Environmental Science and Policy 97 (2019) 116–124

Contents lists available at ScienceDirect

Environmental Science and Policy

journal homepage: www.elsevier.com/locate/envsci

Land-use and socioeconomic changes related to armed conflicts: A Colombian regional case study

Lina Maria Garcia Corrales*, Humberto Avila, Ronald R. Gutierrez

Universidad del Norte, Km 5 via Pto. Barranquilla, 080007, Barranquilla, Atlántico, Colombia

ARTICLE INFO

Keywords:
Armed conflict
Colombia
Land-use change
Livestock

ABSTRACT

Colombia has endured one of the longest armed conflicts in the world, influencing land use, local economies, and the environment. The Department of Córdoba, which is part of the Colombian Caribbean region, was a setting of territorial disputes between illegal armed groups. Recently, peace agreements have been reached, thereby leading to a post-conflict period in which conflict-driven socioeconomic and environmental conditions need to be addressed. We used geoenvironmental satellite information and census data to describe land-use evolution in the Department of Córdoba. Our results explain relationships between socioeconomic and geographic variables by using two factors, namely: (1) natural land cover and armed conflict, and (2) pastures and livestock. Five clusters comprised of smaller Colombian territorial units were obtained, exhibiting challenges of environmental governance, conservation of protected areas, and sustainable livestock and agricultural practices. This information provides critical input for institutional decisions during the current post-conflict period.

1. Introduction

Current socioeconomic drivers of land-use change in Latin America are resulting in contrasting trends in different locations. On one hand, rising food demand accelerates deforestation for conversion to agriculture, particularly extensive pastures for cattle (Wassenaar et al., 2007). On the other hand, rural-to-urban migration and the abandonment of marginal agricultural land favors the recovery of some ecosystems. In addition, some marginal areas have been affected by armed conflict which triggers socioeconomic consequences such as migration and land abandonment, as well as challenges for conservation of protected areas (Grau and Aide, 2008).

Armed conflict in Colombia has significantly reconfigured natural rural landscapes and ecosystems through altered modes of subsistence, modes of economic production, and land cover (Arias et al., 2014). Conflict-driven land-use changes are poorly documented, although some evidence exists that they induce contrasting transformations of ecosystems. In some cases, conflict has favored conservation, and in others it has led to the degradation of natural resources. Colombia has recently reached unprecedented peace agreements with paramilitary groups, as well with the Revolutionary Armed Forces of Colombia (FARC), the main guerrilla group, leading the country to a so-called post-conflict stage. The environmental consequences of these socioeconomic and political changes are uncertain at the present time (Sierra et al., 2017).

Some studies on the relationship among land cover, socio-economic factors, and biophysical factors have been performed in Colombia. Etter and van Wyngaarden, (2000) carried out a nationwide spatial integration of data on ecosystem distribution and transformation concentrated on the Andean region. Their results highlight that rural-to-urban migration increased as a result of armed conflict, although this did not imply the recovery of natural ecosystems, because grazing activities increased.

The beef cattle industry is the largest contributor to the transformation of tropical forests in Colombia (Etter et al., 2006). Colombia has significant regional differences in deforestation causes, patterns, and historical trends, with the Caribbean region having the highest annual loss of forest cover (González et al., 2011). Most research on land-use change in Colombia has focused on characterizing forest transformation processes in the Andean and Amazonian regions, and few studies have focused on the Caribbean region. This is mainly due to restrictions on the availability and quality of the information needed for this type of studies (González et al., 2011; Sánchez-Cuervo and Aide, 2013).

Although information restrictions have repeatedly constrained the study of socio-environmental dynamics by scientists and policy makers, Colombian institutions have made great efforts in recent years to improve data collection and make data available in digital repositories (Sierra et al., 2017). Thus, we believe this post-conflict period

* Corresponding author.
E-mail address: lmcorrales@uninorte.edu.co (L.M. Garcia Corrales).

https://doi.org/10.1016/j.envsci.2019.04.012
Received 26 December 2018; Received in revised form 21 April 2019; Accepted 23 April 2019
Available online 02 May 2019
1462-9011/

represents an unprecedented opportunity to study the past, present, and future of the socio-environmental dynamics triggered by internal conflict, specifically regarding land-use changes.

In this paper, we address the following research questions: (1) Which factors explain the relationship among land-cover type, socio-economic variables, and armed conflict variables? (2) What are the spatio-temporal dynamics of these variables within the territory?, and (3) What are the political implications of these dynamics under post-conflict conditions? To that end, we performed statistical analysis on spatio-temporal information in a context of input data with high uncertainty. The analysis is carried out on the municipality, the smallest Colombian territorial units, thus providing knowledge on complex socio-economic and environmental processes at a fine scale. This approach allowed us to describe the socio-economic and land-use dynamics induced by armed conflict in the Department of Córdoba (Colombian Caribbean region), where marked deforestation processes, steady expansion of the agricultural frontier, and direct interaction of livestock farming with illegal armed groups have occurred historically.

2. Materials and methods

2.1. Study area

The Department of Córdoba is at the northwest corner of Colombia, between 7°22′5″ to 9°26′16″ north latitude and 74°47″43″ to 76°30′01″ west longitude. The department comprises 30 municipalities (2.5 million hectares). Projected population for 2018 is approximately 1.8 million, of which 47% represents rural population. The Department of Córdoba is characterized by rain forest and dry forest ecosystems, together with wetlands that occupy approximately 95,000 ha. The Córdoba territory is influenced by the Caribbean Sea and the northernmost foothills of the Andes Mountains, where Paramillo National Natural Park is located, an area of great importance for biodiversity and hydrologic function. The main hydrographic basins are the Sinú, San Jorge and Canalete Rivers, together with a set of smaller basins leading to the Caribbean Sea (CVS, 2008) (Fig. 1).

The economy of the region is based on agriculture, social services, and financial services (Mincit, 2015). Cattle ranching in the Department of Córdoba is one of the most important economic activities in Colombia, both as large businesses and smaller, informal operations. The cattle inventory was 2 million head in 2017 (ICA, 2017), with production mainly oriented towards breeding (Fedegan and FNG, 2014). Agriculture is found mostly in small areas, with the exception of cotton and maize (CVS, 2008). In the Department of Córdoba, 38% of the land has potential for agriculture, 8% for livestock, 2% for productive forestry and 12% for agroforestry systems. However, only 21% of the land is being used for agriculture and 0.2% for productive forestry, whereas 50% is being used for livestock (UPRA, 2017). Until recently, land-use information for the Department of Córdoba was limited, mainly due to the use of different classification systems, limiting the diagnosis of changes in land use (CVS, 2008). Recently, the Colombian Institute of Hydrology, Meteorology and Environmental Studies (IDEAM) released a set of 1:100 000 land-cover maps for different periods.

During the last 50 years, several illegal armed groups converged in the Department of Córdoba, resulting in different phases of conflict. The 1960s witnessed the rise of the FARC and the People's Liberation Army (EPL). The latter demobilized during the 1980s, at the same time that illegal drug traffic increased in the region. During the early 1990s, paramilitary groups developed and fought the FARC divisions that established in the region. Between 2002 and 2006, a paramilitary demobilization process took place, and the FARC resumed coca production in the region (Observatorio de Derechos Humanos, 2009). In recent years, after peace agreements with the FARC, criminal bands have emerged, fighting against state forces in order to control cocaine distribution routes (Moreno, 2016).

2.2. Data

A territorial dynamics analysis was performed for a period of 10 years. Land-cover and land-use data were obtained for three periods: 2000–2002 (IDEAM, 2012a), 2005–2009 (IDEAM, 2012b), and 2010–2012 (IDEAM, 2014). Fig. 2 shows land-cover types in the

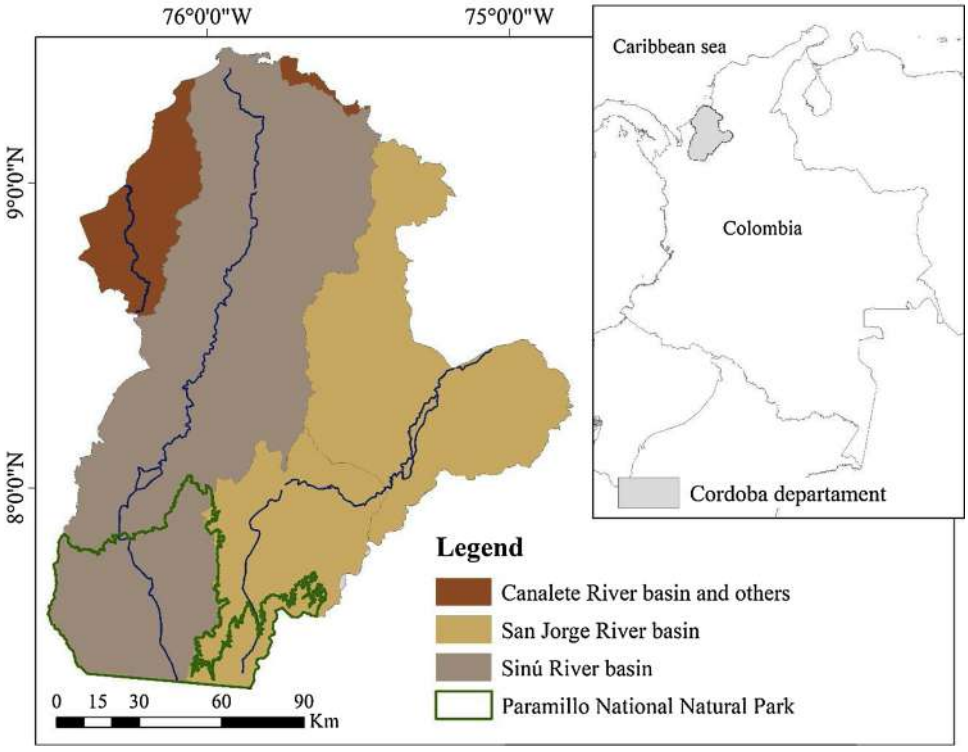

Fig. 1. Location and basin of Department of Córdoba.

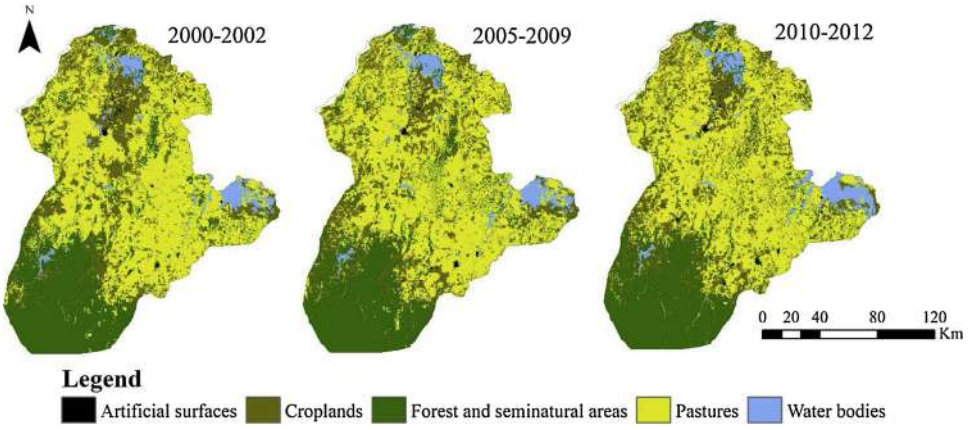

Fig. 2. Land cover in the Department of Córdoba.

Department of Córdoba for each period. Land-cover types with the greatest area are pastures, plantations, and forests/seminatural areas. Land cover classified as croplands includes areas with permanent crops, temporary crops, and heterogeneous areas. Forest/seminatural areas include forests, as well as brush and herbaceous vegetation.

A department-scale analysis was first performed, relating land cover types (pastures, plantations, and forests/seminatural areas) with data on gross domestic product (GDP) for livestock, agricultural, and forestry activities in the Department of Córdoba (DANE, 2017a).

For the municipality-scale analysis, 10 variables were chosen, among which the conflict variables of "kidnapped" and "forced displaced people" are emphasized. These conflict variables were chosen because they represent two of the most outstanding effects of the Colombian armed conflict on the civil population (Guarin et al., 2017). The remaining variables represent socioeconomic indicators and geographic factors. The *displaced people* variable (DP) corresponds to the number of people affected by forced displacement per municipality for a given year (DPS, 2017). The *kidnapped people* variable (KP) also corresponds to an annual record per municipality (Vicepresidencia de la República, 2017).

Reference years were 2001, 2006, and 2011, according to available land-cover data. Limited information at the municipality scale is highlighted in some cases, as is access to statistical information through web portals of public agencies. Table 1 shows the variables used in the socio-environmental dynamics analysis.

The *working age population* (WP) is defined as the population between 15 and 64 years in each municipality, based on the age data obtained and Colombian law regarding minimum working age and retirement age (DANE, 2017b). *Cattle inventory* (CI) refers to the number of animals per municipality, including beef cows, milk cows, bulls, and calves (Instituto Colombiano Agropecuario-ICA, 2012; MADR, 2017; Viloria, 2004). Digital elevation models ASTER GDEM (METI and NASA, 2011a, 2011b) were obtained in order to determine the area of each municipality representing elevations higher (EH) and lower (EL) than 200 masl.

Some variables (e.g., educational coverage, rural property appraisal, mean size of rural property) were excluded, because insufficient data were available for all three periods of study. Other variables (e. g., total population, population below 14 years old, population above 65 years old, rural population, population density, topographic slope) were excluded because of their high intercorrelation.

2.3. Methods

We performed correlational, factorial, and cluster analyses in order to recognize socioeconomic and land-use change dynamics in the Department of Córdoba.

2.3.1. Correlation analysis

Land use is related to economy, particularly recognized in tropical contexts (FAO, 2016). Before performing analyses at the municipality level, a correlation analysis was conducted at the department scale in order to determine whether there were relationships between land-cover types and the sectorial economy, particularly with gross domestic product (GDP). Data on the extent of each land-cover type were extracted from maps available for three periods (2000–2002, 2005–2009, and 2010-2012), whereas GDP data were averaged annually for each period. For this analysis, pasture areas were correlated to the livestock sector GDP, crop areas with the agricultural sector GDP, and forest areas with the silvicultural sector GDP.

2.3.2. Factorial analysis

This method was used because it describes underlying dimensions, explaining data from different sources and facilitating understanding of territorial dynamics. Factorial analysis also reduces the set of variables to a lower number of factors that can be applied to subsequent analyses such as cluster analysis. Data from 2001 were used for this analysis. In this municipality-scale analysis, the data represented the 29

Table 1
Variables used in the analysis.

Variable	Code	Unit	Source
Forest area	FA	Hectares	Geographic information
Cropland area	CA	Hectares	Geographic information
Herbaceous vegetation area	HA	Hectares	Geographic information
Pasture area	PA	Hectares	Geographic information
Displaced people	DP	Number	Statistic data
Kidnapped people	KP	Number	Statistic data
Working age population	WP	Inhabitants	Statistic data
Cattle inventory	CI	Number	Statistic data
Elevation area higher than 200 masl	EH	Hectares	Geographic information
Elevation area lower than 200 masl	EL	Hectares	Geographic information

municipalities of the Department of Córdoba except for its capital Montería, which was not included due to its diverging urban socio-economic conditions compared to the other municipalities.

The variables first standardized prior to analysis and the method relevance were tested by calculating the determinant of the correlation matrix, and by Bartlett's spherical test (a Kaiser-Meyer-Olkin [KMO] measure of sampling adequacy), and a Measure of Sampling Adequacy (MSA) test. Common factors were extracted if their eigenvalue was greater than one. The level of variance retained by common factors was considered, together with the communality (the variance for each given variable, accounted by all the factors). Varimax rotation was used to obtain a factor matrix that is better defined and easier to interpret. Extracted factors were interpreted and names were assigned according to their associated variables.

2.3.3. Cluster analysis

We followed the method of Serra et al. (2014) in order to analyze temporal changes in factors and to group municipalities with similar dynamics. Score coefficients for the factorial analysis of 2001 were calculated, and the value of each factor was quantified for this year using Eq. (1):

$$F_1 = s_1^{t_1} x_1^{t_1} + s_2^{t_1} x_2^{t_1} + \ldots + s_p^{t_1} x_p^{t_1} \quad (1)$$

where F_1 is the value corresponding to the first common factor for the given municipality, and $s_p^{t_1}$ are the score coefficients of the factors for the p standardized variables $x_p^{t_1}$ for the year 2001. The value corresponding to the second factor F_2 was also calculated. The factors F_1 and F_2 were then calculated using the standardized variables for 2006 and 2011 and the score coefficients for the year 2001.

Using this approach, values of the two factors were obtained for each municipality in each period, so the cluster analysis was conducted with six variables corresponding to three periods and two factors. This methodology reduced the number of variables from 30 (10 per each period) to just six. This reduction is convenient for the analysis, because there are 29 municipalities in the Department of Córdoba.

3. Results

3.1. Correlation analysis

A correlation analysis was performed to explore the relationship between economic and land-cover variables at the department scale. Pastures and agricultural areas are strongly correlated with mean GDP (US$), with Pearson correlation coefficients of 0.85 and 0.99, respectively (Fig. 3). These correlations reflect a behavior strongly dependent on land cover. Regarding forest cover, there is a strong negative correlation with the forestry sector GDP, with a correlation coefficient of -0.99, indicating negative ecosystem implications resulting from wood extraction in natural forests. These relationships are illustrated in Fig. 3.

3.2. Factorial analysis

Factorial analysis was conducted to explore the nature of relationships between geographic and socioeconomic variables at the municipality scale. Variables from censuses and statistics were combined with variables obtained from satellite imagery. Socioeconomic variables are often expressed at the municipality level, whereas spatial variables are processed using pixels as their basic unit. In this analysis, we intend to overcome this limitation by using a homogeneous unit, the municipality scale, that corresponds to a smaller administrative unit in Colombia.

Factorial analysis was performed for 2001. Measure of Sampling Adequacy was higher than 0.5, and KMO was higher than 0.7 for all variables. The correlation matrix determinant is close to cero, and Bartlett's spherical test p-value equals zero. Communality was above 0.5 for all variables. This facilitates validation of factorial analysis, because the correlation between the original variables is enough to share common factors. Two factors with eigenvalues greater than 1 were retained. These factors explained 85.3% of the variance, which is considered sufficient for the purposes of this study.

Table 2 and Fig. 4 summarize the rotated loadings for the two first common factors. Factor 1 explains 52.8% of the total variance. Variables with factorial loadings for the first factor are (1) forest area, (2) cropland area, (3) herbaceous vegetation area, (4) elevation over 200 masl, (5) kidnapped people, and (6) displaced people. Factor 1 was called "natural land cover and armed conflict".

Factor 2 explains 33.0% of the variance. Variables with high loadings for the second factor are (1) pasture area, (2) cattle inventory, (3) elevation below 200 masl, and (4) working-age population. Therefore, Factor 2 was called "pastures and livestock". The exploratory factor analysis performed for 2001 reduced 10 variables from censuses, statistics, and satellite imagery processing to only two factors.

3.3. Cluster analysis

Once the factorial analysis was performed, factorial punctuations were calculated for each municipality in 2001. In order to make comparisons between periods, punctuation coefficients calculated for the first period (2001) were applied to the same variables for the other two periods (2006 and 2011), following the method proposed by Serra et al. (2014). In Table 3, numbers are assigned to municipalities as a reference for interpreting the results.

Hierarchical cluster analysis was performed with square Euclidian distances and between-group average, resulting in five groups associated with temporal dynamics. Fig. 5 shows the resulting dendrogram for the municipality groups, and Fig. 6 shows their distribution in the Department of Córdoba.

The first cluster corresponds to municipalities with low values of natural land cover and armed conflict (Factor 1), together with high values for pastures and livestock (Factor 2) that remained constant through the period of study. This first cluster was called "livestock tradition" and includes the municipalities of Lorica, Sahagún, Planeta Rica and Ayapel, characterized by having the highest cattle inventory during the period of study, which is maintained to this day (ICA, 2017).

The second cluster represents municipalities with low values of natural land cover and armed conflict (Factor 1), together with middle values of pastures and livestock (Factor 2) that underwent important changes during the study period. Therefore, this cluster was termed "pasture decrease". The municipalities included in this cluster are Chinú, Ciénaga de Oro, Buenavista, Pueblo Nuevo, and Valencia.

The third cluster corresponds to municipalities with high values of pastures and livestock (Factor 1), as well as high natural-agricultural cover and armed conflict (Factor 1). These municipalities display important changes in both factors during the period of study. Therefore, this cluster was called "livestock and conflict hotspot", including the municipalities of Montelíbano and Puerto Libertador.

The fourth cluster comprises the municipality of Tierralta, with high values of pastures, livestock, natural land cover and armed conflict. Relevant changes in both Factor 1 and Factor 2 were experienced by these municipalities during the period of study. Therefore, this cluster was termed "conflict and deforestation hotspot". This municipality is placed in a different cluster because of its particular conditions. A large portion of its territory is within the Paramillo National Natural Park, in which extensive deforestation has been reported (Sanchez-Cuervo and Aide, 2013), as well as the greatest intensity of armed conflict and highest number of victims and victimizing events (Unidad Víctimas, 2012).

The fifth cluster represents the remaining 16 municipalities with negative values for both factors. There were labeled "regional processes", because they appear to maintain similar processes regarding land use and socioeconomic conditions in the region.

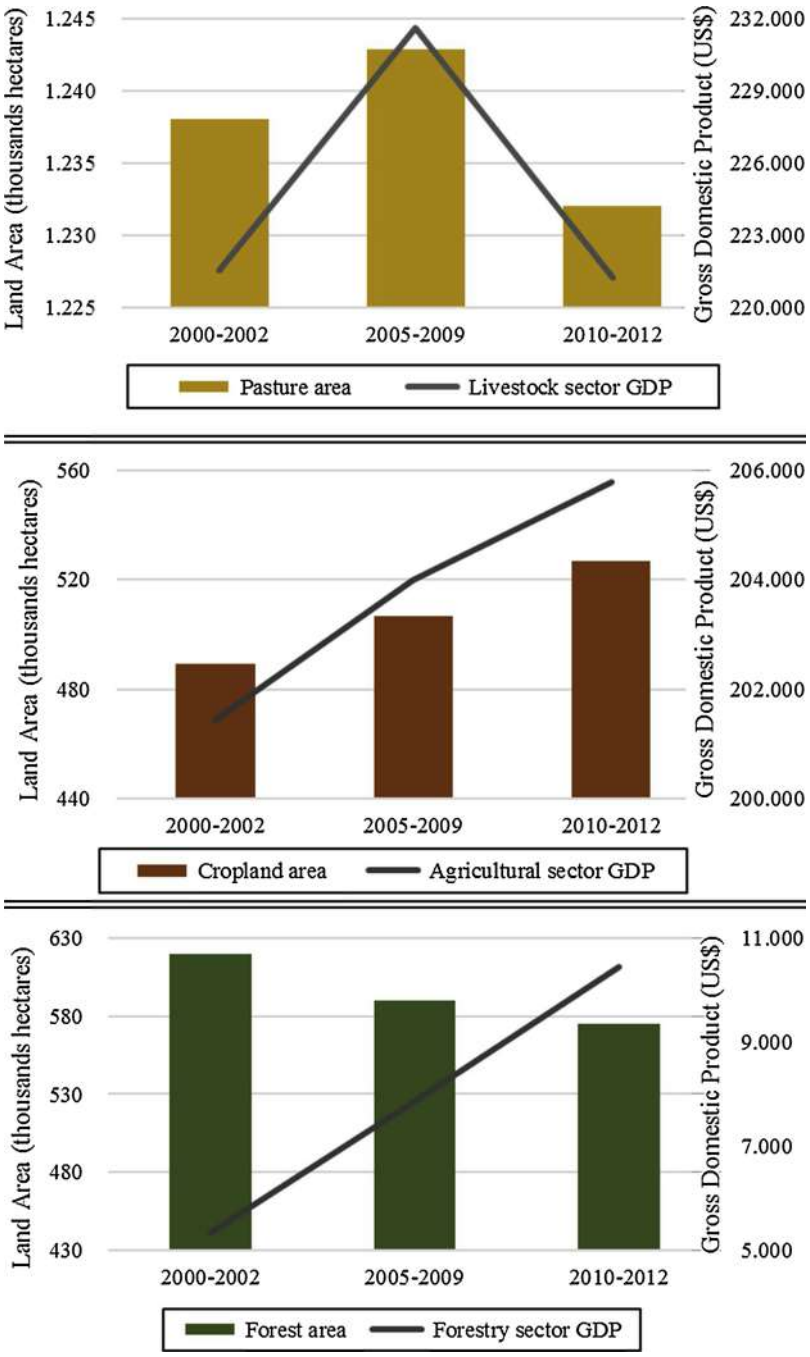

Fig. 3. Relationships between land cover and GDP (US$).

4. Discussion

Statistical methods were applied to assess the dynamics of how armed conflict in Colombia has affected complex socioeconomic and environmental processes. In a data-scarcity scenario, it was possible to define the subjacent dimensions of spatial and socioeconomic variables, showing how the municipality scale facilitates the analysis of statistical data and geographic information.

4.1. Subjacent dimensions

The correlation analysis revealed significant correlations between social actors and land-cover types, affirming the importance of cattle ranching in the Department of Córdoba, and highlighting deforestation processes that are particularly important in the Caribbean region of Colombia, where historical trends of annual loss of forest cover are the highest for the country (González et al., 2011).

Factorial analysis revealed two subjacent factors that should be considered for the post-conflict period in Colombia. The first subjacent factor allowed identification of relationships between variables associated with armed conflict (kidnappings and forced displacement), natural land-cover types, and landform. This is particularly relevant, given that the Department of Córdoba contains tropical rain forest, tropical dry forest, wetland complexes, and mangrove forest (CVS, 2008). The second subjacent factor, “pastures and livestock”, affirms that cattle ranching is the economic activity representative of the Department of Córdoba. Livestock in Córdoba is comprised by extensive systems, which in tropical contexts are characterized by low efficiency

Table 2
Rotated loading for the two factors (bold numbers indicate the variables associated with each factor). Factors 1 and 2 combined account for 85.3% of the variance.

Variables	Factor 1 Natural land cover and armed conflict	Factor 2 Pastures and livestock	Communalities
EH	0.975	0.145	0.971
FA	0.964	0.154	0.953
KP	0.923	0.136	0.871
HA	0.911	0.312	0.926
DP	0.898	0.155	0.830
CA	0.824	0.353	0.803
CI	0.090	0.959	0.928
PA	0.165	0.925	0.883
EL	0.345	0.886	0.904
WP	0.160	0.658	0.458
Eigenvalue	6.286	2.242	
% Variance	52.24	33.03	

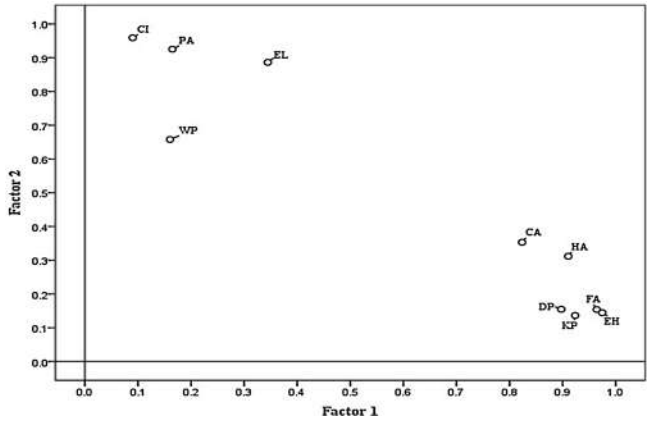

Fig. 4. Rotated loading for the two factors.

Table 3
Municipalities in the Department of Córdoba.

Number	Municipality	Number	Municipality	Number	Municipality
1	Ayapel	11	Los Córdobas	21	San Andrés de Sotavento
2	Buenavista	12	Momil	22	San Antero
3	Canalete	13	Moñitos	23	San Bernardo del Viento
4	Cereté	14	Montelíbano	24	San Carlos
5	Chimá	15	Planeta Rica	25	San José de Uré
6	Chinú	16	Pueblo Nuevo	26	San Pelayo
7	Ciénaga de Oro	17	Puerto Escondido	27	Tierralta
8	Cotorra	18	Puerto Libertador	28	Tuchín
9	La Apartada	19	Purísima	29	Valencia
10	Lorica	20	Sahagún	30	Montería

in soil use and by environmental damage related to deforestation, burning, erosion, diversity loss, and soil compaction (Mahecha, 2003).

The second factor also involves the working-age population, highlighting the socioeconomic importance of the livestock sector in the region. However, this sector is characterized by producing social inequality (Mahecha, 2003), creating minimal direct employment, often with deficient working conditions. These points emphasize the need to consider other employment alternatives, taking into account that the unemployment rate in the Department of Córdoba was 9.7% for the year 2016 and the percentage of working-age population was 77.3% (DANE, 2018).

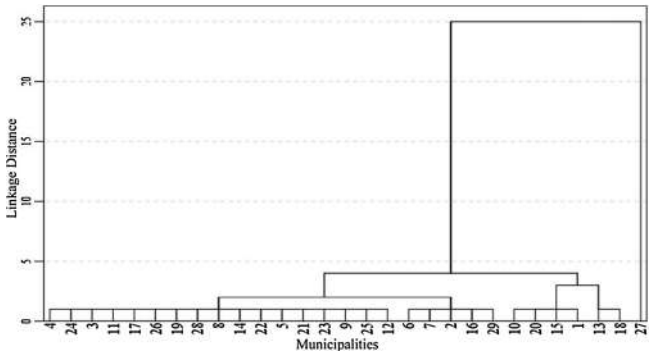

Fig. 5. Dendrogram of municipalities.

4.2. Territorial dynamics

The effects of different economic and armed conflict processes on environmental conditions was identified with clustering of municipalities. These processes highlight the need to propose policies that respond to temporal dynamics within municipality groups, as well as the distinct characteristics of each municipality. This confirms the importance of continued research on land cover and of increased knowledge about ecosystem and social changes (Etter and van Wyngaarden, 2000).

The “livestock tradition” cluster includes municipalities where the extent of pasture areas is indicative of a livestock-based economy. However, two of these municipalities have strategic ecosystems that are affected by cattle ranching. The Lorica municipality is surrounded by the wetland complex known as Ciénaga Grande at the lower Sinú River region. This area was declared as District of Integrated Management of Natural Resources (DIM) by the environmental authority (Lans-Ceballos et al., 2018). On the other hand, the municipality of Ayapel stands out by having the largest number of water buffalo (*Bubalus bubalis*) in Colombia. Large buffalo populations pose new challenges given the facts that the environmental impact of this species is largely unknown (Ruiz, 2016), and a large portion of the municipality is occupied by a Ramsar wetland (also a DIM) (Puerta et al., 2016).

The decrease of pastures on the second cluster recorded for these municipalities reveals a widespread process in the Department of Córdoba during the last 10 years (ICA, 2017), fueled by the effect of climatic variability and degradation processes affecting soils and pastures (Barragan, 2013). Pilot projects for land rehabilitation have been developed in several municipalities in this cluster. These projects have achieved the use of multi-strata forestry systems and the establishment of arboreal and brush species adapted to the region (Portilla et al., 2015).

Both the third and fourth clusters are placed in the high Sinú River basin and the high San Jorge River basin, where the Paramillo National Natural Park is located. In this context, ecological restoration can play a significant role in post-conflict conditions. Recovery from prolonged internal conflict requires a significant investment in the environment, in the face of qualitative and quantitative deterioration of ecosystem services (Aguilar et al., 2015).

Finally, the cluster “regional processes” includes all municipalities in the low and middle Sinú River basins, in the Canalete River basin and coastal areas, and together with some municipalities of the San Jorge River basin. Despite being placed in different basins, their similar social dynamics and land-use trends suggest territorial ordering, and environmental, social, and economic policies with common aspects. Some local differences must be considered, such as the presence of indigenous communities (Chimá and Tuchín municipalities), and the influence of coastal settings where the regional protected area of mangrove ecosystems is located (Cispatá Management District, San Antero and San Bernardo del Viento municipalities).

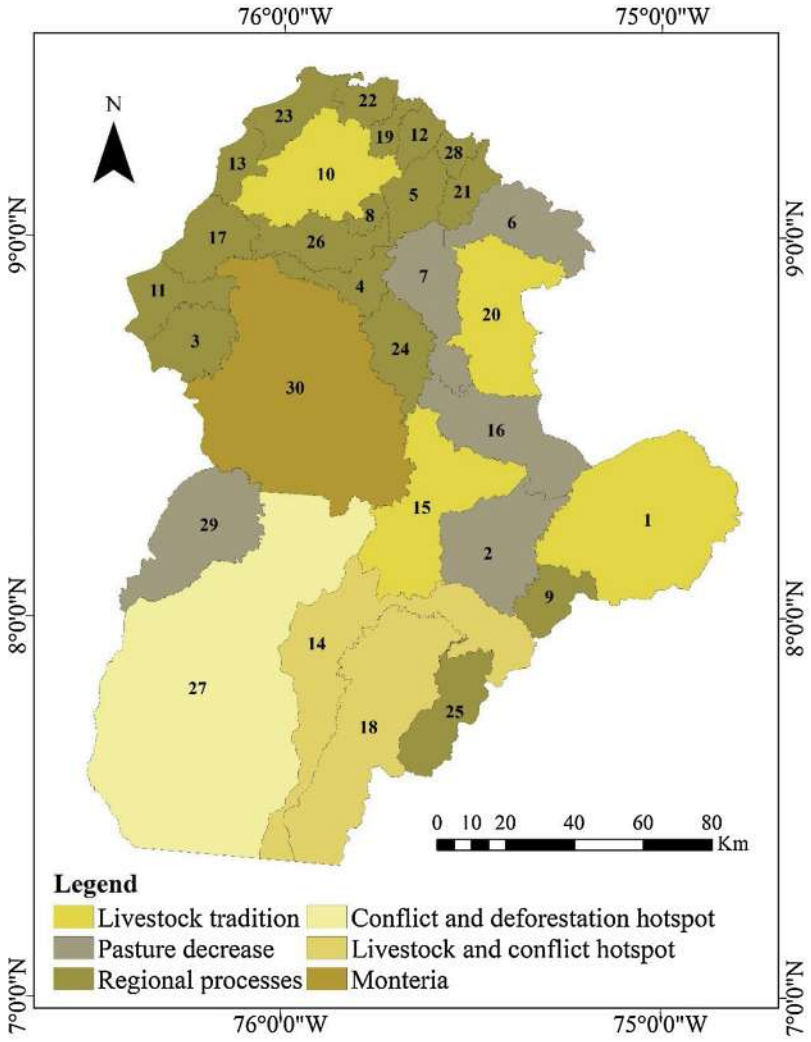

Fig. 6. Clusters in the Department of Córdoba.

Policyimplications in the post-conflict period

The pattern of underlying dimensions and territorial dynamics indicates that important challenges exist for the post-conflict period in Colombia. Relevant political implications for the Department of Córdoba include environmental governance, preservation of protected areas, and sustainable agricultural and livestock practices.

4.3.1. Environmental governance

Relationships between land use, economy, and armed conflict in the Department of Córdoba illustrate the need for strengthening environmental governance. Post-conflict countries direct their priorities toward reestablishing functional socioeconomic conditions, whereas sustainability objectives are often left aside (Suarez et al., 2018a). We propose three initiatives to assess post-conflict conditions in the Department of Córdoba: ecosystem monitoring, territorial control and authority strengthening.

Ecosystem monitoring, and land-use and socio-economic variables are proposed for all clusters, using information analysis tools to facilitate multidisciplinary dialogue between academic and political interests (Sierra et al., 2017). Recent peace agreements provide an opportunity to improve access to information and to include long-term planning (Morales, 2017).

Territorial control is decisive for the "livestock and conflict hotspot" and "conflict and deforestation hotspot" clusters. These clusters include municipalities located in the high segments of the Sinú and San Jorge rivers, which can experience rapid habitat transformation and fragmentation. Previously inaccessible areas in these municipalities become an entrance route for agricultural and livestock activities into environmentally sensitive areas, increasing deforestation (Morales, 2017). In addition, illegal armed groups, such as the National Liberation Army (ELN) and FARC discord, can take advantage of the situation to expand illegal activities such as coca farming and mining (Clerici et al., 2019), even within national protected areas (Hoffmann et al., 2018; Idrobo et al., 2014).

Wetland ecosystems are located in municipalities belonging to all clusters, particularly those in the "livestock tradition" cluster. The presence of these strategic ecosystems highlights the importance of strengthening local and regional authorities, allowing for coordination and guidance of socio-ecological transitions that involve economic development and demographic changes (Baptiste et al., 2017; Hoffmann et al., 2018).

4.3.2. Conservation of protected areas

Deforestation is a common environmental impact in post-conflict scenarios. The return of displaced populations and a strong dependency in the primary sector on increasing the extraction of natural resources (Suarez et al., 2018b). Factorial analysis showed a relationship between natural cover types and conflict variables. Therefore, the post-conflict period is a critical time for conservation of protected areas and connectivity of neo-tropical ecosystems (Clerici et al., 2019). This is particularly important in the Department of Córdoba, where the

northernmost foothills of the Andes and a national protected area (third and fourth cluster), as well as three regional protected areas with wetland and mangrove ecosystems (first and fifth cluster) are located.

Policies that integrate conservation of natural cover are of great value in the post-conflict economy. Resource managers in Paramillo National Natural Park should be complimented for providing a role for local communities through legal mechanisms and economic incentives that promote responsible land use (Baptiste et al., 2017), thus aligning with conservation objectives (Clerici et al., 2019). Similarly, we suggest defining the agricultural frontier to enhance conservation objectives (Gallego et al., 2019). Processes such as relocation of displaced populations, the presence of ex-combatants, and land restitution processes must proceed without violating environmental restrictions (Morales, 2017), particularly within the regional strategic areas present in the Department of Córdoba. Peace agreements are transforming physical and socioeconomic landscapes in Colombia, and although potential benefits for the country are emerging, there is a risk of causing environmental damage, particularly in the context of climate change (Salazar et al., 2018).

4.3.3. Sustainable livestock and agricultural practices

In the Department of Córdoba, as in all Colombia´s Caribbean region, market forces, poverty, and irregular land tenure are associated with the expansion of pastures, providing cattle ranchers with a level of economic flexibility and low financial risk that is unrivalled compared to other land uses. It is essential in the post-conflict period to find economic and socially viable alternatives to improve working conditions, decrease inequality, mitigate environmental damage, and to potentially contribute to habitat restoration (Wassenaar et al., 2007). Agricultural dynamics have been central to resolving armed conflict and implementing peace agreements. Therefore, agricultural policies must be linked to this new post-conflict phase (McKay, 2018).

We propose that agriculture and ranching be modernized, which in a post-conflict context would facilitate improvements in quality of life for populations in rural areas and promote the sustainable use of natural resources (Gonzalez-Salazar et al., 2017). Therefore, agrarian reform is an important aspect of Colombian peace agreements, aiming to encourage displaced people to return to their homelands and to boost local economies in rural regions. Implementation of agrarian reform will likely motivate faster development of agricultural and extractive industries, necessitating concurrent planning for the rural environment, along with its associated economic context (Negret et al., 2017). This planning is particularly relevant in agricultural zones that contain the “livestock tradition” and “pasture decrease” clusters, as well as the “regional processes” cluster.

In addition, including victims in agricultural projects will help to help reestablish their violated rights (Chavez and Camelo, 2018) and will guarantee their access to land and financial credits, alleviating poverty through their contribution to productive agriculture (Suarez et al., 2018a). Integrating ex-combatants in the economy should also be a priority. Offering legal economic opportunities in rural areas is a promising option for restoring local economies (Morales, 2017; Nussio, 2018).

Finally, implementing forestry systems will ensure the complementarity of forestry and livestock grazing, transforming grazing from a vehicle for deforestation and ecosystem degradation to a strategy of ecological rehabilitation (Calle et al., 2011). Intensive forestry systems can produce up to 12 times more meat than extensive grazing and are starting to be considered as tools for climate change mitigation and adaptation, with the potential to reduce methane emissions per ton of beef by up to 1.8 times (Murgueitio et al., 2014). Policies that encourage ranching practices that allow for the coexistence of forests will generate employment and reduce ecological damage (Hoffmann et al., 2018).

5. Conclusions

This study described complex socio-environmental patterns in the Department of Córdoba at the scale of one of the smallest territorial units in Colombia, the municipality. First, the interrelationships between land cover and primary economic activities such as agriculture, livestock, and logging are now clear. Second, a strong association between armed conflict and land-use change, as well as a strong association between livestock and employment, were inferred. Third, as municipalities face different socioeconomic and geo-environmental conditions in the future, they will need to address diverse challenges of environmental governance, conservation of protected areas, ecosystem recovery, and sustainable livestock and agricultural practices. Policy makers and resource managers can apply the results of this work to regional planning, infrastructure development, victim restitution, and reintegration of ex-combatants, as well as to environmental protection and territorial defense.

Relationships between land use and conflict are poorly documented in most parts of the world. Post-conflict conditions in Colombia provided an opportunity to study socioenvironmental dynamics of the country’s Caribbean region, taking advantage of improvements in the collection and diffusion of ecological and socioeconomic data. Further improvement can be achieved by including Updating land-cover information, preferably including data taken during the post-conflict period, would improve this analysis. Expanding the study area to encompass other departments and municipalities, as well as including additional variables, would provide a broader geographic perspective on socioeconomic and environmental relationships.

The next steps in this line of research are to (1) apply participative methods in order to recognize and compile variables for which data are unavailable or incomplete, (2) use geographic models of land-use change to simulate potential future scenarios with varying conflict and socioeconomic conditions, and (3) design environmental policies for the post-conflict period and evaluate their environmental and social impacts. This type of scientific inquiry will ensure that natural resource management and socio-environmental approaches that integrate territorial and ecosystem service planning are relevant for building peace and long-term stability.

Acknowledgements

We thank Colciencias (2014 N0 6172) for their financial support to this research. We would like to thank the insights of the editor and an anonymous reviewer whose comments have helped strengthen this paper.

References

Aguilar, M., Sierra, J., Ramirez, W., Vargas, O., Calle, Z., Vargas, W., Murcia, C., Aronson, J., Barrera Cataño, J.I., 2015. Toward a post-conflict Colombia: restoring to the future. Restor. Ecol. 23, 4–6. https://doi.org/10.1111/rec.12172.

DANE (Departamento Administrativo Nacional de Estadística), 2017a. PIB A Precios Constantes Por Departamentos Base 2005, 2000 - 2016pr. DANE, Bogotá D.C Online at: (accessed at January 2018). https://www.dane.gov.co/index.php/estadisticas-por-tema/cuentas-nacionales/cuentas-nacionales-departamentales.

Arias, M.A., Ibañez, A.M., Zambrano, A., 2014. Agricultural Production Amid Conflict: The Effects of Shocks, Uncertainty, and Governance of Non-State Armed Actors. Universidad de los Andes, Facultad de Economía, CEDE, Bogotá D.C.

Baptiste, B., Pinedo-Vasquez, M., Gutierrez-Velez, V.H., Andrade, G.I., Vieira, P., Estupiñán-Suárez, L.M., Londoño, M.C., Laurance, W., Lee, T.M., 2017. Greening peace in Colombia. Nat. Ecol. Evol. 1, 1–3. https://doi.org/10.1038/s41559-017-0102.

Barragan, W., 2013. Sistemas silvopastoriles para mejorar la producción de leche y disminuir el estrés calórico en la región Caribe Colombiana. Universidad de Antioquia.

Calle, Z., Murgueitio, E., Chará, J., 2011. Rehabilitación ecológica de Agropaisajes Ganaderos en Colombia. In: Vargas, O., Reyes, S. (Eds.), La Restauración Ecológica En La Práctica, pp. 142–151.

Chavez, Y., Camelo, A., 2018. From assistance to the exercise of new citizenships: challenges of Social Workers professional performance towards the post – conflict victims in Colombia. Comunitania 15, 159–169.

Clerici, N., Richardson, J.E., Salazar, C., Pardo-díaz, C., Jiggins, C.D., Linares, M., 2019.

Peace in Colombia is a critical moment for Neotropical connectivity and conservation: save the northern Andes – Amazon biodiversity bridge. Policy Perspect. 12, 1–7. https://doi.org/10.1111/conl.12594.
CVS (Corporación Autónoma Regional de los Valles del Sinú y del San Jorge), 2008. Plan de Gestión Ambiental Regional- PGAR. Actualización 2008-2012. CVS, Montería.
DANE (Departamento Administrativo Nacional de Estadística), 2017b. Estimación y proyección de población nacional, departamental y municipal total por área 1985-2020, Proyecciones de Población. DANE, Bogotá D.C. Online at: https://www.dane.gov.co/index.php/estadisticas-por-tema/demografia-y-poblacion/proyecciones-de-poblacion (Accessed at January 2018).
DANE (Departamento Administrativo Nacional de Estadística), 2018. Boletín técnico: Mercado laboral por departamentos 2017. DANE, Bogotá D.C. Online at: http://www.dane.gov.co/files/investigaciones/boletines/ech/ml_depto/Boletin_dep_17.pdf (accessed July 2018).
DPS (Departamento Administrativo para la Prosperidad Social), 2017. Desplazamiento Forzado - Personas Expulsadas, Sistema de Información Geográfica para la planeación y ordenamiento territorial-SIGOT. DPS. Online at http://sigotn.igac.gov.co (Accessed at January 2018). .
Etter, A., van Wyngaarden, W., 2000. Patterns of landscape transformation in Colombia, with emphasis in the andean region. AMBIO A J. Hum. Environ. 29, 432–439. https://doi.org/10.1579/0044-7447-29.7.432.
Etter, A., Mcalpine, C., Wilson, K., Phinn, S., Possingham, H., 2006. Regional patterns of agricultural land use and deforestation in Colombia. Agric. Ecosyst. Environ. 114, 369–386. https://doi.org/10.1016/j.agee.2005.11.013.
FAO (Food and Agriculture Organization), 2016. State of the World's Forests. Forest and Agricultural: Land-use Challenges and Oportunities. FAO, Rome. Online at http://www.fao.org/3/a-i5588e.pdf (Accessed July 2018).
Fedegan (Federación Colombiana de Ganaderos), FNG (Fondo Nacional de Ganado), 2014. Bases para la formulación del plan de acción 2014 - 2018 para el mejoramiento de la ganadería del departamento de Córdoba. Fedegán-FNG, Montería https://estadisticas.fedegan.org.co/DOC/download.jsp?…2.PlanCordobaFINAL.pdf Online at: (Accessed October 2018).
Gallego, J., Azcárate, J., Kørnøv, L., 2019. Strategic Environmental Assessment for development programs and sustainability transition in the Colombian post-conflict context. Environ. Impact Assess. Rev. 74, 35–42. https://doi.org/10.1016/j.eiar.2018.10.002.
González, J., Etter, A., Sarmiento, A., Orrego, S., Ramirez, C., Cabrera, E., Vargas, D., Galindo, G., Garcia, M., Ordoñez, M., 2011. Análisis de tendencias y patrones espaciales de deforestación en Colombia. Instituto de Hidrología, Meteorología y Estudios Ambientales-IDEAM, Bogotá D.C.
Gonzalez-Salazar, M.A., Venturini, M., Witold-Roger, P., Finkenrath, M., Leal, Manoel Regis L.V., 2017. Combining an accelerated deployment of bioenergy and land use strategies: Review and insights for a post-conflict scenario in Colombia. Renew. Sustain. Energy Rev. 73, 159–177. https://doi.org/10.1016/j.rser.2017.01.082.
Grau, H.R., Aide, M., 2008. Globalization and land-use transitions in Latin America. Ecol. Soc. 13. https://doi.org/10.1057/9780230603554.
Guarin, A., Baron, L., Jenni, L., Salamanca, S., 2017. LADM- a tool for land administration in Post-Conflict Colombia. FIG Working Week 2017.
Hoffmann, C., Garcia, J., Krueger, T., 2018. A local perspective on drivers and measures to slow deforestation in the Andean-Amazonian foothills of Colombia. Land Use Policy 77, 379–391. https://doi.org/10.1016/j.landusepol.2018.04.043.
ICA, 2017. Tabla de población bovina por municipio y por departamento 2016. In: Instituto Colombiano Agropecuario (Ed.), Censo Pecuario Nacional 2016, pp. 1–2.
IDEAM, 2012a. Mapa de Cobertura de la Tierra. Metodología Corine Land Cover. Adaptada para Colombia. Escala 1:100.000. Periodo 2005-2009.
IDEAM, 2012b. Mapa de Coberturas de la Tierra. Metodología Corine Land COver. Adaptada para Colombia. Escala 1:100.000. Periodo 2000-2002.
IDEAM (Instituto de Hidrología, M. y E.A, 2014. Mapa de Coberturas de la Tierra. Metodología Corine Land Cover. Adaptada para Colombia. Escala 1:100.000. Periodo 2010-2012.
Idrobo, N., Mejía, D., Tribín, A.M., 2014. Illegal gold mining and violence in Colombia. Peace Econ. Peace Sci. Public Policy 20, 83–111. https://doi.org/10.1515/peps-2013-0053.
Instituto Colombiano Agropecuario-ICA, 2012. Censo Pecuario 2012.
Lans-Ceballos, E., Padilla-Jiménez, A.C., Hernández-Rivera, S.P., 2018. Characterization of organochloride pesticides residues in sediments from the Cienaga Grande of the lower Sinú river of Colombia. Cogent Environ. Sci. 4, 1–12. https://doi.org/10.1080/23311843.2018.1436930.
Mahecha, L., 2003. Importancia de los sistemas silvopastoriles y principales limitantes para su implementación en la ganadería colombiana. Rev. Colomb. Ciencias Pecu. 16, 11–18.
McKay, B.M., 2018. Democratising land control: towards rights, reform and restitution in post-conflict Colombia. Can. J. Dev. Stud. Can. D Ã‰tudes Du Dã©veloppement 39, 163–181. https://doi.org/10.1080/02255189.2017.1364621.
Mincit, 2015. Perfil económico: Departamento de Córdoba. Manual de diseño geométrico de carreteras. https://doi.org/10.1524/9783486858464.1.
MADR (Ministerio de Agricultura y Desarrollo Rural), 2017. Cabezas Bovinos. Información Geográfica para la planeación y ordenamiento territorial-SIGOT. MADR, Online at accessed January 2018. http://sigotn.igac.gov.co.
Ministry of Economy Trade and Industry-METI, National Aeronautics and Space Administration-NASA, 2011a. ASTGTM2_N08W077. ASTER GDEM.
Ministry of Economy Trade and Industry-METI, National Aeronautics and Space Administration-NASA, 2011b. ASTGTM2_N09W077.
Morales, L., 2017. Peace and environmental protection in Colombia. Proposals for Sustainable Rural Development., Inter-American Dialogue. The Dialogue. Online at: (Accessed September 2018). http://www.thedialogue.org/wp-content/uploads/2017/01/Colombia-report-Eng_Web-Res_Final-for-web.pdf&gt.
Moreno, V., 2016. Multinational mining in Colombia: extractivism and armed conflict in Cerro Matoso, 2000-2013. Cuad. Ciencias Jurídicas y Política Int. 9, 161–213.
Murgueitio, E., Chará, J., Barahona, R., Cuartas, C., Naranjo, J., 2014. Intensive Silvopastoral Systems (ISPS), mitigation and adaptation tool to climate change. Trop. Subtrop. Agroecosyst. 17, 501–507.
Negret, P.J., Allan, J., Braczkowski, A., Maron, M., Watson, J.E.M., 2017. Need for conservation planning in postconflict Colombia. Conserv. Biol. 31, 499–500. https://doi.org/10.1111/cobi.12935.
Nussio, E., 2018. Ex-combatants and violence in Colombia: are yesterday's villains today's principal threat? Third World Themat. A TWQ J. 3, 135–152. https://doi.org/10.1080/23802014.2018.1396911.
Observatorio del Programa presidencial de Derechos Humanos y DIH, 2009. Dinámica de la violencia en el departamento de Córdoba 1967-2008. Bogotá D.C.
Portilla, D., Barragán, W., Carvajal, C., Cajas, Y., Rivero, S., 2015. Establecimiento de sistemas silvopastoriles para la región Caribe. Corpoica, Bogotá D.C.
Puerta, Y., Aguirre, N., Vélez, F., 2016. Ayapel swamp system: a possible Ramsar site in Colombia. Gestión y Ambient 19, 110–122.
Ruiz, J., 2016. Producción bufalina en Colombia : del trópico para el mundo. CES Med. Vet. y Zootec. 11, 1.
Salazar, A., Sanchez, A., Villegas, J.C., Salazar, J.F., Ruiz Carrascal, D., Sitch, S., Restrepo, J.D., Poveda, G., Feeley, K.J., Mercado, L.M., Arias, P.A., Sierra, C.A., Uribe, Mdel R., Rendón, A.M., Pérez, J.C., Murray Tortarolo, G., Mercado-Bettin, D., Posada, J.A., Zhuang, Q., Dukes, J.S., 2018. The ecology of peace: preparing Colombia for new political and planetary climates. Front. Ecol. Environ. 16, 525–531. https://doi.org/10.1002/fee.1950.
Sanchez-Cuervo, A.M., Aide, T.M., 2013. Identifying hotspots of deforestation and reforestation in Colombia (2001–2010): implications for protected areas. Ecosphere 4, 1–21. https://doi.org/10.1890/ES13-00207.1.
Sánchez-Cuervo, A.M., Aide, T.M., 2013. Consequences of the armed conflict, forced human displacement, and land abandonment on forest cover change in Colombia: a multi-scaled analysis. Ecosystems 16, 1052–1070. https://doi.org/10.1007/s10021-013-9667-y.
Serra, P., Vera, A., Tulla, A.F., Salvati, L., 2014. Beyond urban-rural dichotomy: exploring socioeconomic and land-use processes of change in Spain (1991-2011). Appl. Geogr. 55, 71–81. https://doi.org/10.1016/j.apgeog.2014.09.005.
Sierra, C.A., Mahecha, M., Poveda, G., Álvarez-Dávila, E., Gutierrez-Velez, V.H., Reu, B., Feilhauer, H., Anáya, J., Armenteras, D., Benavides, A.M., Buendia, C., Duque, Á., Estupiñan-Suarez, L.M., González, C., Gonzalez-Caro, S., Jimenez, R., Kraemer, G., Londoño, M.C., Orrego, S.A., Posada, J.M., Ruiz-Carrascal, D., Skowronek, S., 2017. Monitoring ecological change during rapid socio-economic and political transitions: colombian ecosystems in the post-conflict era. Environ. Sci. Policy 76, 40–49. https://doi.org/10.1016/j.envsci.2017.06.011.
Suarez, A., Arias-Arevalo, P., Martinez-Mera, E., 2018a. Environmental sustainability in post-conflict countries: insights for rural Colombia. Environ. Dev. Sustain. 20, 997–1015. https://doi.org/10.1007/s10668-017-9925-9.
Suarez, A., Arias-Arévalo, P., Martinez-Mera, E., Granobles-Torres, J.C., Enríquez-Acevedo, T., 2018b. Involving victim population in environmentally sustainable strategies: an analysis for post-conflict Colombia. Sci. Total Environ. 643, 1223–1231. https://doi.org/10.1016/j.scitotenv.2018.06.262.
Unidad Víctimas (Unidad para la Atención y Reparacion Integral a las Víctimas), 2012. Córdoba: Informe departamental de hechos victimizantes a 2012. Unidad para la atención y Reparación Integral a las Víctimas, Bogotá D.C.
UPRA - Unidad de Planificación Rural Agropecuaria, 2017. Departamento De Córdoba.
Vicepresidencia de la República, 2017. Personas Secuestradas por Municipio [WWW Document]. Sistema de Información Geográfica para la planeación y ordenamiento territorial-SIGOT Online at (accessed July 2018). http://sigotn.igac.gov.co.
Viloria, J., 2004. La ganadería en el departamento de Córdoba, Documentos de trabajo sobre economia regional. Banco de la República, Cartagena de Indias.
Wassenaar, T., Gerber, P., Verburg, P.H., Rosales, M., Ibrahim, M., Steinfeld, H., 2007. Projecting land use changes in the Neotropics: the geography of pasture expansion into forest. Glob. Environ. Change 17, 86–104. https://doi.org/10.1016/j.gloenvcha.2006.03.007.