the current governance of protected areas lacks sufficient budgets, personnel and technological capacity for effective conservation, as most of the protected areas in the study area and in Colombia in general are subject to settlements, different non-sustainable land use types and the extraction of natural resources. Hence, these stakeholders stated that instead of creating new protected areas, the already existing ones ought to be strengthened and connected with bio-corridors between them, and communities ought to be given alternatives to survive on.

In summary, no matter the attitude of the interviewees towards the establishment of new protected areas, the majority of stakeholders indicated that protected areas ought to be a part of more integrated and participative land governance instead of areas with restrictions on land use that cannot be translated into the reality of the region.

3.4 Stakeholders’ expectations for the future

As for stakeholders’ expectations for the future post conflict scenario with regards to deforestation and its direct and indirect drivers, 21 stakeholders made indications about potential future risks that they anticipate, and 19 stakeholders mentioned different kinds of opportunities for a more sustainable development within the region.

Risks

Eleven stakeholders mentioned that the post conflict might come along with negative environmental impacts due to increased migration, and that the situation of deforestation might actually become worse than it has been in recent history if the state does not manage migration and land use with adequate regulation. The largest perceived risk among stakeholders concerns the occurrence of further economic booms, an upswing of the oil industry, increased mining activities and cattle ranching, a growing trend in the cultivation of coca and increased free mobility in the region due to the absence of violent actors and hence, accelerated exploitation of natural resources and deforestation.

Those stakeholders who believed that the presence of the guerrilla has contributed to the protection of forests in some areas also think that these areas will be prone to accelerated deforestation in the post conflict as there would be no more coercive force executing control over the land use in these territories. At the same time, all of the indigenous representatives had doubts about the successful reintegration of armed actors into society and feared an increase of violence particularly in Mocoa, and a continuing denial of their territorial rights on behalf of the state also during the peace process.

Another six regional and local stakeholders identified roads and large infrastructure projects for easier connections with other Latin American countries as a major future risk in terms of deforestation. The "marginal de la selva" was mentioned in particular by five stakeholders. The road is currently under construction and will connect Bolivia with Venezuela, with a section of the road leading through the Colombian Amazon, including the study area.

Opportunities

14 Stakeholders hope for different kinds of positive development trends related to a peace agreement: more trust between communities and entities, more adequate governmental planning that will lead to an equilibrium between socio-economic needs and environmental issues through agrarian reforms, investment into health care and education, local food production, reforestation, forest plantations and conservation. Four of these stakeholders saw an opportunity in the potential role of the guerrilla as official forest safeguards and contributors to the management of protected areas, given that members of the guerrilla are said to have excellent knowledge about the forest. Seven

stakeholders anticipate a positive trend in the region due to the gradual establishment of the touristic sector that would attract both national and international visitors and combine an economic growth of the service sector with sustainable land uses.

Six stakeholders indicated that they have started to experience a changing consciousness within communities, but also at the administrative and at the central political level regarding the growing awareness for environmental problems. All of the stakeholders who mentioned these changes emphasized that the shift in the way of thinking about natural resources and ecosystem services provided by forests is a slow process that has just begun and is likely to take several decades, but that they are hopeful in terms of a continuation of this development through environmental education and a gradual change of cultures. According to the interviewees, the negative effect of deforestation can be best understood through the fact that a deterioration of forests has already had the first dramatic consequences for the supply of fresh water in the study area.[29] According to the interviewees, these incidents have contributed to the growing consciousness for the importance of forests among communities and within administrative and political entities.

4 Discussion

In this part, the results of the previous section will be interpreted and the limitations of this thesis and its main conclusions will be presented. The last subsection is an outlook on potential further research topics related to deforestation in the Andean-Amazonian foothills.

4.1 Interpretation of results

In the following, the results presented in section 3 will be interpreted by combining quantitative and qualitative findings and by triangulating them with official information or academic literature in those cases that allow for such a comparison.

[29] For instance, a local stakeholder reported on an incident of a school that had to be closed down temporarily for lacking fresh water, and several local and regional stakeholders stated on the diminishing quality of water bodies and on the proceeding decrease of the water supply of some smaller rivers.

4.1.1 Deforestation pattern

The quantification of deforestation rates in the study area has led to several conclusions, which mainly concern the overall trend of continuing deforestation in the Andean-Amazonian foothills, the role of the altitudinal gradient on deforestation, the effectiveness of protected areas, and the implication of the spatial distribution of deforestation patterns for the interpretation of deforestation drivers.

Firstly, the analysis has shown that deforestation in the study area has been a persistent phenomenon throughout the study period from 2001 to 2014 with an average annual deforestation rate of 0.44 %. Within this period, there were no indications for the beginning of consolidated slowdown of deforestation. Instead, the cyclical behavior of deforestation rates indicates a high degree of responsiveness and vulnerability of forests to local developments.

Secondly, the analysis has given clear indications for a strong influence of the altitudinal gradient on deforestation rates in the region. Approximately 97 % of deforestation has taken place in areas below 800 meters of sea level with an average annual deforestation rate of 0.63 %, suggesting that flatter areas are considerably more prone to forest removal than mountainous areas. This trend coincides with the observations and experiences of the local and regional informants who have been interviewed for this thesis. Steep slopes complicate the access to these areas and have up to now represented a natural barrier to the spreading of land use types that are present in less elevated areas, such as the cultivation of illicit crops, cattle ranching and small-scale agriculture. Nevertheless, the overall trend of deforestation in mountainous areas has been increasing.

Thirdly, the analysis has shown that neither the presence of the forest reserve nor the national park completely prevented deforestation within these territories. Although annual deforestation rates are low in comparison to overall deforestation rates in the study area, there has been an increasing trend from 2001 to 2014 in the PNNSC, and from 2001 to 2010 in the RFPCARM. As stated in the interviews by members of the management of protected areas, both the PNNSC and the RFPCARM have benefited from their locations in mountainous zones and difficult access conditions, and they would probably face higher deforestation rates if the access to these areas was easier. The fact that deforestation rates in the buffer zone surrounding the RFPCARM are actually lower than deforestation rates within the RFPCARM suggests the limited effectiveness of forest reserves for preventing deforestation in comparison to natural boundaries and difficult access conditions. In comparison, deforestation rates in the buffer zone of the PNNSC outnumber deforestation rates within the national park, which can be interpreted in various ways: one possible explanation might be that the access to the buffer zones of the PNNSC is comparatively easy. Another reason could be that the management of the national park has been effective in protecting the territory of the national park; or that the national park has incurred less deforestation due to the coercive control of armed actors who are present in the park,[30] as indicated by members of the management of the PNNSC. The most likely explanation might also be a combination of factors depending on the location within the PNNSC.

Fourthly, the analysis of the spatial distribution of deforestation trends supports the aforementioned findings regarding the impact of the altitudinal gradient and the results of the qualitative analysis of deforestation drivers. The calculation of the spatial distribution of MSPA categories resulted in the islet category with approximately 90 % and 40 % for mountainous and flat terrain respectively. This result indicates that deforestation in areas above 800 meters of sea level has mostly occurred in small and dispersed patches that are smaller than 0.4 hectares, and this trend has continued until 2014 despite the fact that existing deforestation patches have increased in size throughout the study period. Regarding those areas below 800 meters of sea level, the categories core, edge and branch accounted for more than 60 % of deforested areas (in comparison to 37 % in mountainous areas) by 2014, showing that deforestation in those areas is comparatively more consolidated and that existing deforestation patches gain in size and comprise a larger area than deforested islets. These results are supported by an increase in the bridge category and an increasing trend of the effective mesh size of deforested patches, which imply a gradual augmentation of the connectivity of deforested areas. However, it is necessary to emphasize that even though previously deforested areas gained in size from year to year, the average size of deforested patches remained lower than 0.8 hectares even in flatter areas. These results are consistent with the diffuse type of the spatial deforestation typology that has been described by Geist and Lambin (2001, p.66) and are an indicator for dispersed small-scale activities as the

[30] Note that the ambiguous role of the armed conflict on deforestation will be discussed further in section 4.1.2.

main cause of deforestation in the study area. There are some areas for which deforestation patches are more concentrated, especially in the south of the municipality Santa Rosa and in the municipality Puerto Guzmán, which are both located in the south-east of the study area. Still, even in those areas there is no indication for an organized large-scale activity such as land clearing for wide-spread monocultures or planned settlement schemes that have been detected in other Latin American countries and for which a fishbone pattern would be typical (Geist and Lambin, 2001, pp.66–67).

4.1.2 Drivers of deforestation

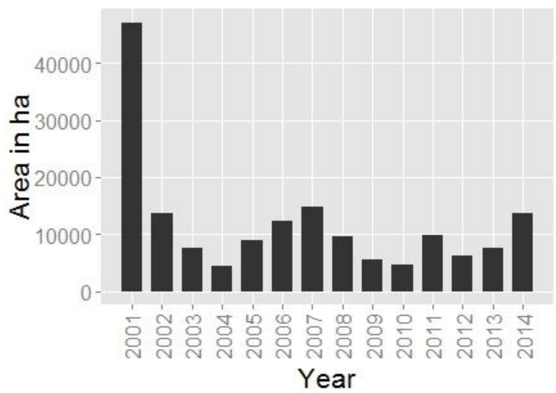
The analysis of the deforestation drivers that were identified by the interviewees reflects the driving force of the extraction of natural resources and of the armed conflict in the study area.

Direct drivers

The main direct deforestation drivers in the study area according to interviewees are illicit crops, small-scale farming, cattle ranching, wood extraction, petroleum, infrastructure and mining.

Both the interviews and the review of official statistics have indicated the major influence of the cultivation of coca on deforestation rates. According to the majority of the interviewees, the cultivation of coca has been one of the major land use types despite the fumigation policy by the Colombian state. Figure 15 displays the areas that have been affected by the cultivation of coca in the department Putumayo from 2001 to 2014 according to the official UNODC report on drug monitoring in Colombia.

Figure 15: Coca cultivation in the department Putumayo



Source: author’s own, based on UNODC (2015 and 2006)

As can be seen in the graph, coca cultivation in Putumayo has an outstanding peak in 2001 and another three peaks in 2007, 2011 and 2014. Except for the last peak in 2014, there are parallels between the years with increased coca cultivation and deforestation peaks in the study area that occurred in 2001 to 2002, 2007 to 2008 and 2012 to 2013. The report identifies the southern part of the study area as the most affected area with regards to the cultivation of coca in Putumayo, particularly the municipalities Puerto Asís and Valle del Guamuez (UNODC, 2015, p.33). It also indicates an increasing trend of the phenomenon in more elevated areas. The results of the report are supported by insights of stakeholders who confirmed that the south of the study area towards the Ecuadorian border is heavily influenced by illicit crops, and that the phenomenon has started to move into more elevated areas, including the PNNSC. Also, the UNODC report mentions that coca cultivation typically occurs in small dispersed, yet growing patches that are spreading eastwards along the river Putumayo (UNODC, 2015, p.33). The description of the pattern of coca cultivation is consistent with the findings on the spatial distribution of deforestation trends of this thesis, especially regarding the small but increasing average size of deforested patches and the unorganized occurrence in the south of the study area.

However, the aforementioned findings on the spatial distribution of deforestation pattern also fit to the activities of unorganized small-scale subsistence farming, which is often linked to the cultivation of coca, but also to wood extraction and the increase of existing pasture land for extensive cattle ranching. The findings of the interviews regarding the impact of the oil industry and mining have indicated that despite the classification of these land use types as direct deforestation drivers, their indirect impact on deforestation might actually be more significant. Especially the extraction of petroleum and related infrastructure have had a stimulating effect on migration and the establishment of settlements with small-scale farming, wood extraction and cattle ranching.

Although it may not be possible to state with certainty on the scope of each direct deforestation driver, it has become evident that farmers and local communities are the most relevant direct agents in terms of deforestation: they engage in subsistence farming across the territory, in the cultivation of illicit crops, partially in cattle ranching and the amplification of meadows, and in woodwork. The underlying causes are poverty, the absence of economic alternatives, lacking knowledge and cultural habits, as many of these communities are not native to the foothills. The fluctuations of deforestation rates in the study area may be interpreted as the high responsiveness of farmers and local communities to the emergence of external influences. As stated by one of the interviewees:

"El campesino es… realmente sólo un peón en ese momento, y simplemente está cumpliendo un rol muy pequeño, si lo vemos en el sentido del proveedor, pero está haciendo un rol de transformación amplio en la transformación del paisaje, porque está alterando totalmente el paisaje en el Amazonas."[31]

Despite the seemingly small impact of each individual, the cumulative influence of farmers, settlers and local communities is what translates into a major damage of the ecosystem of the Andean-Amazonian foothills. In that sense, the case of deforestation in the Andean-Amazonian is in line with a number of studies which stress that agricultural expansion for cropland and pastures is by far the most important direct deforestation driver in tropical regions (cf. d'Annunzio et al., 2015, p.124; cf. Nepstad et al.. 2008, p.1739) – especially if the cultivation of coca is taken into account.

Indirect drivers

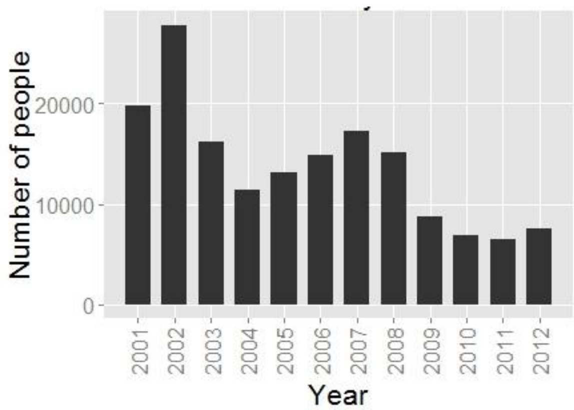
Relevant indirect deforestation drivers that stimulate deforestation in the Andean-Amazonian foothills are the armed conflict, migration and poverty, cultural habits and lacking knowledge and, in a number of ways, the state.

Interviewees have stated repeatedly that the phenomenon of deforestation cannot be fully understood without considering the impact of the long-lasting armed conflict between the FARC, the government and paramilitary groups until their demobilization in 2006. The guerrilla and paramilitary groups have promoted illicit crops and other informal sectors such as mining and the reflectance of assets in accumulated land and cattle ranching. Armed actors have also inhibited the development of protective forest management in some areas. In addition, interviewees have mentioned repeatedly the role of forced displacement and migration in the context of deforestation. Several local and regional stakeholders indicated that they consider forced displacement the second

[31] The quote may be translated as: "The farmer is… really only a peon at this moment, and he only plays a very small roll if we consider him as a provider, but he is playing a big role in the transformation of the landscape, because he totally alters the landscape in the Amazon."
See interview 1 with stakeholder I01 in Appendix 6 at 0:19:28.

most important reason for the first deforestation peak in the study area that occurred from 2001 to 2002. In fact, official data on displacement rates in Putumayo indicate fluctuations that show certain parallels to deforestation rates. Figure 16 displays how forced displacement in Putumayo peaked in 2002 and 2007 and slowed down between 2008 and 2011.

Figure 16: Displacement in the department Putumayo



Source: author's own based on Observatorio del Programa Presidencial de DH y DIH, 2014 in FIP, 2014

According to the corresponding report, displacement during the first peak occurred mainly in the municipalities Valle del Guamuez, Puerto Asís, Puerto Caicedo y Villagarzón and was due to constant pressure on the population through paramilitary groups (FIP, 2014, p.57). The second wave of displacement occurred both through violent activities of paramilitary groups and increased combative confrontations between the FARC and the Colombian military (FIP, 2014, p.57). The information supports the perspective of the interviewees that deforestation rates and forced migration in the study area may be correlated, which would support the argument for a major correlation between the armed conflict and deforestation in the study area. On the other hand, a number of stakeholders were convinced that the coercive control of the guerrilla has prevented the deforestation of some of the biodiversity hotspots especially in the north of the study area, including the territory of the PNNSC. In that sense, the interviews reflected the somewhat ambiguous impact of the armed conflict on ecosystems and on deforestation that has been described in academic literature (Aguilar et al., 2015, p.5; SINUC, 2014, p.1; cf. Álvarez, 2003). Projecting the net effect of the armed conflict on deforestation in the study area would require a separate analysis and a correlation of satellite-based deforestation data with a comprehensive data set on conflict related actions on behalf of the FARC, paramilitary groups and the state. Nevertheless, the strong linkage of armed groups to the cultivation of illicit crops and mining and its stimulating effect on migration rates provide a strong argument for a significant impact of the armed conflict on deforestation in the study area.

Another core node of indirect deforestation drivers is the many-sided role of the state for the socio-economic development of the region. On the one hand, the central government has pursued what it has coined “national interests” in the study area: the extraction of petroleum, which has been associated with an overriding of the rights of local communities and environmental policies. The state has also promoted a concept of development that is linked to extensive cattle ranching, which corresponds to the cultural mindsets of a large proportion of the inflowing population from other departments. On the other hand, the government has had a deficient role in the strengthening of local environmental authorities, the implementation of existing environmental law, the promotion of environmental education and alternative land use practices, the containment of land speculation and the stimulation of conservation.

The relationship of direct and indirect drivers

This thesis provides a first approach in describing the complex and mutually enforcing relationships between direct and indirect deforestation drivers which have been visualized in Figure 14. This approach goes beyond the analysis of deforestation patterns and drivers of most of the existing studies which focus on the quantification of deforestation and an enumeration of direct and indirect deforestation drivers (cf. IDEAM, 2015b; cf. Etter et al., 2006b). However, understanding deforestation processes in an integrative way is a key prerequisite for further research and for the exploration of potential future scenarios of the transformation of the Andean-Amazonian ecosystem.

4.1.3 Potential preventive measures

Suggestions of the interviewees for counteracting direct deforestation drivers mainly concern the improvement of current production systems and the establishment of alternative sectors and land use types that promote the coexistence of forests.

Whereas adapting small-scale agriculture to local conditions through the replacement of traditional crops with local crops and mixed cultivations appears to be a feasible option, extensive cattle ranching as such represents an unsuitable land use type that should be contained in the Andean-Amazonian foothills. The alternative may be intensive cattle production in barns and silvo-pastoral systems that require higher technological inputs to which the access is currently limited. Further suggestions of stakeholders concerned the establishment of alternative sectors and land use types, such as local food production, the production of local commodities, the establishment of a forest sector and a woodworking industry, a pharmaceutical industry, tourism and recycling and reprocessing plants. Similar to the case of intensive cattle ranching, these are suggestions that entail the transfer of knowledge and technology into the region and thus, the allocation of financial resources for stimulating these developments. The task of establishing profitable alternative sectors faces several challenges: 1) these sectors will most likely have to compete with a persistent influence of the highly profitable coca economy which might continue to distort the economic scenario; 2) the stimulation of alternative sectors should ideally focus on diverse approaches and prevent the establishment of monocultures or large-scale impacts on the environment, which is challenging given the high responsiveness of the population to potential economic opportunities and the proneness of the region to booms.

Regarding the establishment of further protected areas, the interviewees agreed that the existing protected areas need to be strengthened as they have been impacted by human intervention in the past. This perspective supports the findings of Daniel Nepstad et al. (2013) and Aldana and Mitchley (2013) who have described the impaired effectiveness of protected areas in several other cases in Colombia. Given the fact that establishing protected areas as such is no guarantee for the conservation of forests, there is a necessity for an integration of protected areas into schemes that support the development and livelihoods of local communities.

The successful implementation of all potential preventive measures will depend heavily on adequate state support. The Colombian government ought to assume responsibility with respect to continuous guidance towards more sustainable land use types, the alteration or adoption of normative conditions, the allocation of funding into the region and the withdrawal of counterproductive stimuli, especially regarding cattle ranching and the accumulation of land. Interviewees have confirmed that there is considerable foregone potential for funding of alternative land use projects and conservation though the deficient or non-existent implementation of environmental compensation schemes. However, it is worth emphasizing the need for large joint efforts that go beyond relying solely on state policies and entail alliances between stakeholder groups that accompany and support education and cultural recovery within local communities. Especially the development of schemes that promote local livelihoods while ensuring the conservation of biodiversity hotspots in the Andean-Amazonian foothills will require alliances between local communities, environmental authorities and the scientific community.

4.1.4 Stakeholders' expectations for the future

The interviews have revealed a high degree of uncertainty among stakeholders regarding the post conflict scenario. Interviewees preferred describing potential risks and opportunities over taking a position regarding which developments they consider the most likely. Interviewees are concerned that the exploitation of natural resources will intensify in a post conflict scenario through the absence of the threat that the guerrilla has posed throughout the armed conflict, and that the region will follow its historical trend of going through cyclical booms that determine migration rates in the region. This perceived risk among stakeholders is consistent with concerns that have been mentioned in literature (Aguilar et al., 2015, p.5; SINUC, 2014, p.1; Álvarez, 2003, p.64). Positive expectations of stakeholders rely largely on adequate governmental stimuli for improved livelihoods and conservation at the one hand, and on the establishment of local participative decision making schemes on the other hand.

4.2 Limitations

The approach in this thesis for quantifying and understanding deforestation in the Andean-Amazonian foothills is subject to several limitations both in the quantitative and the qualitative analysis.

Limitations of the quantitative analysis

One limitation concerns the polygon of the study area. Although the polygon is suitable for quantifying deforestation in the southern Andean-Amazonian foothills, there are some shortcomings with regards to the triangulation of the determined deforestation rates with official information. The fact that the selection of the study area has been made according to geographical and ecological criteria rather than official administrative borders entails limitations for the comparability of the results with official data on deforestation or socio-economic indicators, as these tend to be prepared according to official administrative boundaries.

Furthermore, the quality of the results of sections 3.1.1 and 3.1.2 strongly depend on the data sets of Hansen et al. (2013a). Despite the fact that the data sets provided by Hansen et al. have been appraised for the global coverage, the consistency and the transparency that is provided (Morgan, 2016; Elias et al., 2013), there are several challenges when working with them, which is also true for the analysis of forest cover change in the area of interest in this thesis. The first limitation is rooted in the definition of tree cover that is applied by Hansen et al.: classifying all vegetation taller than five meters as forests implies that plantations with cultivated plants of five or more meters of height fall into the category of "forest", although such systems do not hold the same value in terms of biodiversity or carbon sequestration (Mitchard et al, 2015, p.4; cf. EPI, 2014). Critics have also claimed that the five-meter threshold may lead to an omission of areas where forests with smaller trees are present (cf. EPI, 2014). Another potential shortcoming is the 30 m resolution of the data sets, which is generally considered high, but may still lead to an underestimation and a delayed pick-up of forest cover change particularly in areas where deforestation occurs at a very small scale (Mitchard et al., 2015, p.4 and p.35). A further problem that comes with the data is that in some cases, loss and gain is reported for the same pixels within a certain period. These pixels have been excluded from the deforestation analysis in this thesis as they may cause biases in the estimated deforestation rates.

Limitations of the qualitative analysis

As for the semi-structured interviews with selected locally and regionally engaged stakeholders, it is worth mentioning that most of the interviewees were either holding a job position that promotes the conservation of ecosystem services or they could relate to environmentally friendly land use types through their professional or cultural backgrounds. There were no interviews with representatives of the extractive sector, infrastructure projects or representatives of armed actors of the conflict, which has been a consequence of obvious safety concerns and the limited amount of time that was available during the field trip. Leaving out these stakeholder groups may result in the exclusion of the perspectives of engaged agents and stakeholders who play a significant role in the context of direct and indirect deforestation drivers. Also, the conclusions in this thesis regarding the scope of deforestation drivers in the study area depend strongly on the statements of the interviewees. Backing up these statements with a quantitative approach for measuring the impact of each driver in terms of hectares would be highly interesting but is beyond the scope of this thesis.

Limitations of the interpretation of results

Triangulating the obtained information with additional data on the identified deforestation drivers is difficult due to the existence of a large informal sector regarding cattle ranching, wood extraction and mining for which there is no data. Some stakeholders have also expressed their doubts about the quality of existing official statistics for instance with respect to the cultivation of coca. In addition, some of the measured effects in the study area might be the result of spill-over effects from areas outside of the study area, which are practically impossible to track. For these reasons, assigning concrete events or drivers to detected fluctuations of annual deforestation rates should be done with precaution and regarded as an attempt at explaining the phenomenon rather than an unequivocal result.

Finally, it is noteworthy that the results of this thesis do not necessarily allow for an application of conclusions at a larger scale or within other regions in the Amazon, as the local conditions within the study area are both very particular and complex. They might differ substantially even in neighbouring departments[32], let alone other countries that comprise parts of the Amazon.

4.3 Conclusion

The interdisciplinary analysis of deforestation in the southern Andean-Amazonian foothills of Colombia allows for five core conclusions: firstly, deforestation has been a persistent phenomenon that is highly responsive to local socio-economic developments. There has been no indication for the beginning of a sustained decreasing trend. Secondly, the majority of deforestation has taken place in areas below 800 meters of sea level, which reflects the impact of the altitudinal gradient on access conditions and different socio-economic dynamics in the south of the study area in comparison to the north. Thirdly, the analysis has identified illicit crops, small-scale agriculture, cattle ranching and wood extraction as the main direct deforestation drivers. The indirect effect of the remaining direct drivers, including the oil industry, infrastructure projects

[32] For instance, interviewees have emphasized differing intensities of land use types when comparing the study area with the department Caquetá, in which cattle ranching is the dominating land use.

and mining, is larger than their direct impact on deforestation according to local and regional stakeholders. Fourthly, this thesis argues that deforestation in the study area has largely been stimulated by the armed conflict and its impact on the cultivation of illicit crops and forced displacement, and lacking state sovereignty with respect to land management. Lastly, the analysis of the spatial distribution of deforestation trends has shown that deforestation occurred in very small dispersed but growing patches, which supports the finding that small-scale farmers and settlers are the key agents of deforestation. Despite the seemingly small reach of each individual's activity, the cumulative effect of activities related to day-to-day subsistence implies dramatic damages to the ecosystem of the Andean-Amazonian foothills.

Preventive measures include alternative land use types, improved production schemes and concepts that combine local production with the coexistence of forests and conservation. Promising opportunities comprise local food production, the production of other local commodities such as spices, cocoa or resin, the establishment of certified forestry and woodworking, the establishment of a pharmaceutical sector and different kinds of tourism. Further preventive measures concern the implementation of an effective payment scheme for ecosystem services and the development of advanced conservation schemes that combine the promotion of local livelihoods with the conservation of forests. The necessity to protect forests for ensuring a constant supply of fresh water is likely to be the most powerful argument for making the importance of forests understood within local communities and at administrative and political levels. The actual implementation of the aforementioned preventive measures will depend strongly on stimuli on behalf of the government that must be strong and directive enough to initiate a shift away from counterproductive land use types.

The approaching peace agreement and the associated post conflict situation represent a historical chance for social peace, the stimulation of social and economic development and environmental planning. At the same time, it implies the risk of the accelerated exploitation of natural resources in formerly untouched areas if the increased freedom and mobility in the region is not accompanied with restrictions on land use. Stakeholders perceive particularly high risks associated with the occurrence of new booms related to petroleum and mining and the construction of large infrastructure projects such as the "marginal de la selva". The prevention of deforestation in the future will depend on the joint capacity of stakeholders to combine conservation with locally adapted land use types that can sustain local communities in the long run. Some stakeholders have expressed their hope regarding a beginning cultural shift away from short-term thinking to decision making that incorporates the importance of the ecosystem services provided by the Andean-Amazonian – not only for the region itself but also for the Amazon and beyond. Diminishing forests of the Andean-Amazonian foothills imply the alteration of hydrological cycles that feed the river system of the Brazilian Amazon, which would mean a loss of one of the last existing ecological corridors between the ecosystems of the Andes and the Amazon and a loss of biodiversity and native cultures that is impossible to measure. Therefore, the post conflict represents a historical chance for working towards a future that promotes social peace and both environmental and cultural diversity. The statement of a representative of local farmers summarizes the necessity to plan for the approaching peace agreement not only in social and political terms, but also with readiness and dedicated efforts to tackle environmental conflicts:

"Yo necesito paz ambiental."[33]

4.4 Outlook

There is a wide range of potential research topics that require the attention of the scientific community in order to point out the environmental risks of the post conflict and to combine the findings with adequate environmental planning. More detailed investigation on the quantification of ecosystem services in the Andean-Amazonian foothills is needed to support local decision makers and initiatives regarding the implementation of payment schemes for such services. Research is also required on the suitability and feasibility of alternative land use practices, such as sustainable tropical agriculture and production schemes that promote the coexistence of forests. Another potential research topic is the development of a new model of Amazonian cities that adapt to local conditions and are integrated into the ecosystem of the Andean-Amazonian foothills, especially regarding infrastructure and integrated production systems close to or within these cities.

[33] The quote may be translated as: "I need environmental peace."

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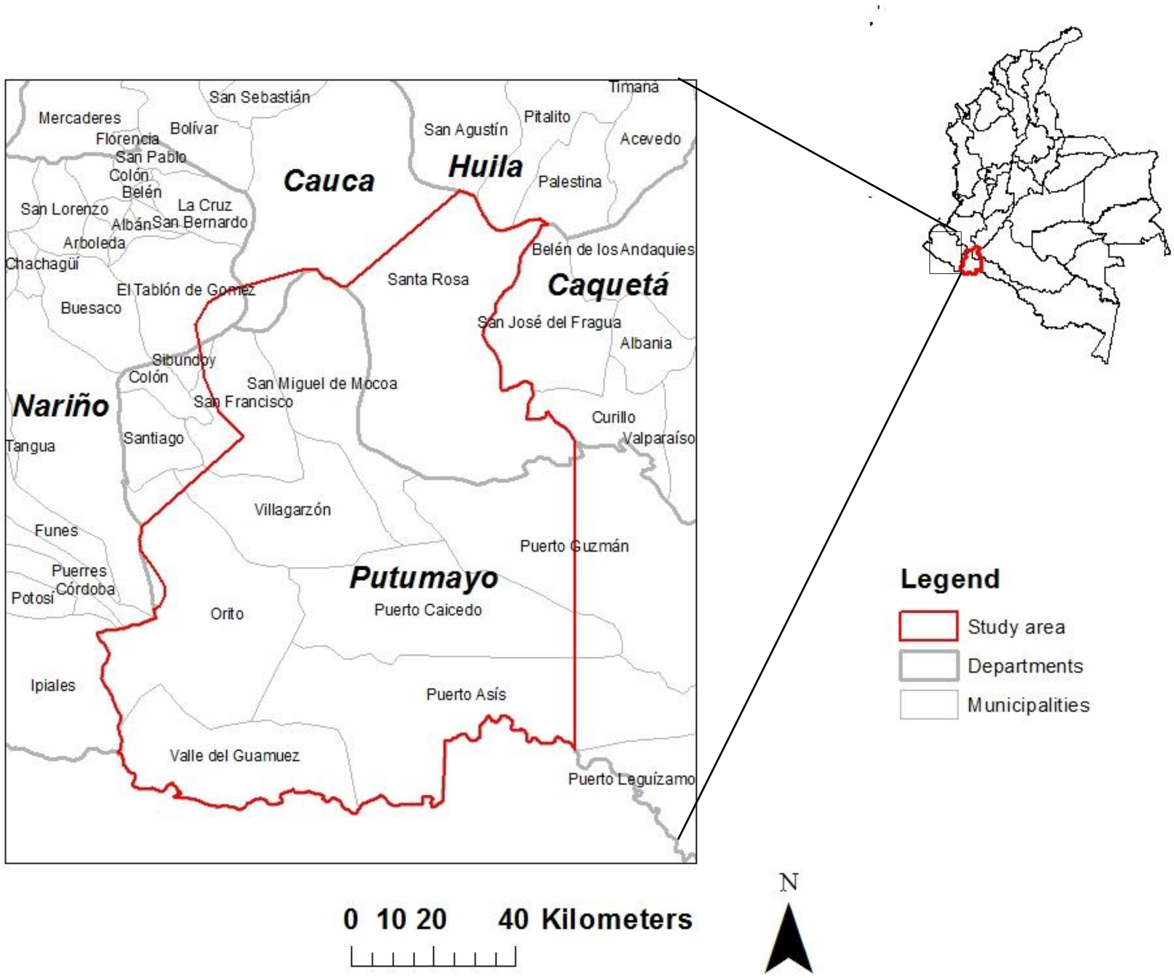
Appendices

Appendix 1: The study area and administrative boundaries



Source: author's own

Appendix 2: Deforestation figures: annual deforestation[34]

Type of area	Year 2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Entire study area	5609.52	6880.67	3339.14	3932.57	3468.12	3396.96	5707.24	5221.72	3703.17	4513.66	5622.25	6750.69	6311.17	3073.30
Area > 800 m above sea level	60.59	87.76	115.63	266.54	101.89	61.21	104.44	157.08	154.07	137.40	152.60	185.49	161.33	49.25
Area < 800 m above sea level	5548.92	6792.91	3223.51	3666.04	3366.23	3335.74	5602.80	5064.64	3549.10	4376.26	5469.65	6565.20	6149.84	3024.05
PNNSC	2.47	4.63	1.93	6.18	3.01	0.77	2.55	10.88	7.41	14.82	9.8	19.45	25.94	7.72
RFPCARM	3.86	11.12	8.72	5.87	12.43	6.25	18.22	20.53	22.08	25.24	9.19	13.28	7.02	2.47
Buffer of PNNSC	84.14	96.02	150.75	216.67	170.13	120.11	264.91	183.71	222.38	246.23	213.51	307.14	196.52	79.81
Buffer of RFPCARM	8.57	11.89	10.65	17.6	22.77	4.55	9.42	29.95	18.6	15.36	13.43	18.37	12.89	4.48

Source: author's own

[34] Figures are indicated in hectares.

Appendix 3: Spatial distribution of deforestation trends in the entire study area[35]

	Year													
Category	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Core	759.39	1659.03	2112.37	2707.96	3318.07	3900.15	4996.09	6029.74	6816.07	7765.88	9210.10	10855.24	12365.22	13025.27
Edge	1573.20	3392.56	4241.18	5368.92	6389.90	7358.24	9016.58	10578.98	11641.41	12961.12	14633.12	16377.45	18281.25	19090.90
Perforation	0.62	2.78	4.63	6.25	9.65	12.50	17.14	21.38	28.64	35.82	50.56	80.82	96.87	101.81
Bridge	91.32	308.76	433.65	583.78	745.03	880.35	1191.81	1479.49	1710.75	1981.76	2359.45	2886.27	3407.84	3692.98
Loop	160.48	380.85	465.53	560.01	638.28	753.45	915.39	1070.39	1173.20	1300.95	1471.08	1684.20	1886.13	2011.48
Branch	791.19	1791.49	2251.31	2827.37	3314.90	3877.46	4748.78	5606.74	6150.85	6837.45	7660.67	8666.76	9670.07	10173.81
Islet	2233.32	4954.72	6320.66	7707.60	8814.19	9844.83	11448.44	12769.23	13738.19	14889.78	16010.03	17594.96	18749.49	19433.93
Number of patches	11574	25207	30740	36876	41593	46159	53169	59294	63372	68020	72631	79680	86535	90213
Mean patch area	0.48	0.50	0.51	0.54	0.56	0.58	0.61	0.63	0.65	0.67	0.71	0.73	0.74	0.75
Effective mesh size	97.72	241.62	345.12	499.06	730.11	922.21	1398.94	1820.33	2281.30	2870.76	4112.66	6307.18	8190.04	9196.61

Source: author’s own

[35] Figures are indicated in hectares, except for the number of patches and the effective mesh size.

Appendix 4: Spatial distribution of deforestation trends in areas above 800 meters above sea level[36]

	Year													
Category	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Core	1.47	5.40	11.73	37.28	43.46	46.47	54.26	70.78	83.13	90.77	111.69	125.97	140.72	142.18
Edge	3.32	15.90	33.65	98.03	115.24	123.19	140.10	166.42	195.83	221.07	259.20	286.45	322.19	326.20
Perforation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.62	0.62	0.62
Bridge	0.00	1.39	4.55	10.27	11.35	11.35	11.73	12.50	18.14	20.76	25.63	27.87	35.35	36.43
Loop	0.23	0.23	1.47	9.11	10.03	11.73	16.60	22.77	23.31	23.47	24.24	29.95	33.89	33.35
Branch	0.93	8.41	19.22	60.52	71.17	78.27	90.08	103.05	120.72	142.49	161.56	184.17	205.25	208.95
Islet	54.65	117.02	193.36	315.32	381.16	422.61	485.29	579.62	668.08	748.04	816.90	929.67	1008.02	1047.54
Number of patches	276	581	930	1468	1755	1951	2279	2735	3163	3566	3919	4492	4921	5142
Mean patch area	0.22	0.26	0.28	0.36	0.36	0.36	0.35	0.35	0.35	0.35	0.36	0.35	0.35	0.35
Effective mesh size	0.83	3.48	9.51	26.88	34.01	35.91	41.76	55.54	67.27	75.99	93.44	106.53	116.89	118.43

Source: author's own

[36] Figures are indicated in hectares, except for the number of patches and the effective mesh size.

Appendix 5: Spatial distribution of deforestation trends in areas below 800 meters above sea level[37]

	Year													
Category	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Core	757,92	1653,63	2100,64	2670,68	3274,61	3853,69	4941,83	5958,95	6732,93	7675,11	9098,40	10729,26	12224,50	12883,08
Edge	1569,88	3376,66	4207,52	5270,89	6274,66	7235,05	8876,48	10412,56	11445,58	12740,05	14373,92	16091,00	17959,07	18764,69
Perforation	0,62	2,78	4,63	6,25	9,65	12,50	17,14	21,38	28,64	35,82	50,56	80,20	96,26	101,20
Bridge	91,32	307,37	429,10	573,52	733,69	869,00	1180,07	1466,99	1692,61	1961,00	2333,82	2858,40	3372,49	3656,54
Loop	160,25	380,62	464,06	550,90	628,25	741,71	898,79	1047,62	1149,89	1277,49	1446,84	1654,25	1852,24	1978,14
Branch	790,27	1783,08	2232,09	2766,86	3243,73	3799,19	4658,70	5503,69	6030,12	6694,95	7499,12	8482,59	9464,82	9964,86
Islet	2178,67	4837,70	6127,30	7392,28	8433,03	9422,21	10963,15	12189,61	13070,11	14141,74	15193,13	16665,29	17741,47	18386,39
Number of patches	11298	24626	29810	35408	39838	44208	50890	56559	60209	64454	68712	75188	81614	85071
Mean patch area	0.49	0.50	0.52	0.54	0.57	0.59	0.62	0.65	0.67	0.69	0.73	0.75	0.77	0.77
Effective mesh size	141.35	348.85	496.19	711.36	1043.23	1320.79	2009.56	2614.39	3276.53	4127.42	5920.57	9095.32	11820.25	13279.31

Source: author's own

[37] Figures are indicated in hectares, except for the number of patches and the effective mesh size.

Appendix 6: Interview guide

BACKGROUND INFORMATION

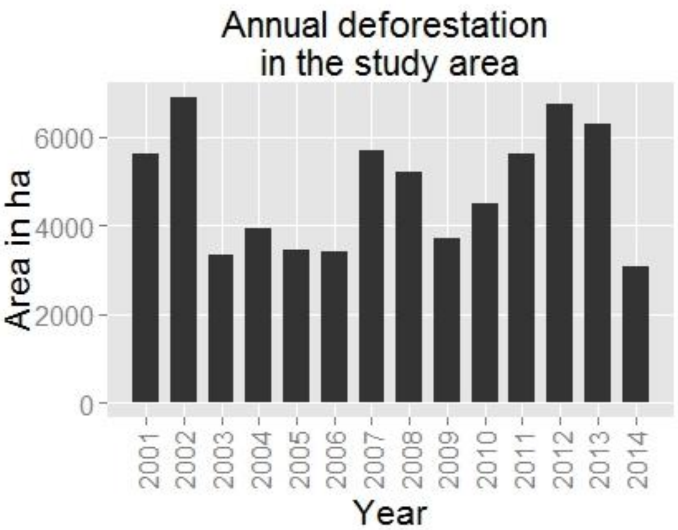
1. What is your occupation? Please describe briefly what your work consists of.
2. For how long have you been working/ living/ studying in the Andean-Amazonian foothills?

CHANGES IN LAND USE SINCE 2000

3. Which were the most important types of land use in the area in 2000?
4. Which are the most important types of land use in the area now?

DEFORESTATION PATTERN

5. Please take a look at the following graph which displays annual deforestation in the area. What may have caused the respective fluctuations in deforestation from 2001 to 2014, especially regarding the three peaks that are visible? (2001-2002, 2007-2008, 2012-2013)



6. Do you know about any differences between deforestation occurring in flat and mountainous terrain of the foothills?
7. If applicable: can you state on deforestation in and close to the national park Serranía de los Churumbelos? Can you state on deforestation in and close to the forest reserve Cuenca Alta del Río Mocoa?
8. Do you know of any measures that could be applied in this territory in order to avoid deforestation?
9. Would it make sense to establish new protected areas?

CONFLICTS

10. Who has been responsible for land use (change) in the area within the period 2000 – 2014?
11. According to your opinion, which are main problems related to land use in the region?

LAND USE IN THE FUTURE

12. Do you anticipate land use change in the next years? Please explain.
13. Which effects might a peace agreement between the government and the FARC have on land use in the area?
14. If you were to decide on future changes in the land use in the area, what would these changes be?

WRAP UP

15. Do you have any other thoughts on the issue?

Affidavit

I hereby declare that the present thesis has not been submitted as a part of any other examination procedure and has been independently written. All passages, including those from the internet, which were used directly or in modified form, especially those sources using text, graphs, charts or pictures, are indicated as such. I realize that an infringement of these principles which would amount to either an attempt of deception or deceit will lead to the institution of proceedings against myself.

Date: July 19th 2016 Signature: