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EXTENSIFICATION OF AGRICULTURAL LAND-USE GENERATES SEVERE EFFECTS ON THE CRITICALLY ENDANGERED INTER-ANDEAN DRY FOREST IN THE ECUADORIAN ANDEAN LANDSCAPE

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ABSTRACT

The Inter-Andean Dry Forest is one of the most endangered ecosystems in the world. The extensification of anthropogenic land-use has transformed the Inter-Andean Dry Forest in the landscape of the Rio Chota watershed, Ecuador. However, there is no evaluation of the land use/land cover dynamics to determine the loss and recovery of this ecosystem. This study aimed to evaluate the effects of the extensification of agricultural land-use on the spatial pattern of the Inter-Andean Dry Forest ecosystem and the state of the landscape in the RCW during the periods 1991–2000 and 2000–2017. The effects of land-use change on the spatial pattern of the Inter-Andean Dry Forest were evaluated at the landscape level using satellite images and landscape metrics. The loss of the Inter-Andean Dry Forest was 45 % from 1991 to 2017, at a deforestation rate of 2.3 % per year. The largest loss of forest (42.7 %) occurred from 2000 to 2017. From 1991 to 2000, the number of patches of Inter-Andean Dry Forest increased by 194 % but decreased by 64 % in 2017. Over the entire study period, the major change in the landscape was the conversion of the Inter-Andean Dry Forest to agriculture (36.7 %), which was related to important changes in the spatial patterns of this ecosystem. Inter-Andean Dry Forest loss and fragmentation were associated with the extensification of agricultural land-use. The Rio Chota watershed is a landscape increasingly transformed by human processes. This study provides baseline information on landscape structure and composition. This information could help make management decisions for the Inter-Andean Dry Forest in specific landscape areas.

Keyword: Anthropogenic processes; Agriculture; Changing landscape; Deforestation; Ecuador; Rio Chota watershed

INTRODUCTION

The forest landscape can change due to two processes that are closely connected. First, the demand for food, fibers, and fuels in society is increasing agricultural land-use

(García-Martínez *et al*., 2021). Second, globally interconnected economies and markets for food products lead to an extensification of agricultural land-use (Meyfroidt *et al*., 2013). The forest landscape change can be evidenced through the spatial pattern changes of forest landscapes (composition and spatial configuration), such as total area, number, and connectivity of patches, among others (Tapia-Armijos *et al*., 2015).

The Tropical Dry Forest is one of the most endangered ecosystems in the world (García-Navas *et al*., 2022). The massive transformation of this ecosystem is due to their usually fertile soils, which are very suitable for agriculture (Arcila *et al*., 2012; Sunderland *et al*., 2015). This transformation has been going on for millennia. The Tropical Dry Forest ecosystem is categorized as Critically Endangered by the International Union for Conservation of Nature (IUCN) (Ferrer-Paris *et al*., 2018). Despite its importance, this ecosystem is one of the least studied forested ecosystems in the world. Therefore, it may be more vulnerable than other tropical forests (Sunderland *et al*., 2015).

The Tropical Dry Forest is important for several reasons: 1) Contributes to local communities' diets with forest products such as wild fruits, vegetables, nuts, edible insects, and medicinal plants, among others (Rowland *et al*., 2015). 2) Contributes wood and charcoal, which are energy sources for local households (Sunderland *et al*., 2015). 3) Dry forests can help mitigate climate change through carbon storage (Dexter *et al*., 2015). 4) The Dry Forests are highly resistant to drought. Consequently, the livelihoods they provide are key to the adaptation of communities to the threats of climate change (Pulla *et al*., 2015). 5) This ecosystem supports the provision of key ecosystem services, such as pollination, nutrient cycling, and soil improvement (Foli *et al*., 2015). 6) The Dry Forests harbor considerable biodiversity that sometimes exceeds that of humid forests (Sunderland *et al*., 2015).

In the Americas, two-thirds of the Tropical Dry Forest in the region (200.000 km^2) has been converted to other land-uses; in some countries, the conversion rate is as high as 95 %, and approximately 70 % of the remaining surface has very high levels of fragmentation (Ferrer-Paris *et al*., 2018; Rivas *et al.*, 2021). In countries such as Ecuador, the data on conversion is much harder to come by. This is primarily because the most reliable authoritative sources, such as the FAO Global Assessment of Forest Resources (FAO, 2022), do not differentiate between humid and dry forest types. According to Miles *et al*. (2006) and Rivas *et al*. (2021), less than one-third of the Tropical Dry Forest area is located within protected areas in Ecuador. Therefore, given this ecosystem's biodiversity and livelihood values, it is necessary to dedicate more efforts to its sustainable management.

The Rio Chota watershed (RCW) in northern Ecuador is part of the Tropical Andes hotspot that includes the unique Dry Forests of Ecuador and Colombia (Ferrer-Paris *et al*., 2018). The Ecuadorian Tropical Dry Forests contain high levels of floristic diversity, and approximately 80 % of their components are regionally endemic (Ministerio del Ambiente del Ecuador, 2012). In the RCW landscape, the Tropical Dry Forest has been described as an Inter-Andean Dry Forest because it is restricted to the lowlands in the inter-Andean valleys (Aguirre *et al*., 2006). Despite the high conservation value of this ecosystem and landscape, extensive agriculture and overexploitation of native species have been associated with the transformation of the Inter-Andean Dry Forest (Mittermeier *et al*., 2011; NatureServe & EcoDecision, 2015). Considering the national, regional, and global importance of this ecosystem, it is necessary to know the changes in the landscape, the changes in the Inter-Andean Dry Forest, and their current states to contribute information to help make management decisions in specific landscape areas.

Studies in the RCW landscape have focused on biodiversity and its conservation (Oleas & Pitman, 2003; Santiana *et al*., 2004a, 2004b; Aguirre *et al*., 2006; Werner & Gradstein, 2009;

Aguirre *et al*., 2011; Cisneros-Heredia *et al*., 2017; Quintana *et al*., 2017; Chimarro-Cumbal *et al.*, 2023), but none have evaluated the transformation of the landscape nor the effects of land-use change on the spatial patterns of the Inter-Andean Dry Forest due to the extensification of agricultural land-use. As a result, there is no crucial information for planning the restoration, conservation, and management of the Inter-Andean Dry Forest on a landscape scale.

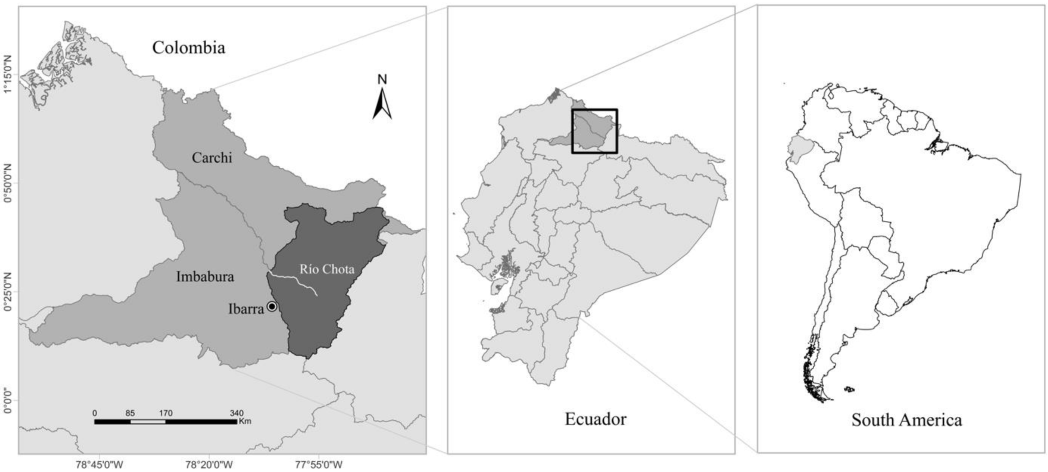
I evaluated the effects of the extensification of agricultural land-use on the spatial pattern of the Inter-Andean Dry Forest ecosystem and the state of the landscape in the RCW during the 1991–2000 and 2000–2017 periods. The study aims to answer the following questions: (1) What have been the main trends in land-use/land-cover (LULC) dynamics during the 1991–2000 and 2000–2017 periods? (2) What are the changes in the Inter-Andean Dry Forest spatial patterns after the extensification of agricultural land-use? (3) What are the landscape areas where it is necessary to implement management actions for the Inter-Andean Dry Forest? I hypothesize that an increase in the area of agricultural land-use has generated a high rate of loss of Inter-Andean Dry Forest, which is greater than 2.0 % per year, and a decrease of at least 50 % in the number of forest patches in the last study period, resulting in a landscape increasingly transformed by human processes.

MATERIALS AND METHODS

Study area

The RCW is located in the provinces of Imbabura and Carchi in northern Ecuador (Fig. 1). It is located in the cordillera of the Andes (0º14'N and 0º44'N), to the northeast of the city of Ibarra. The watershed covers approximately 1,919 km^2, has a maximum elevation of 3,900 m a.s.l., a mean temperature of 21 °C, and an annual rainfall of 600 mm (Instituto Nacional de Meteorología e Hidrología, 2005). The RCW is characterized by steep altitudinal gradients, which consist of almost a 2500 m altitudinal difference between the highest and lowest points in the watershed. Consequently, the RCW has a climate with a complex and changing pattern due to its orographic system. Therefore, the altitude and climate strongly determine the type of natural land-cover.

Fig. 1: Location of the RCW in the provinces of Imbabura and Carchi, Ecuador



Currently, the watershed consists of agriculture 54 %, Tropical Montane Forest 19 %, Paramo 15 %, Inter-Andean Dry Forest 5 %, shrub vegetation 1.6 %, and other LULC types (Thorn Forest, water bodies, bare land, and urban areas) 5 % (Sistema Nacional de Información, 2019). The RCW has a human population of 25,000 approximately inhabitants, with a population density of 13 people km^{-2} (Secretaría Nacional de Planificación y Desarrollo, 2019).

The Inter-Andean Dry Forest is characterized by open canopies and shrubs up to 2 m. The vegetation is composed of *Croton elegans*, *Acacia macracantha*, *Buddleja bullata*, *Caesalpinia spinosa*, *Phaedranassa brevifolia*, *Coursetia gracilis*, and *Euphorbia jamesonii* (Ministerio del Ambiente del Ecuador, 2013). The fauna is represented by *Dipsas elegans* and *Stenocercus chota* reptiles*;* the *Colibri coruscans* and *Chlorostilbon melanorhynchus* birds*;* the *Thyroptera tricolor* and *Myotis nigricans* mammals (Aguirre *et al*., 2011).

Land-use/land-cover changes analysis

LULC changes were evaluated for 26-year between 1991 and 2017. These changes were analyzed based on LULC thematic maps. To generate these maps, Landsat satellite images were acquired for July 1991 (Landsat 4-5 TM), 2000 (Landsat 7 ETM +), and August 2017 (Landsat 8 OLI) from the USGS portal. The images had a spatial resolution of 30 x 30 m/pixel and a cloud cover of less than 5 %. The images were corrected geometrically, atmospherically, and topographically (Chander *et al*., 2009). Through the C factor methodology were eliminated the shadows cast by the topography of the place (Reese & Olsson, 2011). To increase the accuracy of the classification, the vegetation indices NDVI, SR, SAVI, and LSWI were used (Huete, 1988). Supervised classification was carried out using the statistical method of maximum likelihood estimation and 500 training points taken in the field, which represented the patterns of the types of land-cover. The accuracy of the classification of the images was calculated using confusion matrices and 300 control points. The accuracy of the 1991 and 2000 images was calculated through land-cover maps. These maps were created in previous studies (Rodríguez-Echeverry & Leiton, 2021; Arévalo-Morocho *et al*., 2023). The following cover classes, or land-uses, were identified on each map: Inter-Andean Dry Forest, agriculture, paramo, Thorn Forest, Tropical Montane Forest, shrub vegetation, bare land, urban areas, and water bodies.

LULC change was evaluated through changes in the area of the LULC types between the 1991-2000 and 2000-2017 periods. I used the equation developed by Newton (2007) to quantify the annual rate of change:

$$P = \left[\left(\frac{A_2}{A_1} \right)^{\left(\frac{1}{(t_2 - t_1)} \right)} - 1 \right] x\ 100$$

Where A_1 and A_2 are the class areas at t_1 and t_2 time, respectively; and P is the percentage of change per year.

LULC dynamics were evaluated based on trajectory analysis using the transition matrices in each study period. This analysis was carried out using IDRISI Selva software (Eastman, 2012). The analysis was focused on the trajectories of the Inter-Andean Dry Forest toward the main anthropic land-uses reported in this region of Ecuador (Arévalo-Morocho *et al*., 2023). Therefore, the trajectories evaluated were from the Inter-Andean Dry Forest to (i) agriculture; (ii) urban areas; and (iii) bare land.

Analysis of changes in the spatial patterns

I evaluated the effects of land-use change on the spatial pattern of the Inter-Andean Dry Forest through landscape metrics. The estimation and comparison of spatial patterns were performed using seven key landscape metrics widely used in the analysis of forest landscape changes (Tapia-Armijos *et al*., 2015; De la Sancha *et al*., 2021; Rivas *et al*., 2022). These are (i) total area (ha); (ii) number of patches; (iii) largest patch index (% of landscape occupied by the largest patch); (iv) average distance to the nearest neighbor (m); (v) total edge length (km); (vi) adjacency index (km); and (vii) aggregation index (%). The description of these metrics can be found in McGarigal *et al*. (2013). This analysis was carried out using FRAGSTATS software (McGarigal *et al*., 2013).

Identification of the Inter-Andean Dry Forest change hotspots

The change hotspots are the landscape areas with the highest changes from Inter-Andean Dry Forest to other land-uses. That is to say, these are the areas where deforestation and fragmentation were reported for this ecosystem. I identified these hotspots based on the maps of 1991 and 2017 and the trajectories of land-cover change.

RESULTS

Accuracy assessment

The classification accuracy of the 1991, 2000, and 2017 images was 90 %, 89 %, and 93 %, respectively. In 1991, the Inter-Andean Dry Forest obtained an accuracy of 91 %, while the shrub vegetation was the least accurate at 87 %. In 2000, the most accurate classification was in the Inter-Andean Dry Forest (90 %), and the least precise was for Thorn Forest (86 %). In 2017, the Inter-Andean Dry Forest obtained an accuracy of 93 %, while the Paramo was the least accurate at 89 %.

Land-use/land-cover dynamics

The LULC change analysis evidenced the dynamics of gains and losses in the RCW landscape from 1991 to 2017 (Table 1). The Inter-Andean Dry Forest and shrub vegetation were the land-covers with the largest area loss, which were 7,474 ha and 5,571 ha, respectively (Table 1 and Fig. 2a and b). The Inter-Andean Dry Forest and shrub vegetation reported the largest annual change rates of -3.21 % and -5.34 %, respectively, in the second study period (2000–2017) (Table 1). The Inter-Andean Dry Forest area decreased by 45 % from 1991 to 2017 (i.e. at annual rates of -2.3 %). In 2017, Inter-Andean Dry Forest change hotspots were located in the center and south part, where this ecosystem was reported in 1991 (Fig. 2a).

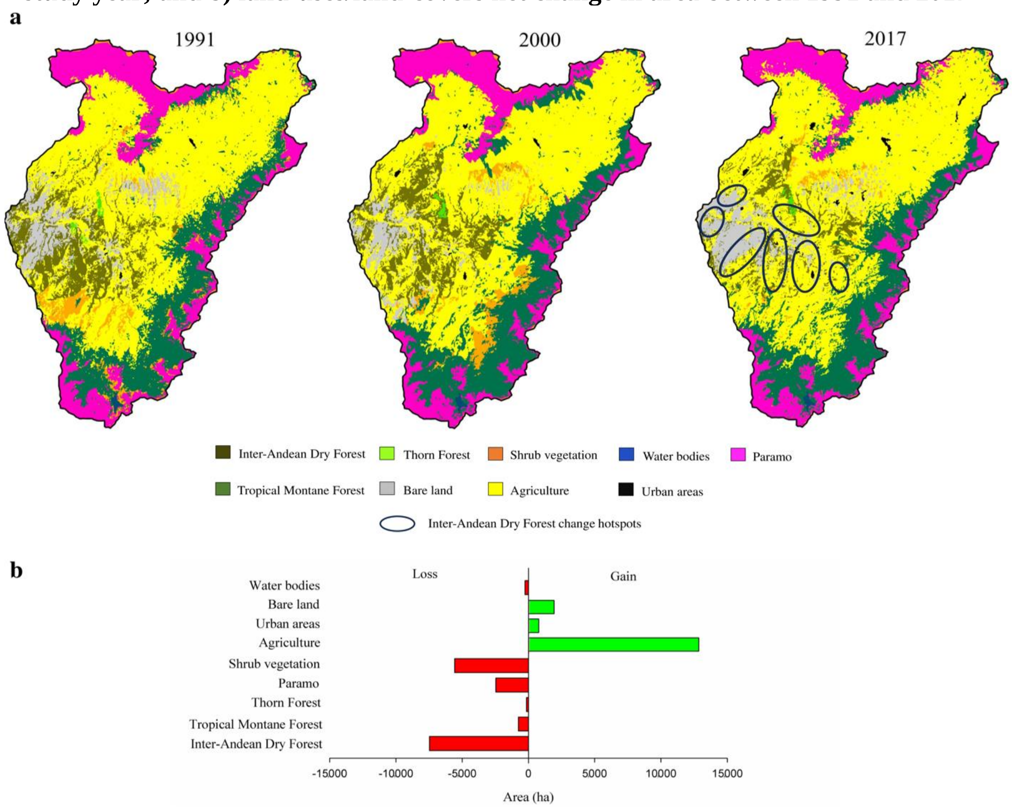
Agriculture was the land-use that registered the largest gain, which was 13,845 ha over the entire study period, and maintained the largest area within the landscape with 52.6 % in 2017 (Table 1 and Fig. 2a and b). Agriculture reported an annual change rate of 0.54 % and 0.58 % in the first (1991–2000) and second (2000–2017) periods, respectively.

Urban areas and bare land showed gains. Urban areas increased by 791 ha between 1991 and 2017, which represented 0.1 % of the total area in 1991 and 0.5 % in 2017 (Table 1 and Fig. 2a and b). Bare land increased by 2,036 ha over the entire study period, decreasing at a rate of -3.83 % between 1991 and 2000 but increasing at an annual rate of 3.19 % in the second period (2000–2018) (Table 1).

Table 1: Area and annual change rate of land-use/land-cover classes for each year in the RCW

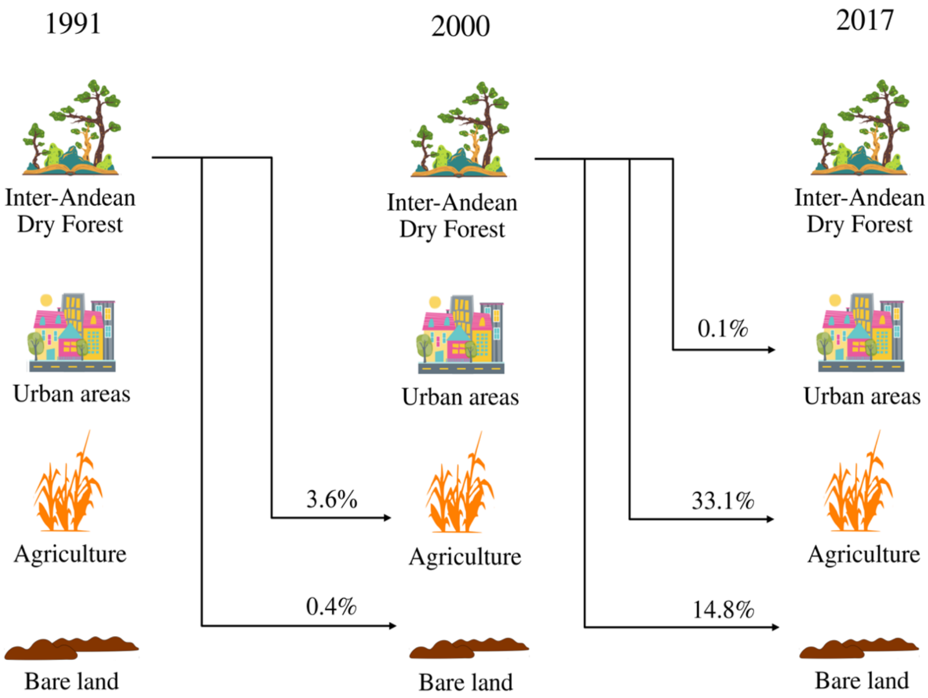
Land-use/land-cover	1991		2000		2017		Annual change rate (%)		Net Change (ha)
	(ha)	%	(ha)	%	(ha)	%	1991-2000	2000-2017	1991-2017
Inter-Andean Dry Forest	16,774.20	8.7	16,161.80	8.4	9,299.61	4.8	-0,41	-3,21	-7,474.59
Tropical Montane Forest	36,985.25	19.2	38,893.10	20.2	36,229.50	18.8	0,56	-0,42	-755.75
Thorn Forest	467.01	0.2	338.40	0.2	321.39	0.2	-3,51	-0,30	-145.62
Paramo	31,394.00	16.3	29,699.87	15.4	28,931.00	15.0	-0,61	-0,15	-2,463.00
Shrub vegetation	8,719.14	4.5	7,975.73	4.1	3,148.00	1.6	-0,98	-5,34	-5,571.14
Agriculture	87,523.90	45.4	91,890.12	47.7	101,369.00	52.6	0,54	0,58	13,845.10
Urban areas	173.61	0.1	290.70	0.2	964.27	0.5	5,89	7,33	790.66
Bare land	10,347.20	5.4	7,278.12	3.8	12,382.80	6.4	-3,83	3,19	2,035.60
Water bodies	450.61	0.2	307.08	0.2	189.35	0.1	-4,17	-2,81	-261.26

Fig. 2: Land-use/land-cover change in the RCW: a) land-use/land-cover maps for each study year; and b) land-uses/land-covers net change in area between 1991 and 2017



From 1991 to 2017, the major contribution to the net change was the conversion of the Inter-Andean Dry Forest to agriculture (36.7 %) (Fig. 3). In the first period (1991–2000), the loss in the Inter-Andean Dry Forest was mainly by trajectories towards agriculture by 3.6 %. In the second period (2000–2017), the loss in the Inter-Andean Dry Forest was due to trajectories towards agriculture and bare land of 33.1 % and 14.8 %, respectively (Fig. 3). Agriculture was the dominant cover in the landscape over the entire study period.

Fig. 3: Major trajectories of LULC change and their contributions to the net change in percentage of the total area of the respective LULC types



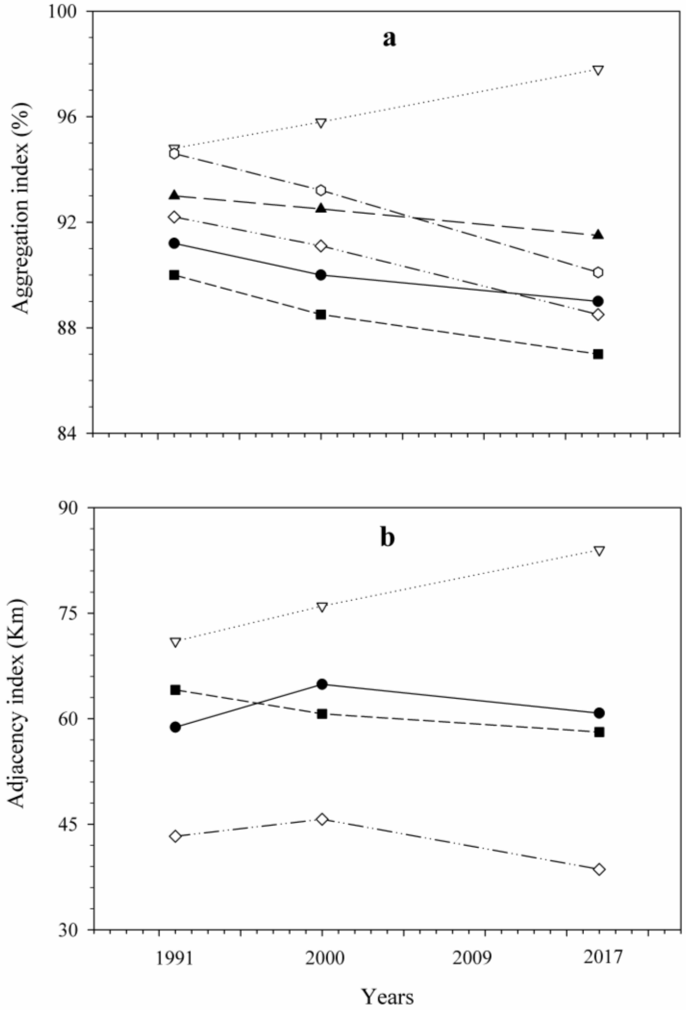
Spatial pattern of the Inter-Andean Dry Forest

The number of patches of Inter-Andean Dry Forest increased by 194 % in the first period (1991–2000) but decreased by 64 % in 2017 (Table 2). From 1991 to 2017, the largest forest patch decreased by 1.9 %. The total edge length decreased by 139.86 km and 120.84 km in the first and second study periods, respectively (Table 2). From 1991 to 2017, the distance to the nearest neighbor increased by 129.71 m. In the second period (2000–2017), the largest increase was registered in this metric, which was 122.95 m (Table 2).

Table 2: Changes in landscape pattern metrics for the Inter-Andean Dry Forest in the RCW between 1991 and 2017

Landscape metrics	1991	2000	2017
Largest patch index (%)	3.05	2.04	1.15
Total Edge (km)	1,914.75	1,774.89	1,654.05
Number of patches	450	872	559
Average distance to the nearest neighbor (m)	143.79	150.55	273.50

Fig. 4: Temporal changes in (a) aggregation index and (b) adjacency index applied to the major land-cover types in the RCW.
LULC types: ⬡ = Inter-Andean Dry Forest, ▽ = Agriculture, ▲ = Tropical Montane Forest, ◇ = Thor Forest, ■ = Bare land, ● = Shrub vegetation



Spatial relations between land-uses/land-covers

In 1991, all the LULC registered an aggregation greater than 90 % (Fig. 4a). From 1991 to 2000, agriculture was the only cover that registered an increase in aggregation in the landscape (96 %), while the other LULC showed disaggregation. From 2000 to 2017, agriculture reported the highest aggregation in the landscape (98 %), while the aggregation of the Inter-Andean Dry Forest decreased to 90 %. The largest decrease in the aggregation index of the Inter-Andean Dry Forest occurred during the second period (3.11 %) (Fig. 4a). Inter-Andean Dry Forest patches were gradually becoming increasingly adjacent to agriculture and shrub vegetation between 1991 and 2000 (Fig. 4b). In 1991, most of the Inter-Andean Dry Forest patches were mainly adjacent to agriculture and bare land, while in 2000, they were adjacent to agriculture and shrub vegetation. From 2000 to 2017, the Inter-Andean Dry Forest patches were mainly adjacent to agriculture due to the expansion of this land-use (Fig. 4b).

DISCUSSION

Accuracy of classification

Remote sensing images are attractive for the production of land-cover maps. However, the classification of these images into land-cover types is never completely accurate due to the uncertainty in the form of mixed pixels in the images (Bastin *et al*., 2013; Brus *et al*., 2017). Nevertheless, by appropriately accounting for these uncertainties in each stage of supervised classification, the accuracy can be improved (Tarko *et al*., 2021). The results reported in this study have demonstrated the above. The high percentages of accuracy of the images revealed that the supervised classification provided a suitable identification of land-cover types in the RCW.

Land-cover dynamics

The present study has revealed that over the 1991–2017 period in the RCW landscape, the Inter-Andean Dry Forest was the land-cover that experienced the greatest loss (45 %), which was mainly generated by the extensification of agricultural land-use. The annual rate of change registered in the present study (2.3 % per year) is higher than the rate reported for other Dry Forest that are part of hotspot landscapes, such as the Dry Deciduous Forest in the Indo-Burma hotspot, east Bangladesh (0.62 % per year; Reddy *et al*., 2016) and the Dry Forest in the tropical Andes hotspot, south Ecuador (1.2 % per year; Tapia-Armijos *et al*., 2015). Similar to these hotspot landscapes, the deforested areas in the RCW are mostly used for agricultural land-use. The loss trend reported in this study is very concerning because the RCW represents one of the last areas with Dry forests in South America.

The Inter-Andean Dry Forest change hotspots are located on the lower slopes, where there is greater accessibility to land-use. It is possible that the Ecuadorian Agrarian Reform of 1964 generated the conversion of the Inter-Andean Dry Forest to agriculture in the RCW. Moreover, since the 2000s, this conversion may have increased due to the expansion of the road system in the country, the population increase, and the low cost of the extraction of wood (Peters *et al*., 2013; Arévalo-Morocho *et al*., 2023). The findings of this study show that the Inter-Andean dry Forest represents one of the least extensive land-cover in the RCW landscape. Maintaining the remaining patches of the Inter-Andean Dry Forest can contribute to the conservation of this ecosystem, which is decreasing globally (García-Navas *et al*., 2022). Despite the world importance of the Inter-Andean Dry Forest, this ecosystem is not protected in the RCW landscape, which could also explain why, between 1991 and 2017, almost half of the forest area was lost.

Change on the spatial pattern of the Inter-Andean Dry Forest

The dynamics of LULC found in this study are associated with important changes in the spatial patterns of the Inter-Andean Dry Forest. Specifically, this ecosystem registered fragmentation in the first study period, which was the main effect of the conversion of forest land to agriculture, while deforestation was the main effect in the second period. The fragmentation reported is similar to that registered for other Dry Forest in Ecuador (Tapia-Armijos *et al*., 2015; Rivas *et al*., 2022), Dry Chaco Forest (De la Sancha *et al*., 2021), as well as in the Tropical Dry Forest in Colombia (Arcila *et al*., 2012). In the RCW landscape, the Inter-Andean Dry Forest fragmentation was associated with a decrease in the total edge length metric. In this sense, patch shape has an impact on the presence of species; in less geometrically complex patches, fewer species are reported (Fontúrbel & Jiménez, 2014; Nguyen *et al*., 2023). In the RCW landscape, the Inter-Andean Dry Forest is restricted to small patches that are less geometrically complex, which can affect the mobility of the organisms (Bitters *et al*., 2022).

The reduction of the large patch index and the increase in the average distance to the nearest neighbor over the entire study period are highlighted. These findings indicate that the area of the greatest patch of Inter-Andean Dry Forest in the landscape was reduced and that the proximity among patches became more distant from each other. This indicates fragmentation and deforestation and, consequently, disruption of landscape connectivity (Thompson *et al*., 2017). Discontinuous spatial patterns in the Inter-Andean Dry Forest can decrease their functional connectivity and an alteration of the dispersal capacity of organisms (Bennett, 2003). For example, in the Rio Mira watershed of northern Ecuador, the functional connectivity loss of native forests has had substantial consequences for the distribution and persistence of populations of *Dipsas elegans*, a species that is at risk of extinction (Arévalo-Morocho *et al*., 2023). If the current trajectory of isolation of the Inter-Andean Dry Forest patches in the RCW continues, the dispersal capacity of organisms at risk of extinction, such as *P. brevifolia, C. elegans, C. gracilis*, and *E. jamesonii* (Oleas & Pitman, 2003; Neill & Pitman, 2004; Santiana *et al*., 2004a, 2004b) can be altered.

The spatial configuration of non-forest LULC types indicates changes in the spatial patterns of the Inter-Andean Dry Forest since the 1990s. From 1991 to 2000, agriculture was the land-use most aggregated. In this period, patches of agricultural, bare land, and shrub vegetation surrounded the Inter-Andean Dry Forest. By 2017, agriculture was the main land-use that surrounded the Inter-Andean Dry Forest. The extensification of agriculture generated this land-use became more aggregated and compact over time. In contrast, the Inter-Andean Dry Forest gradually disappeared. A similar situation was reported in the Ecuadorian seasonal dry forest between 1990 and 2018, where anthropogenic land-use caused the loss and isolation of native forests (Rivas *et al*., 2022). Since the 1990s, the RCW landscape has been affected by the loss and isolation of the Inter-Andean Dry Forest due to its conversion to agricultural land-use.

State of the RCW landscape

In 2017, the RCW landscape reported severe effects of the extensification of agricultural land-use on the Inter-Andean Dry Forest. Specifically, this ecosystem became highly fragmented and deforested, immersed in a matrix dominated by agricultural land-use. In this context, and according to McIntyre & Hobbs (1999) and Echeverría *et al*. (2012), the RCW is a landscape in an advanced state of transformation. In this landscape state, forest deforestation predominates over fragmentation, and this occurs through the extensification of agricultural land-use (McIntyre & Hobbs, 1999; Echeverría *et al*., 2012). The transformation state of the RCW landscape is more advanced than that reported in the Dry Forest of Chaco, Argentina, between 1972 and 2007 (Gasparri & Grau, 2009) and in the Loja and Zamora Chinchipe provinces in southern Ecuador, between 1976 and 2008 (Tapia-Armijos *et al*., 2015), where also deforestation and fragmentation of Dry Forests occurred. The advanced state of landscape transformation in the RCW evidences a landscape with extensification agricultural development and no limits to the expansion of this land-use. The city of Ibarra, the capital of the province of Imbabura, located in the south of the landscape, generates important pressure on this landscape. This pressure may have generated the largest Inter-Andean Dry Forest deforestation in this part of the study area. The results of this study evidence that the RCW landscape must be considered a premium conservation landscape. Therefore, it is urgent to carry out forest management, conservation, and restoration actions at local (change hotspots reported) and landscape scales.

Implications for forest landscape ordination and management

The trend of change in LULC reported in the RCW landscape between 1991 and 2017 highlights the urgent need to implement Inter-Andean Dry Forest management, conservation, and restoration strategies at multiple spatial scales. Multi-scale actions are required because there are multiple ecological scales for different ecological processes and species. Therefore, there is no single "right" or "sufficient" scale for the management, conservation, and restoration of forests. A strategy designed for a single spatial scale will only meet a limited scope (Lindenmayer & Franklin, 2002). In this sense, strategies at multiple spatial scales can be carried out based on baseline information such as that provided in this study. That is, based on the current configuration of the landscape and the hotspots of change identified.

I also suggest that these strategies should have the following goals: 1) To increase landscape heterogeneity. This is a key aspect because the arrangement, size, and diversity of the forest patches are important for many organisms. 2) To increase forest connectivity. This will influence ecological processes such as population dynamics and forest recovery after disturbances (Lindenmayer & Franklin, 2002). 3) To increase patches' structural complexity. Higher structural complexity in the forests generates the largest resistance and resilience to new disturbances in the patch and landscape levels (Mina *et al*., 2021).

In this context, I suggest the following strategies: 1) Prioritizing conservation and maintenance of large and structurally complex forest patches. The presence of large patches with great internal heterogeneity contributes to a greater diversity of native species and increased resilience to disturbances. 2) Conserve and maintain small forest patches. Although the conservation of large patches is a priority, small patches and even isolated trees within the matrix significantly influence landscape connectivity for species. Small patches provide resources, habitats, and resting places for the organisms. Thus, strategically located, these structures can serve as "stepping stones" between larger fragments for species and ecological processes (Fischer & Lindenmayer, 2002). 3) Increase the quality of forest patches and maintain the structural complexity of their surrounding area. The quality of the patches can affect the long-term survival of the species. Thus, the presence of critical resources, such as the availability of refuges in the form of cavities in the trees for certain bird species, is a factor that must be considered when applying conservation strategies. In addition, the structure and configuration of the area surrounding the patches can strongly modulate the internal dynamics of the patches. The more similar matrix structure is to that of the patch, the greater the effectiveness in reducing edge effects, the maintenance of native species within the patches, and the lower the risk of extinction (Williams *et al*., 2006). 4) Connectivity. Some authors have stated that there might be a window of opportunity for restoring dry ecosystems in climatic oscillations such as El Niño Southern Oscillation (ENSO) years due to higher water availability and elevated seed production (Holmgren & Scheffer, 2001; Detto *et al*., 2018). This opportunity for restoration could be interesting to establish corridors between remaining Inter-Andean Dry Forest patches, which would increase the availability of habitat for species such as *D. elegans, S. chota, P. brevifolia, C. elegans, C. gracilis*, among others. 5) Complement the action of the corridors with the improvement of the properties of the matrix. The greater the structural similarity between the corridor and the matrix, the greater the effectiveness of ecological corridors (Herrera, 2011). Therefore, implement sustainable production practices such as agroforestry in adjacent areas of the corridors could improve this function. 6) Community Forest Management (CFM). The Inter-Andean Dry Forest areas provide wood and food products to the local communities, which have generated overexploitation of the ecosystem and its degradation. Therefore, carrying out CFM is a necessity, not an option. This management type is one of the most promising options to resolve the great dilemma of reconciling nature preservation and economic development. In this context, the CFM pursues the planned use of the forest by local populations. Therefore, CFM has two fundamental objectives: a) To ensure or improve the well-being of the local community, and b) To contribute to the conservation of forest to ensure the services they provide to society in general (Sabogal *et al*., 2008; Gómez *et al*., 2018). These objectives involve the following activities: i) Develop comprehensive management plans with a rotational harvesting approach that ensures non-forest degradation. ii) Develop forest management programs based on harvesting techniques with reduced environmental impact. iii) Install and strengthen capacities in silviculture, forest management, community forestry, and processing technologies for native timber and non-timber species that promote sustainable production. iv) Provide incentives (financial and non-financial) for enrichment with valuable native species and encourage sustainable use free of deforestation, and v) Train community forestry promoters and promote exchanges of experiences, community-community on innovative initiatives dedicated to forest resources management (Sabogal *et al*., 2008; Gómez *et al*., 2018). This strategy requires the commitment and participation of the Ecuadorian government and of the community. 7) Land-use planning. This strategy should complement the previous ones. In land-use planning, the inter-Andean dry forest should be the main component of this planning.

CONCLUSIONS

The present study provides the first empirical evidence of the effects of the extensification of agricultural land-use on the spatial patterns of the Inter-Andean Dry Forest in the RCW landscape. The main effects were fragmentation in the first study period (1991–2000) and deforestation in the second study period (2000–2017). The conversion of forest land to agricultural land-use was the mainland-cover dynamic over the entire study period. In 2017, the Inter-Andean Dry Forest hotspots were located in the center and south parts. This finding indicates that these areas must be considered in the management, conservation, and restoration strategies.

This study constitutes the first analysis conducted on the state of the RCW landscape after the extensification of agricultural land-use. The findings of this study indicate that the RCW landscape must be considered a premium conservation landscape due to its advanced state of transformation by anthropogenic land-use. Therefore, Inter-Andean Dry Forest management, conservation, and restoration strategies at multiple spatial scales are required, which can be carried out based on the baseline information provided in this study. These strategies must be guided by the following goals: i) To increase landscape heterogeneity, ii) To increase forest connectivity, and iii) To increase patches' structural complexity.

The present study provides key information on the current status of the Inter-Andean Dry Forest in a high global conservation priority landscape. This information can contribute to implementing environmental policies, which, based on the 17 sustainability criteria of the UN, aim to restore, conserve, and manage this ecosystem of great world relevance.

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CONFLICTS OF INTEREST

The author declare no conflict of interest.

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