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Article

Land use dynamics in a Priority Hydrological Region of the *Bravo* river basin, *Nuevo León* State

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Abstract:

The *San Juan* River watershed (SJRW) is considered one of the most important area in northeast Mexico because its economic and urban development relevance; however, recent pressure by the land use change has led to environmental problems. This study analyzes the spatial and temporal land use changes over time at the SJRW 1976 to 2011 in order to understand the dynamics and patterns of land use. The cartographic information from two government agencies [National Institute for Geography a Statistics (Inegi), and the National Forest and Soil Inventory (INFyS)] was used. A spatial analysis of cartography was carried out by using the Geographic Information System Idrisi Selva, transition matrixes and change rates were calculated for the time periods 1976-1993, 1993-2000 and 2000-2011. In 1976 the most representative land uses were scrubland (76 %), agriculture (19 %) and grassland (2 %); however, in 2011 the most affected land use was the scrubland area that decreased 30 % and showed the highest negative change rate in all time periods. Agriculture and grassland increased by almost 15 % and 7 %, respectively, which is explained by the agricultural development and urbanization, promoted the removal of vegetation in scrublands.

Key words*:* Multitemporal analysis, land use change, change rate, hydrologic region, image segmentation, GIS.

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Introduction

The change of land use and the fragmentation of habitats are two factors related to climate change and the loss of biodiversity as they affect carbon density and the continuity of the of ecosystems (Santos and Tellería, 2006) In this context, social demands influence the quantity and quality of environmental services (GLP, 2005).

At the global scope, the change in land use has been more dynamic recently, and in Mexico, in particular, in the last 50 years; the bushes and tropical forests have deteriorated and reduced their area up to 50 % of their original territory (Lambin, 1994; Masera *et al.,* 1997; Rosete *et al.,* 2008; Challenger and Dirzo, 2009) with degradation rates around 4 % per year (Semarnat, 2013). The effects of land use change are especially evident in the hydrological basins, through abrupt avenues with greater sediment production, which arouse concern to keep the basins working and preserve the environmental services, including the protection of biodiversity (Casillas, 2007).

The *San Juan* River sub-basin, which is part of the *Río Bravo* basin, is the most important water resource that sustains the socioeconomic and urban development of northeastern Mexico, due to its contribution to the national GDP (Monroy, 2013) and, therefore, the sustainable management of its natural resources is a priority. However, the increase in the authorization of changes in land use has caused environmental problems that favor deforestation and erosion, by industrial, urban and agricultural-livestock activities (Návar and Rodríguez, 2002).

As a result of the productive intensity of the *Río Bravo-San Juan* watershed, it is expected that there will be changes in land use, as well as high substitution rates due to anthropogenic coverage and, consequently, changes in its landscape. The objective of this study was to analyze space and time changes in land use and coverage in the Priority Hydrological Region (RHP) number 53 proposed by Conabio, during the years of 1976, 1993, 2000 and 2011, in order to identify the dynamics of change that serve as a basis for the design of strategies and territorial policies in terms of conservation and sustainable management.

Materials and Methods

Study area

The Priority Hydrological Region (RHP) number 53 is 13 724.34 km^2 that are displayed over *Nuevo León* and *Tamaulipas* states (Arriaga *et al.*, 2002), and includes a great part of the *Bravo-San Juan* River Basin (Návar and Rodríguez, 2002) (Figure 1).

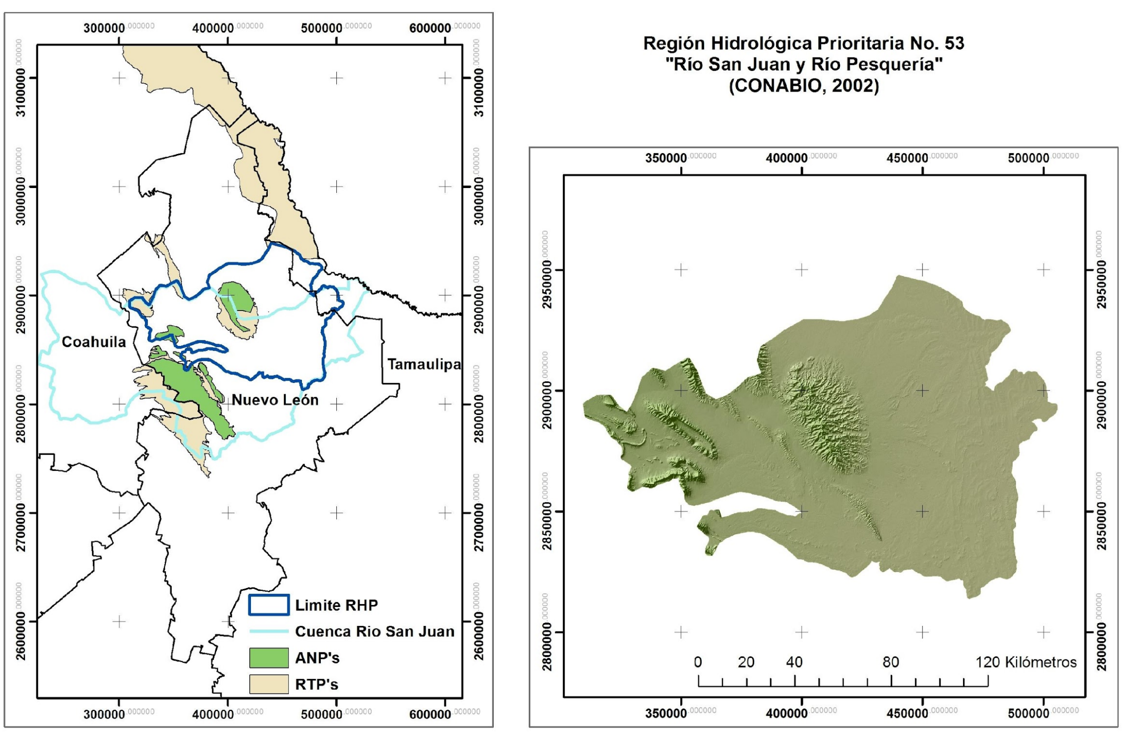


Figure 1. River Priority Hydrological Region (RHP) number 53 *San Juan* River – *Pesquería* River, *Nuevo León*.

The productive activities in the RHP include the cultivation of citrus fruits, livestock, aquaculture and rainfed agriculture; however, there are environmental problems from the lack of control in the discharges of water by industrial, urban and agricultural sources due to the deregulation of water use, the lack of biological inventories; monitoring and current status of biological groups. There, 14 % of land use is under some protection regime, either as Protected Natural Areas (ANP) or as Priority Land Region (RTP) (Figure 1), which constitutes it as an area of importance for the conservation of both biological and water resources.

Generation of land use cartography for 2011

The generation of land cover and land use cartography for 2011 was carried out through the processing of two Landsat TM images (path 27, row 42), with a UTM area 13 N, Datum WGS84 projection, which were selected for the dry season (March and April) of each year (Meneses, 2009). Each image was corrected atmospheric and radiometrically and was orthorectified, to later make a mosaic with the Idrisi Selva geographic information system (Eastman, 2009). A principal component analysis (PCA) was applied in order to identify the bands that would allow a better classification of the image.

This classification was executed through an image segmentation process using the Idrisi Segmentation Analysis module, which allows recognizing the pixels and grouping them based on their symmetry in the spectrum. The segments were defined according to established parameters of similarity to the scale 1: 250 000 and the categories designated according to Velázquez *et al.* (2002) (Table 1). The training polygons were selected by category according to the centroids of the polygons that did not show any change from 1976 to 2000, to later obtain the spectral signatures and make a supervised classification through a maximum likelihood algorithm.

For the evaluation of the quality of the vegetation cover classification for the year 2011, the Validate module of Idrisi was used by the Kappa statistic based on a confusion matrix with control points obtained from the National Forestry and Soil Inventory 2009-2014 (Conafor, 2018) likewise, control points verified through the Google Earth® platform (Google Earth, 2017) to corroborate with image truth.

Analysis of land use change

The cartography used for the multitemporal analysis was generated by Inegi Series I (1976), Inegi Series II (1993), the National Forestry Inventory INF (2000) (Semarnat, 2001), as well as the one produced for 2011, all at a scale of 1: 250 000 and transformed into a raster format with a spatial resolution of 100 m pixel^{-1} through the Idrisi Selva geographic information system (Eastman, 2009). To achieve a hierarchical and homogeneous classification system, each of the cartographies was reclassified as shown in Table 1.

Table 1. Hierarchical system of land use classification*.

Form	Type of vegetation and land use
Crops (Clt)	Agriculture (water and moisture), rain fed agriculture and forest plantation
Forests (Bsq)	Conifers, conifers + broadleaves, broadleaves, and mountain cloud forest
Shrub (Mtr)	Mesquite and xerophylous shrub
Grassland (Pst)	Grassland
Different vegetation types (Otv)	Hallophylous and gypsophylous vegetation
Other covers (Ocob)	Area without apparent vegetation, human settlements and water body

*Adjusted from Velázquez *et al*., 2002.

For the analysis of land use change, the Idrisi Crosstab module was used (Eastman, 2009), which generates matrixes of change between the different categories for each period (1976-1993, 1993-2000 and 2000-2011). Once the matrices were generated, they were analyzed through the computer program SPSS (SPSS, 2004) by means of the Kruskal-Wallis test to establish if the changes are statistically significant. From these matrices, the analysis of the transitions of each category was made according to the methodology proposed by Pontius *et al*. (2004); the profit and loss matrices were estimated for each category and the probability of change / permanence was calculated in the different periods, in order to distinguish if the transitions of g did so randomly. To do this, systematic gain and loss matrices were calculated using the following equations.

$$Gij = (P + j \ - \ Pjj)\,\frac{(Pi+)}{(P \ - \ Pi+)}$$

Where:

Gij = Expected gain from category *i* to category *j* due to a random profit process

$P + j \ - \ Pjj$ = Total net profit of the *j* category between time 1 and time 2

$Pi +$ = Size of the *i* category in time 1

$P \ - \ Pi +$ = Sum of the size of all the categories except *j* in time 1

$$Pij = (Pi + \ - Pjj)\,\frac{(P + j)}{(P \ - \ P + j)}$$

Where:

Pij = Expected loss from the *i* categories to the *j* category from a process of random losses

$Pi + \ - Pjj$ = Total net loss of the *i* category between time 1 and time 2

$P + j$ = size of the j category in time 2

$P - P + j$ = Sum of the size of all the categories except j in time 2

Also, the change rate was calculated for each category by periods through FAO's (1996) equation:

$$X = \left(\frac{S2}{S1}\right)^{1/n} - 1$$

Where:

X = Change rate (to express in % it must be multiplied by 100)

S_1 = Area in date 1

S_2 = Area in date 2

n = Number of years between the two dates

Results and Discussion

The classification of land use prepared for the year 2011 had an accuracy of 83.1 % (Kappa: 0.82) when compared with the information from the National Forestry and Soil Inventory, which indicates that the information generated in this project for such year is reliable and useful for future work (Palomeque-De la Cruz *et al*., 2017). Likewise, when using the level of training of the land use classification system, it is even better (Mas *et al.,* 2002). The scale of the inputs as well as to which the analysis was developed is used at a regional level and, although it may show biases and inaccuracies inherent to the coverage analysis, it allowed to have a perspective of the dynamics of land use.

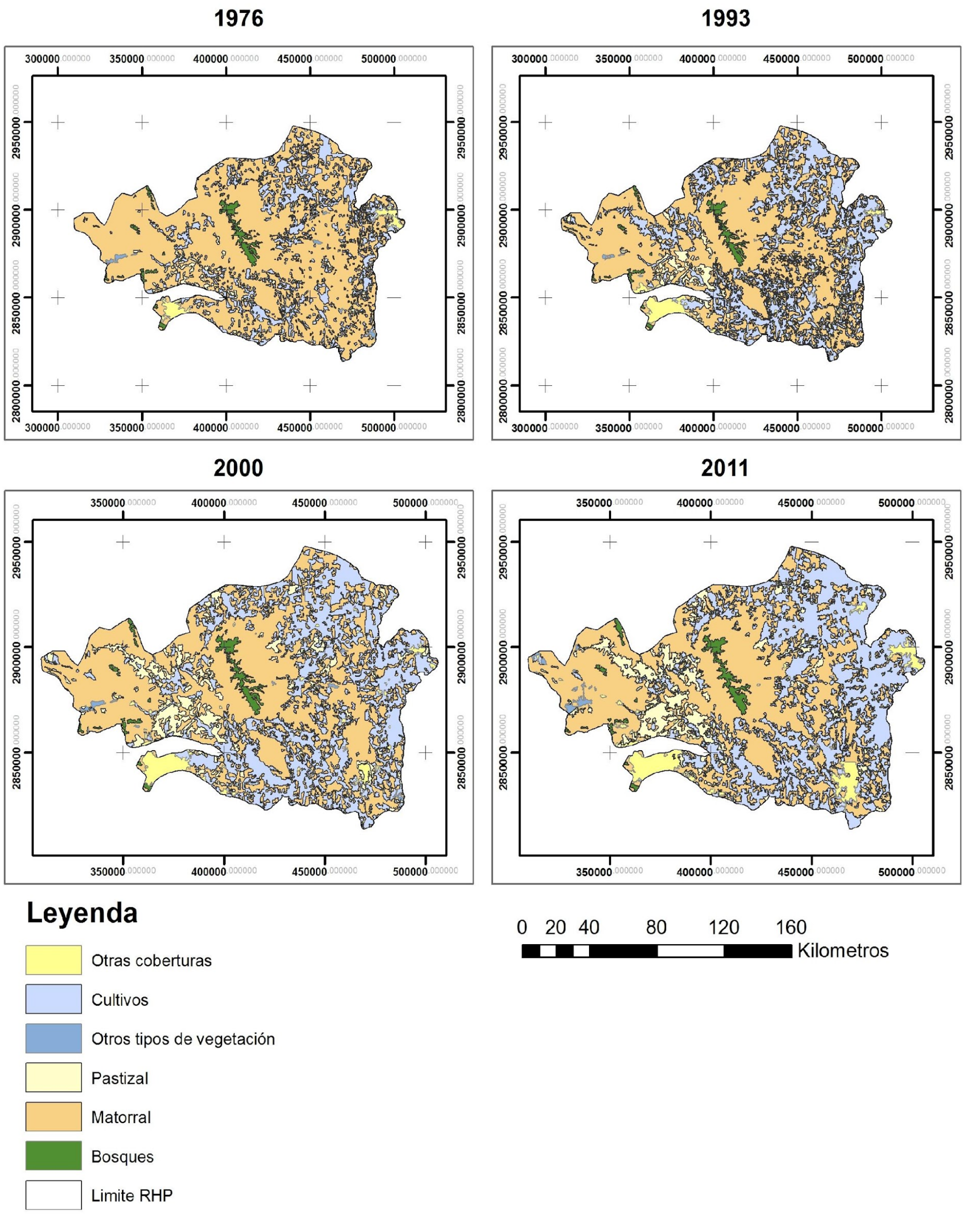
Representativeness of land use

The representativeness of land use for each of the years (1976, 1993, 2000 and 2011) is described in Table 2 and Figure 2. Land use in 1976 is dominated by scrubland and crops, which occupy close to 95 % of the total extension and the rest is represented by forests and grasslands in smaller proportion. However, as of 1993, the scrub registered a significant loss of its area; on the other hand, crops and grasslands experienced an increase of 70 % and 115 % respectively; likewise, other coverages, which include human settlements, increased by 94 %. For the years 2000 and 2011 the same pattern is observed for shrubs and crops, with changes to a lesser extent, highlighting the case of grasslands, which increased their area. The analysis of the changes in coverage using the Kruskal-Wallis test showed that those which showed significant changes throughout the 1976-2011 period were the bushes, crops, grasslands and others.

Table 2. Representativeness of land use and net change within the RHP during the 1976-2011 period.

Category	1976		1993		2000		2011		1976-2011	
	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
Bsq	263.0	2	251.7	2	247.5	2	245.9	2	-17.1	0
Clt	2 800.2	19	4 755.7	33	4 831.9	33	4 915.2	34	+2 115.0 *	15
Mtr	11 052.3	76	8 680.7	59	8 014.5	55	7 494.0	51	-3 558.3 *	-25
Ocob	188.8	1	366.1	3	391.5	3	608.1	4	+419.3 *	3
Otv	50.7	0	16.1	0	52.4	0	64.8	0	14.1	0
Pst	247.0	2	531.7	4	1 064.2	7	1 273.9	9	+1 026.9 *	7
Total	14 601.9	100	14 601.9	100	14 601.9	100	14 601.9	100		

Kruskal-Wallis test - *p< 0.001. Bsq = Forests; Clt = Crops; Mtr = Shrub; Ocob = Other covers; Otv =Different vegetation types; Pst = Grassland



Kilómetros = Kilometers; *Leyenda* = Leyend; *Otras coberturas* = Other covers; *Cultivos* = Crops; *Otros tipos de vegetación* = Different vegetation types; *Pastizal* = Shrub; *Bosques* = Forests; *Límite RHP* = RHP limit.

Figure 2. Land and vegetation use of the Priority Hydrological Region Number 53 *San Juan* river – *Pesquería* river, *Nuevo León*.

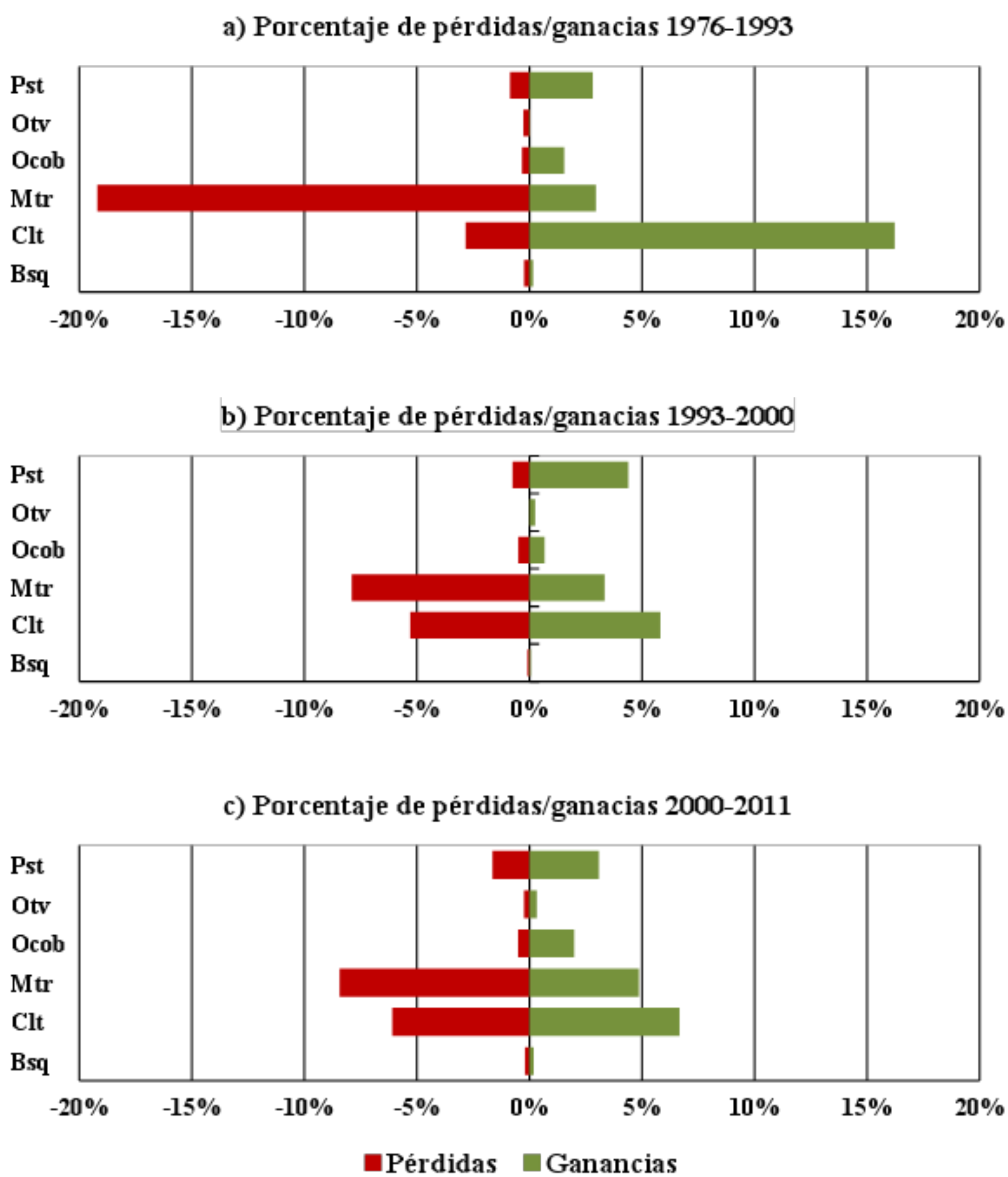
Dynamics of change in land use

Profit and loss analysis

In general, during all the periods analyzed, 1976-1993, 1993-2000 and 2000-2011, the bushes coverage was the most affected (Figure 3), recording losses for each of them, which accentuates the process of environmental degradation, with deforestation rates of 0.33 % per year and that has led to desertification with effects at the national level (Semarnat, 2013); the shrub loss pattern is associated with the increase of grasslands and crops derived from anthropogenic activities (Lambin, 1994; Rosete *et al*., 2008; Challenger and Dirzo, 2009; Pineda *et al*., 2009; Pérez *et al.,* 2012); according to Vela and Lozano (2010), by 2030 increases in grasslands are projected by 10 % and crops by 5 % in the northeast region of the country.

The tendency of expansion of land dedicated to livestock (pasture) and agriculture (crops), turns out to be an important factor of environmental deterioration, since changes were recorded in the range of 5 % and 14 %, respectively, in several studies at regional and national scope during the 1993-2000 period (Vela *et al*., 2007a, Semarnat, 2013), which is reflected in the report published by Sagarpa (2001), in which these lands occupied around 57 % of the national territory.

In spite of the general trend of shrub cover loss, there have been increases in it due to the abandonment of agricultural areas, which allows the recovery of this type of vegetation (López *et al*., 2006; Rosete *et al*., 2008; Valenzuela *et al*., 2012).



Porcentaje de pérdidas/ganancias = Losses/ gains percentage; *Pérdidas* = Losses; *Ganancias* = Gains; Pst = Grassland; Otv =Different vegetation types; Ocob = Other covers; Mtr = Shrub; Clt = Crops; Bsq = Forests.

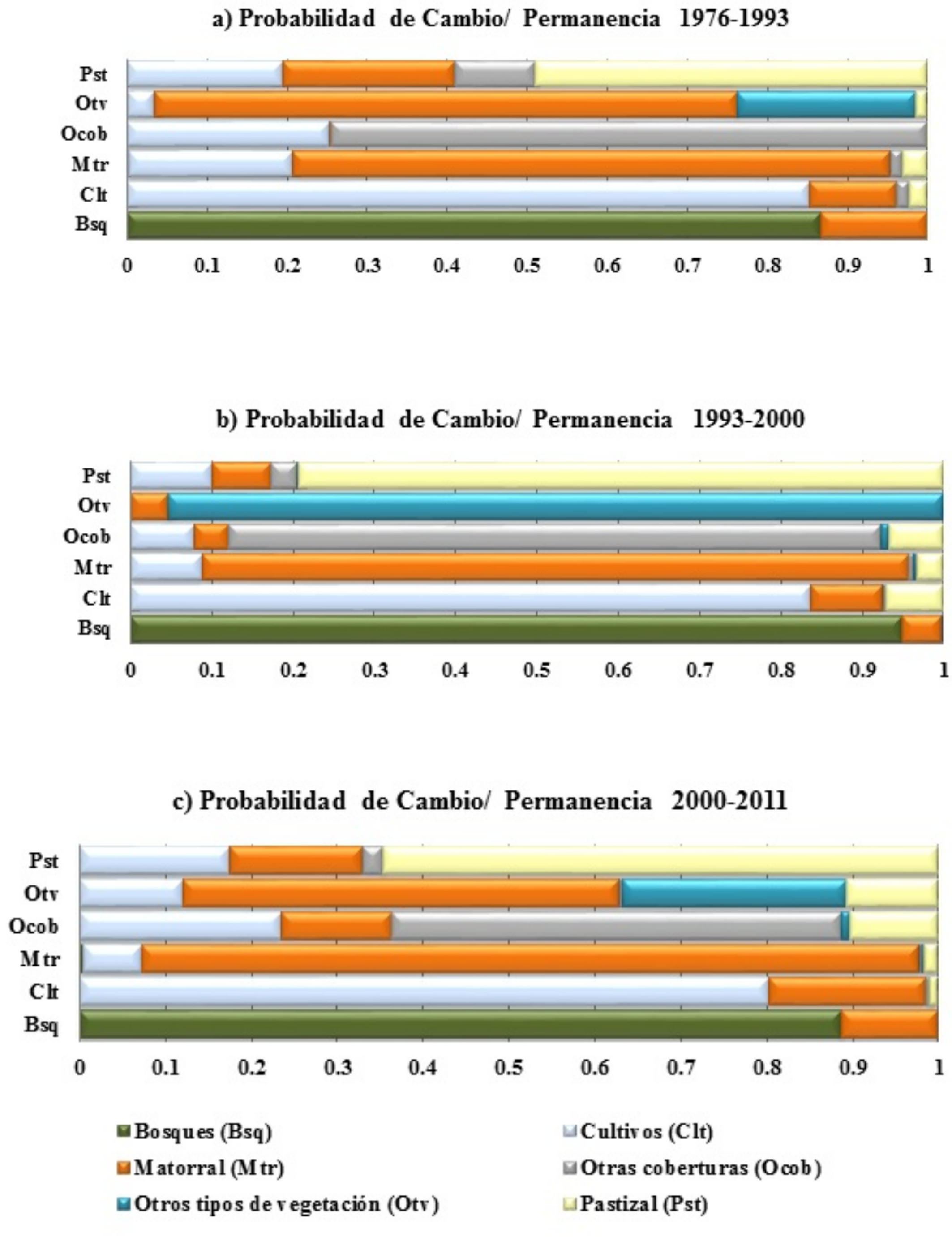
Figure 3. Changes in coverage in terms of gains and losses: a) 1976-1993; b) 1993-2000 and c) 2000-2011, expressed as a percentage relative to the total area of the RHP.

Transitions from land use change

From the analysis of transition between categories, it was observed that, particularly for the period from 1976 to 1993 (Figure 4a), the main transition that resulted from a systematic nature was that of bushes to crops and grasslands; another transition that showed a high probability was that of grasslands to crops (0.19); however, this transition was considered as random. In addition, the change of grasslands to shrubs (0.22) and to crops (0.19) was recorded, which represents a great tendency of modification towards these land uses from grasslands, similar to that made by Masera *et al.* (1997), transitions that were considered the product of a random change due to their representativeness in the area.

From 1993 to 2000 (Figure 4b), the most drastic change in coverage occurred in the transformation of crops and bushes to grasslands, which led to systematic transitions. From 2000 to 2011 (Figure 4c) the trend with respect to the substitution of scrub and grassland for crops is maintained, similar to that for the 1990 -2010 period (Velázquez *et al*., 2002; Mas *et al*., 2004; Pérez *et al.,* 2012; Monroy, 2013).

A decisive factor in the trajectories of the change in the coverage of the RHP is that it is located in an area where a large part of the population of the state is concentrated, which showed significant changes, increasing from 1 694 000 inhabitants in 1970 to 3 550 000 in 1995 and 4 653 458 in 2010 (Inegi, 1970; Inegi, 1995; Inegi, 2010). The increase in population has led to a greater demand for land to satisfy the productive and consumption needs of the population; this, in turn, has favored the degradation of native vegetation coverings (bushes and grasslands), due to the fact that land dedicated to livestock production has supported populations that exceed the allowable range (Vela *et al*., 2007a; Vela *et al*., 2007b; Semarnat, 2013), as well as areas with secondary vegetation (Vela *et al*., 2007c) and the exploitation of timber resources for commercial and local use purposes (Ortega, 2011).



Probabilidad de cambio/permanencia = Probability of Change / Permanence; Pst = Grassland; Otv =Different vegetation types; Ocob = Other covers; Mtr = Shrub; Clt = Crops; Bsq = Forests.

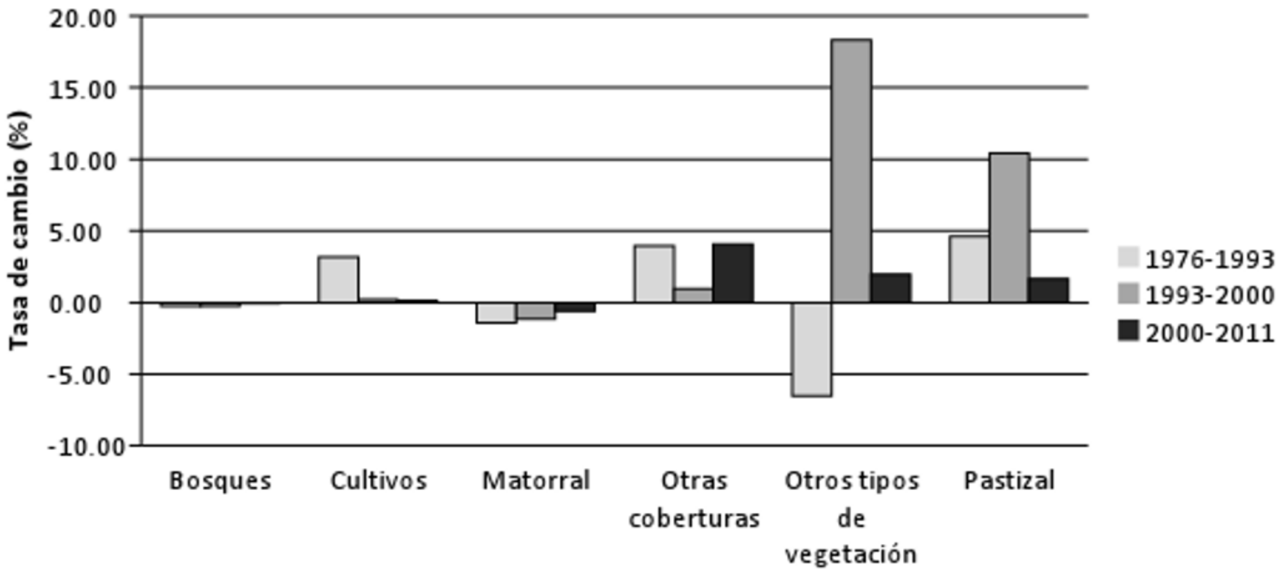
Figure 4. Probability of Change / Permanence of Land Use: a) 1976-1993; b) 1993-2000 and c) 2000-2011.

Land use change rate

Land use change rates between 1976 and 1993 are higher than those recorded between 1993 and 2000 for almost all coverages, except for pastures and other types of vegetation (Figure 5), which reflects a scenario that follows the trend which indicates Semarnat (2013). For the period 2000-2011 highlights the increase in other coverage, including human settlements, as well as bodies of water, which, due to various meteorological events, reached their extraordinary maximum levels in 2003 according to the records of Conagua (Conagua, 2009), which impacted the vegetation that in previous years was within the limits of the basin.

Particularly for the 1976-1993 period crops, grasslands and other coverage with positive rates of change stand out. Between 1993 and 2000, the most significant rates of increase were grasslands, as well as other coverings, which contrasts with the records of Pérez *et al.* (2012), in which grasslands had a negative rate of -1.2 %; however, during this period both shrublands and forests showed negative rates of change above the rate recorded at the regional level (-0.1 %) (Pérez *et al*., 2012) and national (-0.33 and -0.52) (Velázquez *et al*., 2002; Mas *et al*., 2004).

From 2000 to 2011, the positive change rate with the greatest magnitude was that of other coverings, grasslands and other types of vegetation. On the other hand, the use of soil with the highest rate of loss was shrub with 0.6 % per year.



Tasa de cambio = Exchange rate; *Bosques* = Forests; *Cultivos* = Crops; *Matorral* = Shrub*; Otras coberturas* = Other covers; *Otros tipos de vegetación* = Different vegetation types; *Pastizal* = Grassland.

Figure 5. Exchange rate (annual %) of land use during the 1976-1993, 1993-2000 and 2000-2011 periods.

The dynamic of changes in coverage shown by the RHP leads to various consequences in ecosystems, the most important of which correspond to changes in the structure of the water and socioeconomic system at the basin level (Monroy, 2013; Khadka, 2014). This affects the availability of goods and services provided and the loss of biological diversity in different taxonomic groups (Martínez *et al*., 2009; Newbold *et al*., 2014).

Another problem derived from the dynamics of land use is the overexploitation of water resources (Arriaga *et al*., 2002; Esquivel, 2012). The sub-basins of the area have a deficit in the availability of surface water, because it is compromised for the irrigation districts within the basin and downstream (Návar y Rodríguez, 2002; Ortega, 2011); likewise, the replacement of coverings with dense vegetation such as grasslands and bushes, favors changes in the availability of groundwater (Mendoza *et al.,* 2010). On the other hand, there was an increase in the discharges to the tributaries by the various productive sectors (Monroy, 2013).

In terms of climate change, according to a projection for the year 2080, in the state of *Nuevo León*, there will be a deficit of precipitation and an increase in temperature of up to 3 °C (Cabral *et al.,* 2010), implying possible impacts to forests, bushes and crops mainly, which could intensify these tendencies.

Conclusions

The configuration of the use of soil and vegetation in the sub-basin of the *San Juan* River, particularly in the area of the RHP, has undergone significant changes in its structure. In 1976, it was mainly represented by bushes, crops, grasslands; however, in 2011, significant changes were observed such as the increase in extension of more than 3 100 km^2 of land linked to livestock and agriculture. The bushes suffered the greatest loss (3 500 km^2), which leads to consider mitigation actions, as it is one of the communities that holds the greatest biological diversity.

During the period between 1976 and 2011, grasslands recorded the highest exchange rates, in particular from 1976 to 1993 (-4.6) and from 1993 to 2000 (-10.4); likewise, the changes occurred in the crops and other coverings suggest a great process of anthropization of the territory of the study area, together with the generalized elimination of the scrub along the whole country, since this coverage showed rates of loss in all the analyzed periods.

The analysis of coverage change and its transitions made it possible to determine the trends of substitution and identify priority areas for conservation, as well as to establish the bases for the proposal of corrective policies and the formulation of action plans for the better management of natural resources.

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Conflict of interests

The authors declare no conflict of interests.

Contribution by author

Manuel Torres Barajas: writing of the manuscript, design of figures and maps; Susana Favela Lara: supervision of the project, review and correction of the article; Glafiro Alanís Flores: supervision of the project, review and correction of the article; José I. González Rojas: review and correction of the article.