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Research note

Análisis del cambio de uso de suelo en los bosques de galería de Linares, Nuevo León

Analysis of land use change in the gallery forests of *Linares*, *Nuevo León* State

María Cecilia Hernández Cavazos[1], Eduardo Alanís Rodríguez[1], Rufino Sandoval García[2]*, Víctor Manuel Molina Guerra[1,3], Javier Jiménez-Pérez[1], Oscar Alberto Aguirre Calderón[1], Luis Gerardo Cuellar Rodríguez[1]

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[1]Universidad Autónoma de Nuevo León, Facultad de Ciencias Forestales. México.
[2]Universidad Autónoma Agraria Antonio Narro, Departamento Forestal. México.
[3]RENAC, S. A. de C. V. Departamento de Investigación y Gestión. México.

*Autor por correspondencia; correo-e: rufino.sandoval.garcia@gmail.com.
*Corresponding author; e-mail: rufino.sandoval.garcia@gmail.com.

Abstract
Gallery forests are plant communities that grow along rivers and streams. They provide numerous ecosystem services, but like other vegetation associations they are strongly threatened by anthropic activities such as agriculture. The objective of the present study was to know the current state of the gallery forests of *Linares* municipality, state of *Nuevo León*, by means of a multitemporal analysis of land use change and vegetation cover in four periods: 1995-2008, 2008-2014, 2014-2022 and 1995-2022. The analysis used high-resolution space images from the Airbus Defence and Space, GeoEye-1 and Birdseye satellites. The net change and relative percentage change for each type of land use was determined over time, as well as the annual rate of change using the equation proposed by Puyravaud. As a result, a loss of coverage of gallery forests and an increase in agricultural area was found. Over a period of 27 years (1995-2022), the annual rate of change for gallery forests was -0.55 %, whereas for agriculture it was 0.51 %. Considering the values obtained, it is concluded that the area of the gallery forests of *Linares* municipality tends to decrease according to the time to become agricultural land. It is important to stop this trend, as gallery forests play an important role in protecting biodiversity, water and soil resources and must be recovered and preserved.
Key words: Anthropic activities, agriculture, multitemporal analysis, vegetation cover, remote sensing, annual rate of change.

Resumen
Los bosques de galería son comunidades forestales que crecen a lo largo de los ríos y arroyos. Proporcionan numerosos servicios ecosistémicos, pero al igual que otras asociaciones vegetales están severamente amenazadas por actividades antrópicas como la agricultura. El objetivo del presente estudio fue conocer el estado actual de los bosques de galería del municipio Linares, Nuevo León por medio de un análisis multitemporal de cambio de uso de suelo y cobertura vegetal en cuatro periodos: 1995-2008, 2008-2014, 2014-2022 y 1995-2022. Para el análisis se utilizaron imágenes de alta resolución espacial de los satélites *Airbus Defence and Space*, *GeoEye*-1 y *Birdseye*. Se

determinó el cambio neto y el cambio relativo porcentual para cada tipo de uso de suelo a lo largo del tiempo, así como la tasa anual de cambio mediante la ecuación propuesta por Puyravaud. Los resultados indican una pérdida de cobertura de los bosques de galería y un aumento del área agrícola. En un periodo de 27 años (1995-2022), la tasa anual de cambio registrada fue de -0.55 %; por el contrario, para la agricultura fue de 0.51 %. Con base en los valores obtenidos, se concluye que la superficie de los bosques de galería del municipio Linares tiende a disminuir, en función del tiempo para convertirse en tierras agrícolas. Es importante detener esta tendencia, ya que los bosques de galería desempeñan un papel importante en la protección de la biodiversidad, los recursos hídricos y edáficos, por lo que deben ser recuperados y conservados.
Palabras clave: Actividades antrópicas, agricultura, análisis multitemporal, cobertura vegetal, percepción remota, tasa anual de cambio.

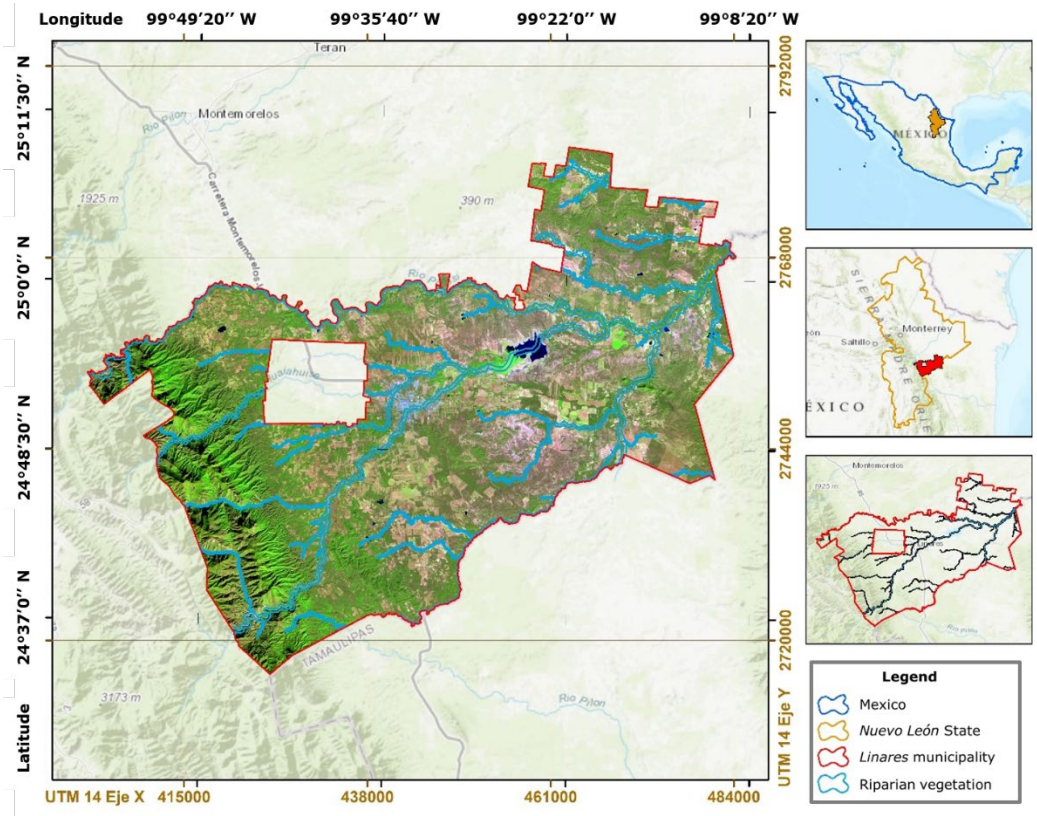
The gallery forest is defined as the transition and interaction region between terrestrial and aquatic environments (Holguín-Estrada *et al.*, 2021). It grows on the margins of bodies of water such as rivers and streams (Canizales-Velázquez *et al.*, 2021), and provides numerous ecosystem services to society, such as shelter and food for many species of animals, functioning as a biological corridor, increasing in this way the connectivity and dispersion of populations of some species (Seaman and Schulze, 2010). Also, it acts as a carbon sink (Díaz-Lezcano *et al.*, 2022) and plays important hydrological functions such as runoff control, thermal balance of water, nutrient cycling, margin stabilization, water purification, as well as erosion control (González-Abella *et al.*, 2021).

This forest depends on the presence of water to survive: when water is abundant, its coverage increases and in periods of drought, it decreases. Excessive water extraction, alteration of flow regimes, canalization of rivers and streams, as well as untreated wastewater discharges put pressure on this type of vegetation and cause the degradation of biodiversity and ecosystem services that they supply to society (Saha, 2023). At the same time, the replacement of the forest for extensive agriculture and livestock, the use of wood for domestic and industrial consumption and unsustainable tourism have caused changes in its distribution and structure (Treviño *et al.*, 2001; Alanís-Rodríguez *et al.*, 2020). As a consequence, most gallery forests are currently heavily disturbed or have been completely destroyed (Habel and Ulrich, 2021).

Therefore, the objective of the present study was to know the current state of the gallery forests of the *Linares* municipality, state of *Nuevo León*, through a multi-temporal analysis of the change in land use and vegetation cover in four different periods: 1995-2008, 2008-2014, 2014-2022 and 1995-2022.

The hypothesis states that the surface of the gallery forests of the *Linares* municipality tends to decrease as time goes on to become agricultural areas.

The study was carried out in *Linares* municipality, state of *Nuevo León* (Figure 1), located 130 km southeast of the Metropolitan Area of city of *Monterrey* (Northeastern Mexico). Its extreme geographical coordinates are north 24°33', south 25°10' north latitude; to the east 99°09', to the west 99°58' west longitude (INEGI, 2010). The study area is part of the RH25 *San Fernando-Soto la Marina* Hydrological Region and the Northern Gulf Coastal Plain province. The dominant climate is semi-warm subhumid with rain in summer, rainfall varies from 500 to 1 100 mm per year and the temperature range is from 16 to 24 °C (INEGI, 2010).



México = Mexico; *Monterrey* = City of *Monterrey*; *Montemorelos* = *Montemorelos* municipality; *Hualahuises* = *Hualahuises* municipality; *Tamaulipas* = *Tamaulipas* State; UTM 14 *Eje X* = UTM 14 Axis X; UTM 14 *Eje Y* = UTM 14 Axis Y.

Figure 1. Location of *Linares* municipality, *Nuevo León*, delimited in red and the riverside vegetation in light blue.

The rivers associated with the gallery forests of the present study correspond to *Pablillo*, *La Lajilla*, *Cabezones*, *Pamona*, *Cabra*, *El Fresno*, *El Tulillo*, *Conchos* and *Encajonado*, as well as the *La Reforma*, *Bagre* and *Anegado* streams.

Gallery forests are characterized by trees with heights from 4 to more than 30 m, with evergreen, sub-deciduous or deciduous species. The most representative species in the north of the country is the *Taxodium mucronatum* Ten. (*sabino* or *ahuehuete*), associated with other species such as *Fraxinus* spp. (ash), *Salix* spp. (willow), *Populus* spp. (poplar) and *Platanus* spp. (sycamore) (INEGI, 2014).

In order to evaluate the dynamics of the loss of vegetation cover in gallery forests, orthophotos were obtained from the platform of the National Institute of Statistics and Geography (*Inegi*) with a resolution of 2 m/pixel (1995), from Birdseye (0.28 m/pixel; 2008), Airbus Defence and Space (1.14 m/pixel; 2014) and GeoEye-1 (0.28 m/pixel; 2022). Images from different satellites were generated and processed since they are available for free and are from progressive years.

For the assignment of the strip size of the riparian vegetation, the following was considered. The size of the protective strip of riparian vegetation recommended to exert a buffer effect will depend on the type and sensitivity of the aquatic habitat, the intended function of the strip (nutrient reduction, sediment removal, flood control, fish habitat and wildlife), the physiography of the place (type of soil, slope) and land use (Granados-Sánchez *et al.*, 2006). The functions of riparian strips are invaluable, therefore, it is advisable to maintain an interval between 100 to 300 m wide (Burton *et al.*, 2016). The size of the strip must be assigned based on the slope, the degree of vulnerability to soil erosion, the objectives pursued and the current regulations regarding protection (Olson and Ares, 2022).

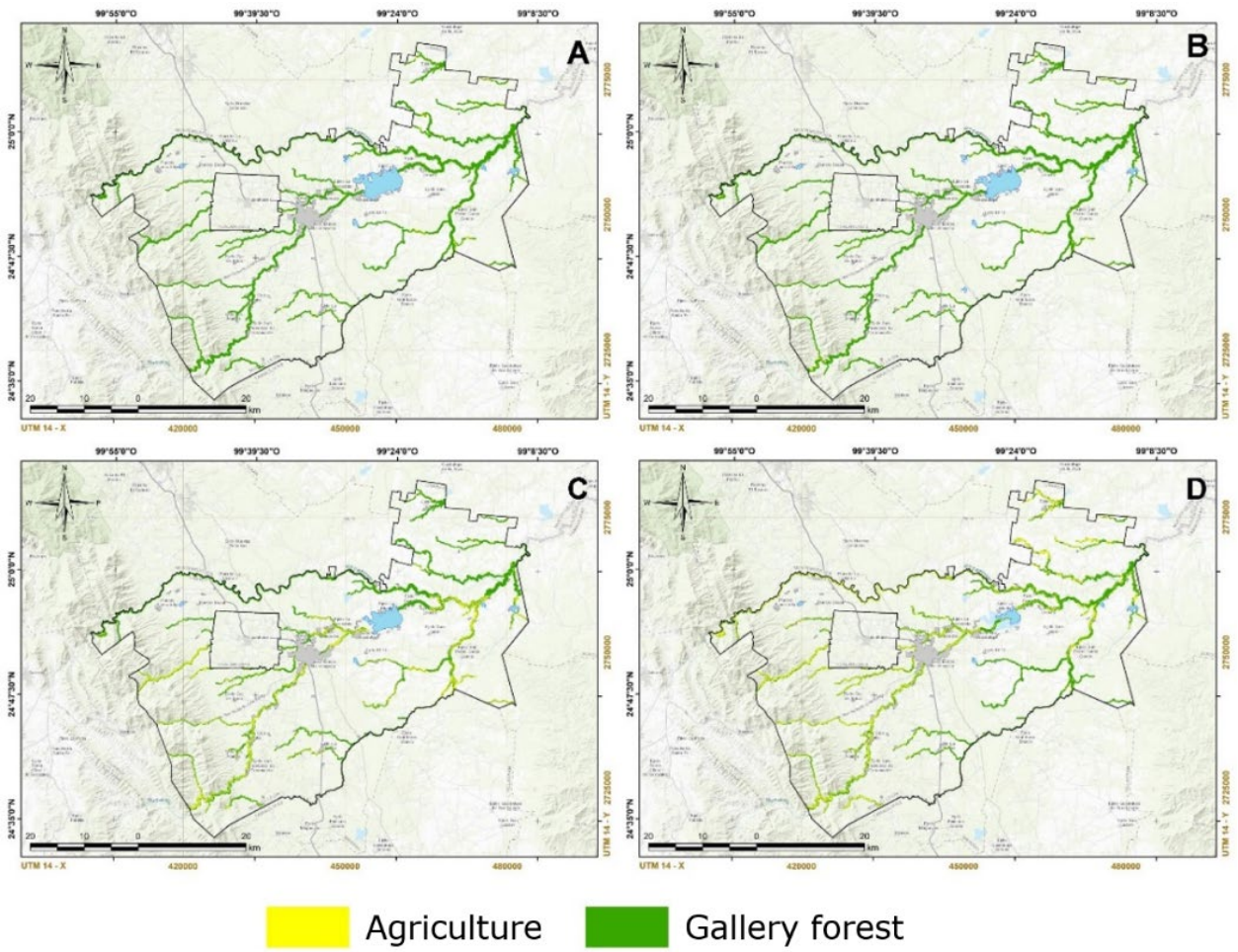
The size of the riparian strip used for this study was established according to the current classification; a 100 m strip was assigned to those of order 4, 150 m to those of order 5, 200 m to those of order 6, 250 m to those of order 7 and 300 m to those of order 8.

For the classification of the images, the supervised classification method was used with a validation of 40 field sampling sites, which were distributed randomly.

To calculate land use changes (increase or loss of forest area), a cross tabulation was generated between four different periods: 1995-2008, 2008-2014, 2014-2022 and 1995-2022. The net change and relative percentage change were determined for each land use type over time. The net change was obtained from the difference in forest area between two points in time. When the result of the net change is positive it means that there has been an overall gain in forest area and when it is negative it

means an overall loss of forest area (FAO, 2020). To calculate the relative percentage change (ΔA %), the equation proposed by Meshesha *et al.* (2016) was used, and the annual rate of change with the equation proposed by Puyravaud (2003).

Land cover maps were prepared to determine the changes that occurred between 1995 and 2022 in the gallery forests of *Linares* municipality, *Nuevo León* (Figure 2). Agricultural soils were included in the multi-temporal analysis to compare changes in this sense in the same period.



A = 1995; B = 2008; C = 2014; D = 2022.

Figure 2. Maps of land use and vegetation cover of the gallery forest.

In 1995, gallery forests covered an area of 9 203.26 ha, while agriculture was 9 818.47 ha (Table 1). In 27 years (1995-2022), gallery forests presented a loss of cover of 1 280.31 ha (-13.91 %), contrary to agriculture, which had an increase of 1 453.06 ha (14.80 %) in this same period (Table 2).

Table 1. Total coverage of gallery forest and agriculture in the years 1995, 2008, 2014 and 2022.

Soil type	Coverage (ha)			
	Year 1995	Year 2008	Year 2014	Year 2022
Gallery forest	9 203.26	9 141.60	8 156.30	7 922.95
Agriculture	9 818.47	9 910.06	10 958.18	11 271.53
Total	19 021.73	19 051.66	19 114.48	19 194.48

Table 2. Net change and relative change that occurred during the 1995-2008, 2008-2014, 2014-2022 and 1995-2022 periods.

Soil type	Net change(ha)				Relative change%			
	1995-2008	2008-2014	2014-2022	1995-2022	1995-2008	2008-2014	2014-2022	1995-2022
Gallery forest	-61.66	-985.30	-233.35	-1 280.31	-0.67	-10.78	-2.86	-13.91
Agriculture	91.59	1 048.12	313.35	1 453.06	0.93	10.58	2.86	14.80

From 1995 to 2022, gallery forests recorded an annual rate of change of -0.55 %, the period from 2008-2014 showed the highest annual rate of change with -1.90 %, followed by the interval 2014-2022 with -0.36 %. Agriculture had a similar behavior in the different study periods, however, unlike gallery forests, the annual rate of change was positive (increased). During the entire time considered in the study (1995-2022), agriculture registered an annual rate of change of 0.51 %, from 2008-2014 the highest annual rate of change was verified with 1.68 %, followed by the period from 2014-2022 with 0.51 % (Figure 3).

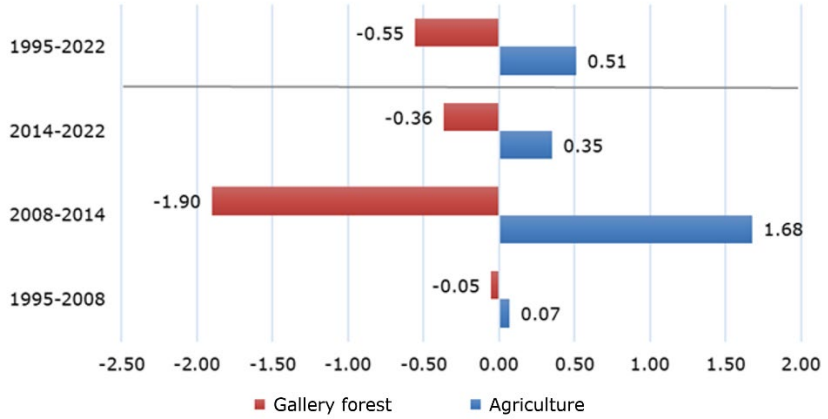


Figure 3. Annual rate of change in land use and vegetation cover of gallery forest and agriculture.

Globally, agriculture, as well as livestock farming, forest fires and clandestine logging, are considered the main causes of forest cover loss (ONUAA and PNUMA, 2020).

In Mexico, agriculture is the second cause of loss of natural vegetation (Conafor, 2020). In the Citrus Region of *Nuevo León* of which *Linares* municipality is part, 13 % of the primary vegetation was converted into agricultural areas or cultivated grasslands in 32 years (1976 to 2008) (Pando *et al.*, 2014).

According to the results of this study, in 27 years (1995-2022), 13.91 % of the gallery forest surface of the municipality of interest was transformed for agricultural use, with change rates of -0.55 and 0.51 % respectively. When comparing these data with similar studies carried out in Mexico, agreement was recognized with what was reported by Treviño *et al.* (2001) for the *Cabezones* and *Ramos* rivers, located in south-central *Nuevo León*; in 19 years (1975-1994) gallery forests presented change rates of -0.49 and -0.45 %, on the contrary, for areas dedicated to agriculture they were 1.64 and 1.14 % respectively. The above coincides with the contributions of Leija *et al.* (2020), who carried out an analysis of change in vegetation cover and land use in the lower part of the *Nazas* River

Basin in the central-northern region of Mexico and concluded that in 26 years (1990-2016), the gallery forest experienced an annual rate of change of -2.1 %, unlike agriculture which was 2.1 %.

The opening of new areas for agriculture and extensive livestock farming has caused the replacement of natural vegetation with crops over the years. In a study carried out by Sandoval-García and Cantú-Silva (2021) for the *Río Copalita* sub-basin, state of *Oaxaca*, it was observed that in 20 years (1995-2015) most land uses had a decrease in surface area, but not for grassland and agriculture; specifically for the gallery forest, an annual rate of change of -0.17 % was calculated, while for agriculture it was 0.66 %.

In conclusion, this multi-temporal analysis allowed us to know the current state of the gallery forests in *Linares* municipality, from which the loss of surface area as time passes to become agricultural areas is evident. It is important to stop this trend, since gallery forests play an important role in the protection of biodiversity, water and soil resources, which is why they must be recovered and conserved. Therefore, natural resource managers, as well as people involved in the formulation of public policies, must pay special attention to the decline of gallery forests and other plant ecosystems in *Linares* municipality and the state of *Nuevo León*, with the purpose of reducing its loss and conserving its ecosystem services.

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Conflict of interests

The authors declare no conflict of interest. Eduardo Alanís Rodríguez, as Section Editor of the Revista Mexicana de Ciencias Forestales, declares not to have participated in the editorial process of this article.

Contribution by author

María Cecilia Hernández Cavazos, Eduardo Alanís Rodríguez and Rufino Sandoval García: conception of the research, data recording, interpretation of results and writing; Víctor Manuel Molina Guerra, Javier Jiménez-Pérez and Oscar Alberto Aguirre Calderón: review, interpretation of results and writing of the manuscript; Luis Gerardo Cuellar Rodríguez: general review, drafting of Conclusions.

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