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Spatial Scenarios of Land Use/Cover Change for the management and conservation of Paramos and Andean Forest in Boyacá, Colombia.

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Abstract: The aims of this study were to identify the dynamics of land use change, the factors associated to these changes, and potential transformations of paramo and Andean forest, through the modeling of land use change scenarios in the department of Boyacá, Colombia. Throughout the classification of satellite images, we assessed land use change in two time periods: 1998 to 2010 and 2010 to 2018. Seven transition sub-models were analyzed and associated to 36 explanatory variables. Three future scenarios of land use change were projected for the years 2030 and 2050: trend, agricultural expansion and conservation scenarios. We found a gradual reduction in paramos and Andean forests, together with an increase in secondary vegetation. The most relevant variables explaining land use change were: elevation, distance to roads and distance to protected areas. The scenario with the greatest impact in paramos and Andean forest was Agricultural Expansion, where forest would have a loss of 29% and 41% for 2030 and 2050, and Paramos 44% and 59% for the same years. Forest and paramos in the central eastern area showed critical losses and highly fragmented distributions in all scenarios; hence, we recommend focusing conservation efforts in these areas.

Keywords: land transformation; explanatory variables; land change modeling; transitions; mountain ecosystems; Boyacá (Colombia)

1. Introduction

Land use transformation is recognized as a key factor in global change, influencing human environmental, and socioeconomic welfare [1, 2]. Many factors are identified as drivers of land-use change. The rise of the human population and an increase in meat demand, especially in developing countries, are two main drivers that have increased the need for agricultural land [3, 4]. Therefore, crops and pastures have gradually replaced forests in many places on earth, altering natural ecosystems [5,6,7].

Conversion to pastures and crops is constant in Latin América [8]; particularly, the south American tropical Andes have endured an intense agricultural activity, as they have been high populated over the years [9,10].

In the Colombian Andes, the department of Boyacá is one of the main agricultural producers at the national level. This department holds most of the Andean forest and paramos in the country, for it is a place with high biodiversity and numerous endemic species [11-12]. Agricultural pressures have accelerated the transformation of these natural ecosystems in the department, to cover products demand both locally and nationally [13]. These high mountain ecosystems are especially vulnerable to climate change, which in addition to high transformation rates, can lead to habitat and biodiversity loss, impacting social and ecological processes [14]. Boyacá aims to maintain a high sustainable agricultural production while keeping its strategic ecosystems and biodiversity [13]. This situation, along with a high rural population with needs, represents a complex challenge. Hence, it is crucial to know and understand potential future patrons that could guide optimal planning decisions in the territory.

Modeling spatial land-use change scenarios can be an effective tool for managing and planning the use of natural resources, as it allows us to explore where and when certain changes could be expected. It also provides a look at a potential future, where different pathways of change can be analyzed and support important conservation decisions [15]. Our objectives included an analysis to explore land-use changes in the Andean forest and paramos of Boyacá from 1998 to 2018, assessing the drivers associated with these changes and exploring potential future changes throughout the spatial modeling of three pathways for the years 2030 and 2050: i) Trend (Busines as usual) ii) Agriculture expansion and iii) Conservation.

2. Methods

2.1. Land Use/Cover changes

Study area is in the Boyacá department, Colombia. This department sites in the Central East region of the country, along the central part of the eastern Andes mountain range. Altitudes in the department vary from 400 to 5.000 m.a.s.l. This study focuses on the Andean forest and paramos above the 900 m.a.s.l.

To estimate both quantitively and spatially land use change in the study area, three maps of land use/cover were created for the years 1998, 2010, and 2018. The maps were produced by classifying Landsat images 5, 7, and 8 L1T. Images classification was performed using the Erdas Imagine software 2015, using the maximum likelihood supervised parametric method. We undertook an accuracy test for each classified image in the module "Accuracy Assessment" of Erdas, using stratified sampling. Outcoming values for general accuracy and Kappa coefficient were satisfactory. Map 2018 presented a general accuracy of 86% and Kappa coefficient of 0.8337. Maps from 2010 and 1998, obtained values of: 85% and 0.8325 and 84% and 0.7861 correspondingly.

Land-use change analysis was performed using the Land Change Modeler (LCM,) in the Idrisi Selva software V. 17.2. Changes in land use/cover were analyzed in 11 categories: Andean forest, paramo, secondary vegetation, pastures and crops, thickets, shrubs, rock surfaces, bare soil, urban, forest plantations, and water bodies. The analysis was carried out in two periods: 1998-2010 and 2010-2018. Gains, losses, and persistence were calculated in the two periods for each land cover category [16]. We also calculate the annual rate of change for each category, applying the Puyravaud (2003) formula [17]:

$$\mathrm{r} = \frac{1}{t2 - t1} * ln\frac{A2}{A1} * 100$$

Where: r is the rate of change, *t1* is the initial time, t2 final or next time step, A1 cover area (ha) in t1 and A2 cover area (ha) in *t2.*

2.2. Transition Sub models and Drivers of Change

We worked seven sub models, grouped in two categories: degradation and regeneration.

Degradation: 1) Andean forest to pastures and crops, 2) Andean forest to secondary vegetation, 3) Paramo to pastures and crops, 4) Paramo to secondary vegetation, 5) Paramo to bushes.

Regeneration: 6), Pastures and crops to secondary vegetation, 7) Pastures and crops to scrub.

We prepared a group of 36 variables to be consider as drivers of change (Appendix A). Many of them were previously reported as important factors that induced change in south American Andes [18]. Variables were both quantitative and categoric, discriminated in eight categories: 1) Physical environment, 2) Accessibility , 3) Landscape composition, 4) Landscape structure, 5) Management policies, 6) Degradation, 7) Demographic, 8) Socioeconomic.

For each sub-model, most suitable variables were assigned taking into account the explanatory value for Cramer statistic (optimal values > 0.15), the relevance of the variable towards the transition and its potential influence in the process, based on previous studies in the Andean biome. We also consider the combination of variables that yields highest accuracy values to the sub-model.

We model each transition using the MLP (Multilayer Perceptron) method in Idrisi. After running each sub-model, we obtained seven transition maps and their corresponding accuracy values.

2.3. Scenarios construction and predictions

Land use/cover change predictions were done using Markov chains analysis in the Land Use Change Modeler (LCM) in Idrisi. Three future scenarios were developed: i) Trend, ii) Agricultural expansion and iii) Conservation. Projections for each scenario were made for the years 2030 and 2050. Scenarios were inspired on different climate change IPCC (Intergovernmental Panel on Climate Change) scenarios, showing distinct plausible future pathways.

i) Trend scenario. Assumes that observed trends in Andean forest and paramos during 1998 and 2010 will continue the same in the landscape for 2030 and 2050. No conservation actions nor incrementation in crop and pasture area was considered.

ii) Agricultural expansion scenario. This scenario was created based on the RCP 8.5 IPCC scenario: *A scenario of comparatively high greenhouse gas emissions*, which assumes an increase of 12% of arable land in the planet for 2050 [20]. In this line, our Agricultural Expansion scenario contemplates a 12% increment of the arable land in the study area. Transition probabilities from secondary vegetation, Andean forest and paramo to pastures and crops were incremented in 2%, 5% and 5% respectively. This scenario does not apply any conservations actions, leading to lost and degradation of Andean forest and paramos.

iii) Conservation scenario. Scenario based on the RCP 4.5 IPCC scenario: *A Pathway for Stabilization of Radiative Forcing by 2100.* RCP 4.5 rises a slight decrease in greenhouse gases in the planet for 2100, given to forest expansion and the implementation of green technologies [21]. Our conservation scenario assumes the implementation of conservation measures like restauration projects, protected areas expansion and payment for ecosystem services, allowing regeneration processes in the area. Transition probabilities from pastures and crops to secondary vegetation and Andean forest were incremented in 4% each, for a total regeneration increase of 8%.

3. Results and Discussion

3.1. Land Use/Cover Change

3.1.1. Land Use/Cover Change during 1998-2010

Most representative land/use covers during this period were pastures-crops and Andean Forest with 39% and 29.2% of the area (Table1). Andean forest, and paramo, were the land covers that went through a higher reduction at the end of the period. Andean forest showed the highest annual rate of loss; -1.3% while bushes and secondary vegetation presented the highest annual gaining rate; 7% and 4.2%.

Table 1. Land cover change between 1998 and 2010 (%). Persistence, losses, and gains for 2010 in hectares. Annual gain/loss per category is presented as annual exchange rate (%).

Land Cover	1998%	2010%	Persistence	Gain	Loss	Annual exchange rate
Pastures-crops	39	34.7	597.986	66.736	145.721	-0.9
Secondary Vegetation	10.4	17.1	131.37	197.228	66.978	4.2
Andean Forest	29.2	24.8	432.893	41.716	122.853	-1.3
Paramo	11.4	10	137.739	54.583	78.923	-1
Bushes	3	7	43.385	90.011	14.392	7

3.1.2. Land Use/Cover Change during 2010-2018

Larger land covers categories for this period were pastures-crops and Andean forest, followed by secondary vegetation with a cover percentage of 41.8%, 18.4% and 17.6% for 2018. The category that experimented a bigger reduction was Andean forest, losing 154.792 hectares, at a loss rate of 3.7% annually. Category with greatest increment was pastures-crops, earning 2.3% of its area annually, represented in 192.458 hectares in the study area for 2018 (Table 2).

Table 2. Land cover change between 2010 and 2018 (%). Persistence, losses, and gains for 2018 in hectares. Annual gain/loss per category is presented as annual exchange rate (%).   .

Cobertura	2010	2018	Persistence	Gain	Loss	Annual exchange rate
Pastures-crops	34.7	41.8	610.661	191.458	54.062	2.3
Secondary Vegetation	17.1	17.6	175.805	161.41	152.792	0.3
Andean Forest	24.8	18.4	319.771	33.725	154.837	-3.7
Paramo	10	10.1	146.634	47.91	45.688	0.1
Bushes	7	6.5	72.253	52.238	61.143	-0.9

For the first study period our results showed an increment in secondary vegetation, while crops and pastures decreased. The opposite situation was found in the second period. This is consistent with a repetitive patron previously reported in the tropical Andes, where secondary vegetation and crops-pastures replaced systematically to each other. This is given to a dynamic where the land is abandoned after agricultural use, permitting secondary vegetation recovery. This patron has also been reported in the Venezuelan, Bolivian and Colombian Andes before [22, 23, 24, 25, 26].

3.2. Transition sub-models and drivers of change

Overall, the variables that intervene the most in the land use change dynamics were the digital elevation model and the distance to national protected areas. The distance to other categories of protection (distance to regional natural parks, distance to municipal natural parks and distance to civil society reserves) played an important role as well, ranked in the second place of frequency intervention, together with distance to secondary roads. Concerning to socioeconomic variables; agricultural density, number of households and conflict overuse were the most frequent variables explaining land use change.

The elevation (DEM), our most frequent variable in the transitions, showed high positions of influence, and has also being reported to be an important factor affecting land transformation in the Andes according to previous studies [27, 23]. Similar situation occurs with the variables distance to roads, and distance to protected areas, also particularly important in our study and in previous investigations in the Andean region [10]. Once more, these variables have proved to be drivers of change in Andean forest and paramos.

Compared to other land use change investigations, we included numerous socioeconomic variables in this study. In many of the cases, the influence of this variables in the transitions was low. This is in line with Redo et al (2012) [23], where the influence in land use change of variables related to needs, development, education, and demographics, turned out to be low in the Bolivian Andes. However, socioeconomic variables were present in all the transitions, and in some cases, occupying high positions of influence.

3.3. Spatial explicit land use scenarios for 2030 and 2050

Taking 2010 as the reference year, the scenarios indicated land cover reductions in three categories: Andean Forest, paramo and crops-pastures (negative values), as well as an increase in bushes and secondary vegetation (positive values). The most drastic changes occurred in the agricultural intensification scenario, while trend and conservation scenarios behaved more closely (Table 3).

Paramo land cover reached its highest percentage of change in the agricultural intensification scenario, reducing its area by 44.17% in 2030 and 59.78% in 2050. Change percentages for paramo behaved very similarly in trend and conservation scenarios. Also, agricultural intensification scenario would represent the greatest impact on Andean forest cover, generating losses of 29.67% in 2030 and 41.80% in 2050. Crops and pastures would achieve their greatest reduction in the conservation scenario, and secondary vegetation the highest increasing values (Table 3).

Table 3. Percentages of change for each land cover and scenarios.

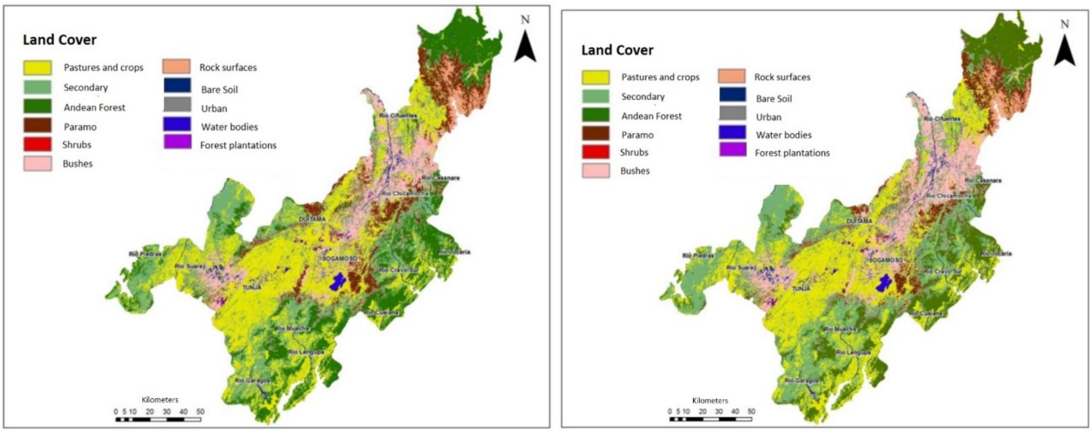
		TR				AI				CO			
	2010	2030		2050		2030		2050		2030		2050	
	% A	% A	% C	% A	% C	% A	% C	% A	% C	% A	% C	% A	% C
P-C	34.7	29.66	-14.45	27.68	-20.17	31.40	-9.43	29.42	-15.15	28.27	-18.45	26.29	-24.16
SV	17.1	28.26	64.92	32.68	90.65	28.26	64.91	32.67	90.65	29.65	73.00	34.06	98.74
AF	24.8	18.65	-24.67	15.65	-36.79	17.41	-29.67	14.41	-41.80	18.65	-24.67	15.64	-36.80
P	10	6.10	-39.17	4.54	-54.78	5.60	-44.17	4.03	-59.78	6.10	-39.17	4.54	-54.78
B	7	10.88	56.32	13.02	87.11	10.88	56.35	13.02	87.10	10.88	56.35	13.02	87.10

TR: Trend scenario. AI: Agricultural Intensification Scenario. CO: Conservation scenario. PC: Pastures-crops. SV: Secondary Vegetation. AF: Andean Forest. P: Paramo. B: Bushes. A%: Percentage of Area. C%: Percentage of chang.e

Agricultural expansion scenario would represent the biggest impact in terms of fragmentation and connectivity in the study area. These disturbances can lead to ecosystems degradation, altering energy flows and leading to the loss of biodiversity [28, 29]. Less resilient species with low plasticity and restricted distribution, could be the most affected [30]. For example, Agudelo et al, (2019) [31] report a loss of suitable habitat for the anurans in the Colombian Andes, between 49.6% and 72.6% by the year 2050, given to climate and land use change; which would certainly increase the risk of extinction of several species in this group.

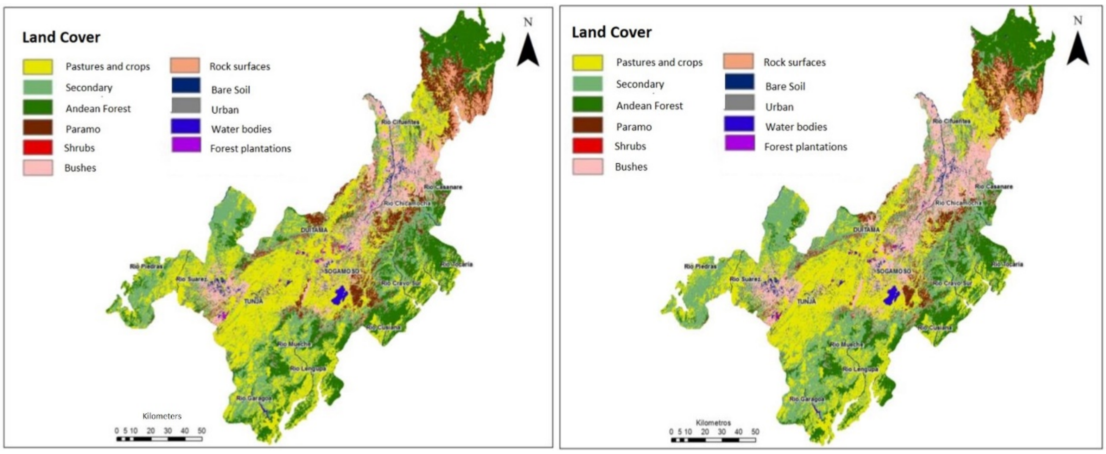
The conservation scenario was the best pathway for Andean forest and paramos, with lower losses values. This is consistent with Jantz et al., (2015), who reported the lowest values of natural cover loss (77%) for the Andean hotspot by 2100, in a scenario that considers forest expansion (RCP 4.5). Our conservation scenario presents the lowest decline values in the Andean forest and paramo; however, the impact in these natural covers is important and differ little from trend scenario values. This can indicate that degradation processes are happening fast in the area, suggesting that better and prompt conservation measures are needed to safeguard these resources and the ecosystem services they provide. These measures can be thought linked to climate change mitigation actions, as they can also prevent habitat and biodiversity loss, due to land use change [32].

In all scenarios biggest and more conspicuous changes would take place in Tota-Bijagual-Mamapacha and Pisba paramo complexes. Particularly, Tota-Bijagual-Mamapacha has went through an intense agricultural pressure, as it is placed near the municipality of Aquitania; a high agricultural producer. Our results revealed congruent information with Sarmineto et al., (2013) [33], where after the paramo complex of Altiplano Cundiboyasense (not taking into account in this study, as it is very reduced and no paramo cover was detected), Tota-Bijagual-Mamapacha showed the biggest percentage of transformation: 31.39%. Most vulnerable areas to be transform agree with Armenteras et al., (2012) [18], which stated that the majority of hot spots of paramo loses in the Colombian Andes, are located in the eastern mountain range, particularly in Boyacá and Cundinamarca departments.



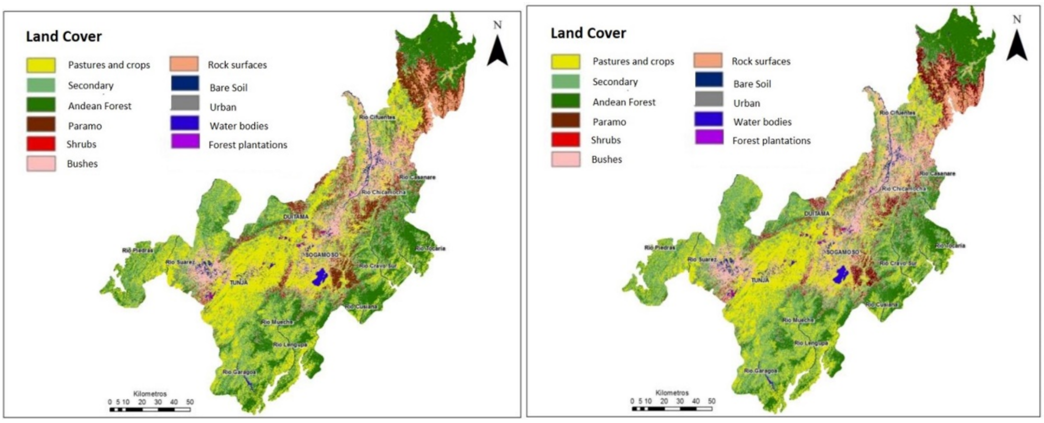
(a) (b)

Figure 1. Land cover for according to Trend Scenario, a) 2030, b) 2050.



(a) (b)

Figure 2. Land cover for according to Agriculture Expansion Scenario, a) 2030, b) 2050.



(a) (b)

Figure 3. Land cover for according to Conservation Scenario, a) 2030, b) 2050.

4. Conclusions

In 20 years (1998-2018), a gradual loss of Andean forests and paramos was observed in the study area. We also found an increase in secondary vegetation and a dynamic between crops-pastures and secondary vegetation, that agrees with a cyclical pattern previously reported in the South American Andes.

The most recurrent explanatory variables that influenced the transitions in the study area belonged to three categories: physical-environmental (DEM), accessibility (distance to secondary roads), and management policies (distance to national protected areas). Overall, the socio-economic variables obtained medium and low positions of influence in the transitions, but they were recurrent in the changes; therefore, it is recommended to include and explore this type of variables in future investigations.

The scenario with the most drastic values of forest and paramo loss was the Agricultural Intensification scenario, while the Tendency and Conservation scenarios showed similar loss values. Tota-Bijagual-Mamapacha and Pisba turned out to be the most affected paramos in all three scenarios, thus, it is recommended to increase conservation efforts in these areas (e.g. restoration or PES initiatives).

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Conflicts of Interest: "The authors declare no conflict of interest."

Appendix A. Explanatory variables used in the transition sub-models.

Categorie	Variable Name
Physical environtment	Digital Elevation Model (DEM)
	Slope
	Northness
	Eastness
	Ground roughness index
Accessibility	Distance to primary roads
	Distance to secondary roads
	Distance to tertiary roads
	Distance to urban areas
Landscape Composition	Distance to rivers
	Distance to lagoons and reservoirs
	Distance to crops and pastures
	Distance to Andean Forest
	Distance to secondary vegetation
	Distance to bushes
	Distance to paramo
Landscape Structure	Forest patch size
	Paramo patch size
Management Policies	Distance to National Protected Areas
	Distance to regional national parks
	Distance to municipal National parks
	Distance to civil society reservs
Degradation	Size of mining concession areas
	Distance to concession areas
	Distance to eroded areas
	Eroded areas
	Livestok density
	Agricultural density
Demographic	Total population
	Number of homes
Socioeconomic	Unsatisfied Basic Needs (UBN)
	Multidimentsonal Poverty Index (MPI)
	Gross Domestic Product (GDP)
	Municipal Performance Measurement (MPM)
	Fiscal Performance Index (FPI)
	Overuse Conflict

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