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Article

Almacenamiento de carbono en la reserva ecológica de Ternium en Pesquería, Nuevo León

Carbon storage in *Ternium* Ecological Reserve at *Pesquería, Nuevo León* State

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Resumen

La reserva ecológica Ternium es un área de conservación de flora y fauna, que incluye al Matorral Espinoso Tamaulipeco. En este estudio se cuantificó el almacenamiento de carbono en las diferentes áreas de la reserva ecológica. Se realizó un muestreo estratificado al azar con imágenes satelitales para definir las comunidades. En ellas, se muestrearon 10 sitios rectangulares de 10 × 20 m (100 sitios en total) en los que se evaluó el diámetro basal, la altura total y los diámetros de copa de cada individuo con diámetro basal > 3 cm. Para determinar el almacenamiento de carbono se estimó la biomasa mediante ecuaciones alométricas y, una vez calculada la biomasa, se utilizó el factor de 45.4 % para la estimación de carbono propuesto para especies del Matorral Espinoso Tamaulipeco. Se registraron 16 familias, 27 géneros y 28 especies. La comunidad vegetal que presentó mayor biomasa total y contenido de carbono fue la de Mezquite-Huizache con 102.44 y 46.10 Mg ha^{-1}, respectivamente; mientras que en las comunidades vegetales derivadas de plantaciones forestales se registraron las cifras más bajas (1.74 y 3.96 Mg ha^{-1}). En general, el contenido de carbono promedio en el área fue de 12.77 Mg ha^{-1}. Los taxones que contribuyeron a capturar la mayor concentración de carbono por sus dimensiones fueron: *Prosopis glandulosa, Acacia farnesiana* y *Cercidium macrum.*

Palabras clave: *Acacia farnesiana* (L.) Willd., captura de carbono, *Cercidium macrum* I. M. Johnst., Matorral Espinoso Tamaulipeco, *Prosopis glandulosa* Torr., reserva ecológica.

Abstract

The *Ternium* Ecological Reserve is a flora and fauna conservation area, which includes the Tamaulipan Thornscrub. In this study, carbon storage was quantified in the different areas of the ecological reserve. Stratified random sampling was carried out, using satellite images to define the different communities. In each one of them, 10 rectangular sites of 10 × 20 m (a total number of 100 sites) were sampled, in which the basal diameter, the height and the diameters of the crown of each individual with a basal diameter> 3 cm were measured. To determine carbon storage, biomass was estimated by allometric equations and once it was calculated, a 45.4 % factor was used for carbon estimation proposed for the Tamaulipan Thornscrub species. 16 families, 27 genera and 28 species were recorded. The vegetal community that presented the highest total biomass and carbon was the *Mezquite-Huizache* with 102.44 and 46.10 Mg ha^{-1} respectively, while the vegetal sources derived from the plantations, recorded the lowest numbers (1.74 and 3.96 Mg ha^{-1}). In general, the area has an average carbon content of 12.77 Mg ha^{-1}. The species that contributed to a greater carbon concentration due to their size were: *Prosopis glandulosa*, *Acacia farnesiana* and *Cercidium macrum*.

Key words: *Acacia farnesiana* (L.) Willd., carbon capture, *Cercidium macrum* I. M. Johnst., Tamaulipan Thornscrub, *Prosopis glandulosa* Torr., ecological reserve.

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Introduction

Protected natural areas, biosphere reserves, national parks, natural monuments, natural resource protection areas, flora and fauna protection areas and sanctuaries are destined for conservation in the world (Toledo, 2005). When they began, their objective was the preservation of natural scenic beauty (Halffter, 2011), but over time this vision evolved until today these areas are intended to maintain biodiversity, habitat, as well as ecological processes such as water, soil and carbon sequestration (Dudley *et al*., 2008).

Among the environmental services provided by ecosystems, forests play a key role in the cycle and capture of carbon (C), since they manage to store large amounts of carbon in biomass and soil, and exchange with the atmosphere through the photosynthesis and breathing processes (Brown, 1999). Plant communities have some ability to store carbon. and this will depend on the floristic composition, age and density of the population of each stratum (Schulze *et al*., 2000). Carbon stored in terrestrial ecosystems changes due to natural or induced transformations such as erosion and land use change (Figueroa *et al.,* 2005). These processes of carbon release to the atmosphere can be reversed by reforestation and restoration of degraded ecosystems (Rodríguez *et al.,* 2008).

Some areas in Mexico are privately owned and their managers dedicate them to conservation in order to protect part of the country's biological capital (Semarnat, 2013). Despite having these areas, there are few studies that have been conducted on them to determine their carbon sequestration (Roldán *et al*., 2010; Cuellar and Larrea, 2016; Mora *et al*., 2017). The objective of the research was to evaluate the carbon storage that the plant communities and their main species gather in the ecological reserve of the company *Ternium*, *Pesquería, Nuevo León* State, Mexico, to determine which of these rerecords the highest carbon content.

Materials and Methods

Study area

The research was carried out in the Ecological Reserve of the company *Ternium* Mexico (Figure 1), whose area is 96.17 ha in the municipality *Pesquería*, *Nuevo León*; Its geographical coordinates are 25°45´25” N and 99°58´07” W, at 306 meters above sea level. The climate of the place corresponds to dry BS_0hw according to the Köppen classification modified by García (1988). The average annual temperature is 20 to 22 °C, the annual rainfall varies between 500 and 700 mm (INEGI, 1986). The soils present are: Castañosem, Vertisol, Leptosol, Chernozem and Fulisol (INEGI, 1986). The predominant vegetation in the study area is the *Tamaulipas* thorny thicket (MET) with different successional states and degrees of disturbance. There are mature and other MET plant communities in different successional states of 2, 4 and 6 years of age due to applied ecological restoration practices (reforestation) and others in which, after the disturbance, secondary vegetation species prevail.

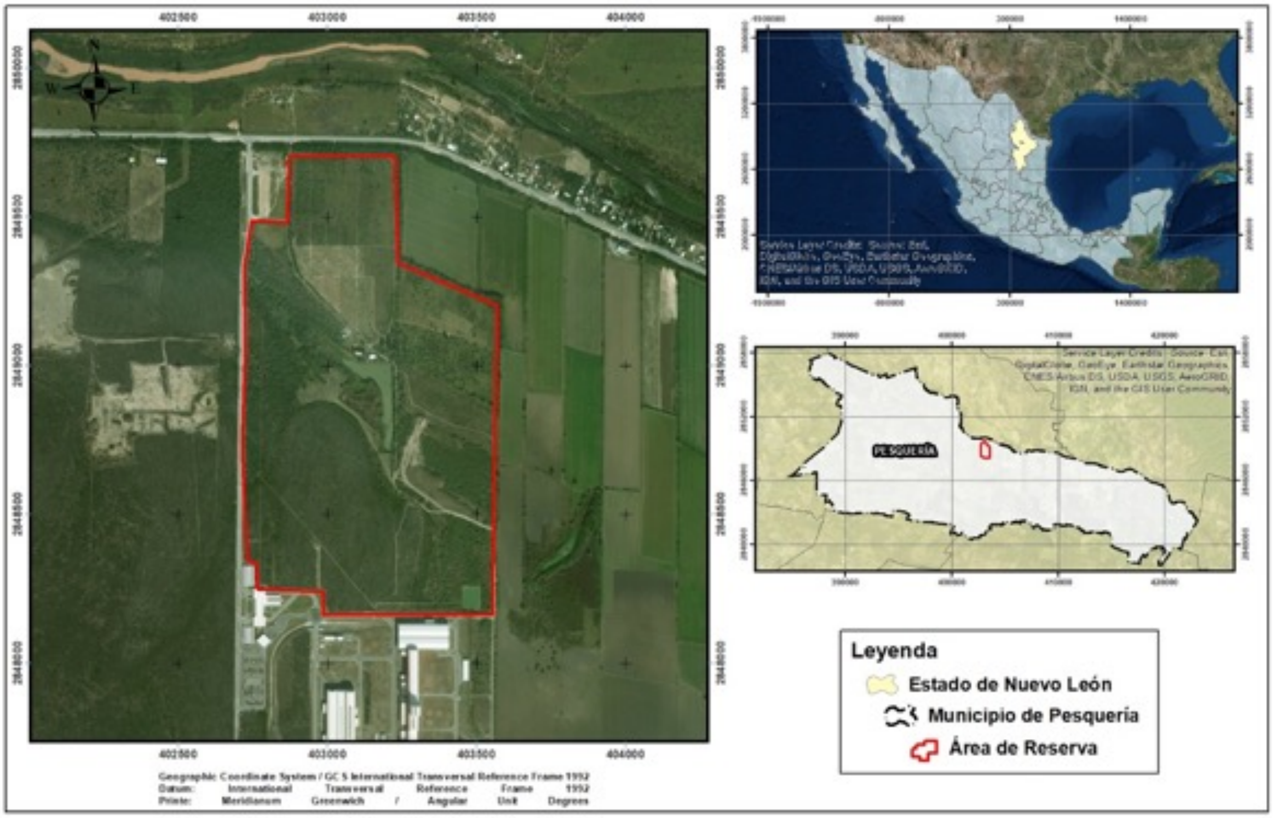

Figure 1. Location map of the study area.

Data collection

Preliminary tours were made in the study area during which differences were recognized in the structure of the plant community. These contrasts may be explained by to the orography and the history of the plant communities (Table 1). By means of satellite images taken from Google Earth Pro, the area was stratified to estimate the carbon of each specific area.

Table 1. Orographic characteristics and history of use of plant communities.

Vegetal community	Orography	History record
Mature scrub	Valley	Without disturb
Mature scrub	Valley	Without disturb
Ash scrub	Hill	Without disturb
Ash scrub	Hill	Without disturb
Mature scrub	Low part of the basin	Without disturb
Mezquite-Huizache	Valley	Regeneration
Ash scrub	Hill	Without disturb
6 year plantation	Valley	Plantation
4 year plantation	Valley	Plantation
2 year plantation	Valley	Plantation

Based on the heterogeneity of the plant community, a random stratified sampling was made, and based on the orography, history of use and species composition, canopy coverage and density of individuals, 10 strata were defined, of which seven are of established vegetation before declaring it a conservation area and the remaining three are areas where ecological restoration activities were carried out.

A pre-sampling was carried out to determine the coefficient of determination and to estimate the number of sites needed to have representative information. The sample size was determined by means of the following mathematical model (Mostacedo and Fredericksen, 2000), based on the volume.

$$n = \frac{t^2 * CV^2}{E^2 + \frac{t^2 * CV^2}{N}}$$

Where:

n = Number of sampling sites

E = Error (20 %)

t = Value taken from the Student t ($P<0.05$) tables

N = Total of sampling units of the whole population

CV = Variation coefficient

The rectangular sampling sites (10 × 20 m) (200 m^2) were established randomly, based on the extreme coordinates of each area and by random numbers; in Excel, the sampling points of each stratum were obtained. According to the result of the mathematical model, 10 sites were established for each plant community (100 sites in total); where all individuals with a basimetric diameter > 3 cm were considered, and the total height (h) was measured with a Hastings™ E-15-1 telescopic rod, the basimetric diameter ($d_{0.10}$) with a Haglöf Mantax Blue calliper™ 1270 mm and cup diameters (k) in NS and EO directions with a 10 m Truper™ flexometer.

Data analysis

To calculate the carbon storage of tree and shrub species, aerial biomass was determined using the allometric equation developed by Návar *et al.* (2004) for arboreal and shrub species of the Tamaulipas thorn scrub (r^2 = 0.80):

$$BT = 0.026884 + 0.001191 * d^2h + 0.044529 * d \ - 0.01516 * h) + (\ 1.025041 + 0.023663 * d^2h - 0.17071h - 0.09615 * \ln(h)) + (\ -0.43154 + 0.011037 * d^2h + 0.113602 * d + 0.307809 * \ln\,(d))$$

Where:

BT = Total aerial biomass (Kg)

d = Basimetric diameter (cm)

h = Total height (m)

From the characteristic stem of *Yucca filifera* Chabaud whose shape is different from the scrubs and trees assessed, the following formula proposed by Návar (2008) was used:

$$BT = exp(0.360 + 1.218 * ln(h) + 0.325)$$

Where:

BT = Total aerial biomass (Kg)

h = Total height (m)

Once the total aerial biomass was determined, the carbon content concentration was calculated by using the 45.4 % factor recommended by Yerena *et al.* (2011).

Results and Discussion

The flora of the study area comprises 16 families, 27 genera and 28 species (Table 2). The families with the highest number of species were: Fabaceae with nine, Asteraceae, Boraginaceae, Cannabaceae and Euphorbiaceae with two species; the rest of the families register only one species The Fabaceae family is one of the most representative in the scrub communities of the state, being the species *Acacia farnesiana* (L.) Willd. and *Acacia rigidula* Benth. of the most important within these plant communities in terms of dominance (Estrada *et al.,* 2004; Jiménez *et al.,* 2009).

Table 2. Floristic list of the study area.

Family	**Species**	**Common name**	**Life form**
Asparagaceae	*Yucca filifera* Chabaud	*Yuca*	Tree
Asteraceae	*Baccharis salicifolia* (Ruíz & Pav.) Pers.	*Jarilla*	Scrub
	Gymnosperma glutinosum (Spreng.) Less.	*Escobilla*	Scrub
Boraginaceae	*Cordia boissieri* A. DC.	*Anacahuita*	Tree
	Ehretia anacua (Terán &Berland.) I.M. Johnst.	*Anacua*	Tree
Cactaceae	*Cylindropuntia leptocaulis* (DC.) F.M. Knuth	*Tasajillo*	Scrub
Cannabaceae	*Celtis pallida* Torr.	*Granjeno*	Scrub
Ebenaceae	*Diospyros texana* Scheele	*Chapote*	Tree
Euphorbiaceae	*Bernardia myricifolia* (Scheele) S. Watson	*Oreja de ratón*	Scrub
	Croton cortesianus Kunth	*Croton*	Scrub
Fabaceae	*Acacia farnesiana* (L.)Willd.	*Huizache*	Tree
	Acacia rigidula Benth.	*Chaparro prieto, gavia*	Scrub
	Caesalpinia mexicana A. Gray	*Hierba del potro*	Tree
	Cercidium macrum I.M. Johnst.	*Palo verde*	Tree
	Ebenopsis ebano (Berland.) Barneby & J.W.	*Ébano*	Tree
	Eysenhardtia texana Scheele	*Vara dulce*	Tree
	Havardia pallens (Benth.) Britton & Rose	*Tenaza*	Tree
	Parkinsonia aculeata L.	*Retama*	Tree
	Prosopis glandulosa Torr.	*Mezquite*	Tree
Oleaceae	*Forestiera angustifolia* Torr.	*Panalero*	Scrub
Passifloraceae	*Turnera diffusa* Willd.	*Damiana*	Scrub
Rhamnaceae	*Karwinskia humboldtiana* (Schult.) Zucc.	*Coyotillo*	Scrub
Rutaceae	*Zanthoxylum fagara* (L.) Sarg.	*Colima*	Scrub
Sapotaceae	*Sideroxylon celastrinum* (Kunth) T.D. Peen.	*Coma*	Scrub
Scrophulariaceae	*Leucophyllum frutescens* (Berland.) I.M. Johnst.	*Cenizo*	Scrub
Simaroubaceae	*Castela erecta* Turpin	*Crucillo*	Scrub
Zygophyllaceae	*Guaiacum angustifolium* Engelm.	*Guayacán*	Scrub

Table 3 shows the 10 strata registered in the conservation area. The plant community dominated by *Mezquite* and *Huizache* has the highest total biomass and carbon stored with 102.44 and 46.10 Mg ha^{-1}, respectively (Table 3), followed by mature scrub communities.

Table 3. Total biomass and carbon content by stratum.

Vegetal community	Surface area (ha)	TB (Mg ha^{-1})	C (Mg ha^{-1})	C (Mg) per vegetal community
Mature scrub 1	19.76	17.24	7.76	153.34
Mature scrub 2	16.86	47.43	21.34	359.79
Ash scrub 1	5.37	14.82	6.67	35.82
Ash scrub 2	8.16	17.16	7.72	63.00
Mature scrub 3	9.71	26.56	11.95	116.03
Mezquite-Huizache	12.78	102.44	46.1	589.16
Ash scrub 3	1.71	22.23	10	17.10
6 year plantation	12	21.38	9.62	116.52
4 year plantation	2.2	8.73	3.93	8.71
2 year plantation	7.62	5.57	2.50	19.13
Sums and averages	Σ = 96.17	$\bar{x}$ = 28.36	$\bar{x}$ = 12.76	Σ = 1 228.09

With the exception of reforested areas and *Mezquite* and *Huizache*, plant communities recorded biomass values between 14.82 Mg ha^{-1} to 47.43 Mg ha^{-1}. These recorded biomass values are similar to those reported by different authors such as Návar *et al*. (2002), Návar *et al*. (2004), Návar (2008), who report values of 12.93, 36.75, 44.40 and 48.40 Mg ha^{-1} respectively for the thorny thicket, respectively, while Yerena *et al*. (2011) recorded a value of 25 Mg ha^{-1}. The plantation areas recorded lower total biomass and stored carbon, since the vegetation in these areas is younger and smaller. Despite this situation, the plantation with six years presents higher values than the communities called Ash scrub 1 and 2, which are dominated by the *Leucophyllum frutescens* (Berland.) I. M. Johnst. Shrub, so reforestation activities are giving positive results in biomass production.

In general, the *Ternium* ecological reserve area stores an average of 28.36 Mg ha^{-1} of biomass, which is equivalent to 12.76 Mg ha^{-1} of carbon. The mature scrub has an average carbon content of 13.68 Mg ha^{-1} which resembles the values reported by Yerena *et al.* (2011) of 11.70 Mg ha^{-1} in a primary scrub, while for areas with different uses, the values were 4.67 and 2.98 Mg ha^{-1}; the former coincides with the local plantation areas, where the plants are still young. In the *Mezquite-Huizache* area, the values obtained are higher than those of Yerena *et al.* (2015) for a 30-year-old *mezquital* area, where 18.83 Mg ha^{-1} were calculated.

Within each plant community or stratum dominant species were identified in the area according to the concentration of total biomass and carbon. Table 4 shows the taxa of each stratum. *Prosopis glandulosa* Torr., *A. farnesiana* and *Cercidium macrum* I. M. Johnst. They have the largest total biomass and stored carbon, with 34.96 % of the total biomass. These species are important for their great abundance and dominance in plant communities; they belong to the Fabaceae family, which has been referred to as the most representative in the scrubs of the state (Rojas, 1965; Rzedowski, 1978; Briones and Villarreal, 2001).

Table 4. Mensuration characteristics, total biomass (Mg ha^{-1}) and Carbon (Mg ha^{-1}) of the vegetal communities of the study area.

Species	**Individuals (ha^{-1})**	**Average height (m)**	**Average diameter (cm)**	**Average crown area (cm^2)**	**TB (Mg ha^{-1})**	**C (Mg ha^{-1})**
			Mature scrub 1			
Acacia farnesiana (L.)Willd.	119	4.9	13.5	4.6	5.47	2.46
Havardia pallens (Benth.) Britton & Rose	531	3.7	5.9	1.8	1.80	1.17
Ebenopsis ebano (Berland.) Barneby & J.W.	25	9.1	30	7.3	0.08	0.84
Cordia boissieri A. DC.	6	2.9	8.9	1.9	0.04	0.81
Acacia rigidula Benth.	31	2.7	4.1	1.3	0.07	0.81
Cercidium macrum I.M. Johnst.	75	3.5	9.1	2.7	1.38	0.62
Prosopis glandulosa Torr.	125	3.5	9.2	2.3	1.81	0.39
Sideroxylon celastrinum (Kunth) T.D. Peen.	44	2.1	4.5	2.1	0.11	0.16
Forestiera angustifolia Torr.	6	2.9	4.3	2.3	0.16	0.13
Diospirus texana Scheele	6	3.7	13	2.7	1.87	0.07
Leucophyllum frutescens (Berland.) I.M. Johnst.	6	1.5	3.7	1.3	0.03	0.06
Croton cortesianus Kunth	19	1.9	4	1.7	0.04	0.05
Zanthoxylum fagara (L.) Sarg.	94	2	4.1	1.7	0.29	0.04
Karwinskia humboldtiana (Schult.) Zucc.	6	1.5	3.9	1.2	0.01	0.04
Bernardia myricaefolia (Scheele) S. Watson	363	2	4.3	1.7	2.59	0.04
Celtis pallida Torr.	38	2	3.6	1.3	0.09	0.03
Eysenhardtia texana Scheele	56	2	3.7	1.5	0.12	0.02
Castela erecta Turpin	31	3.1	6.5	1.8	0.86	0.02
Ehrieta anacua (Terán &Berland.) I.M. Johnst.	113	2	6	1.9	0.35	0.01
Gymnosperma glutinosum (Spreng.) Less.	38	1.1	3.5	0.7	0.10	0.01
Sum	1731	2.91	7.29	43.80	17.24	7.76
			Mature scrub 2			

Cercidium macrum I.M. Johnst.	45	4.7	30.1	3.9	1.34	12.95
Acacia rigidula Benth.	860	2.8	6.5	2.1	8.84	3.98
Havardia pallens (Benth.) Britton & Rose	35	3.8	7	2.6	0.07	0.90
Cordia boissieri A. DC.	55	2.8	10	2.2	0.24	0.73
Ebenopsis ébano (Berland.) Barneby & J.W.	50	4.3	13.6	3.5	28.77	0.72
Acacia farnesiana (L.)Willd.	110	3.9	9.9	3.5	1.63	0.60
Prosopis glandulosa Torr.	130	2.7	9.3	2.4	0.23	0.37
Forestiera angustifolia Torr.	35	2.1	4.4	1.8	1.61	0.27
Eysenhardtia texana Scheele	175	2.3	3.6	1.7	0.46	0.21
Leucophyllum frutescens (Berland.) I.M. Johnst.	180	1.7	4.7	1.8	0.61	0.21
Celtis pallida Torr.	190	1.9	4.5	1.5	1.98	0.11
Croton cortesianus Kunth	35	1.2	3.3	0.8	0.20	0.10
Karwinskia humboldtiana (Schult.) Zucc.	105	1.7	4.8	1.2	0.46	0.09
Zanthoxylum fagara (L.) Sarg.	50	1.3	4.1	1.2	0.81	0.06
Castela erecta Turpin	20	1.9	3.6	1.9	0.05	0.03
Sideroxylon celastrinum (Kunth) T.D. Peen.	50	1.3	4.4	1.1	0.13	0.02
Sum	2125	2.53	7.74	33.20	47.43	21.34
		Ash scrub 1				
Cercidium macrum I.M. Johnst.	435	4.3	12.9	3.6	2.05	2.27
Cordia boissieri A. DC.	20	2.4	10.5	2.3	0.10	1.94
Leucophyllum frutescens (Berland.) I.M. Johnst.	70	1.8	3.6	1.7	5.04	1.01
Acacia rigidula Benth.	175	2.3	5.1	1.8	4.32	0.92
Yucca filifera Chabaud	25	5.1	29	4.2	0.07	0.14
Havardia pallens (Benth.) Britton & Rose	25	1.8	5.1	1.8	0.05	0.10
Forestiera angustifolia Torr.	110	1.6	3.1	1.3	0.21	0.09
Zanthoxylum fagara (L.) Sarg	10	1.8	3.3	1.8	0.03	0.06

Celtis pallida Torr.	55	1.9	4.3	1.7	0.21	0.04
Karwinskia humboldtiana (Schult.) Zucc.	30	1	3.2	1	0.08	0.04
Croton cortesianus Kunth	1060	1.5	3.4	1.3	2.24	0.03
Eysenhardtia texana Scheele	20	1.3	3.2	1.1	0.30	0.02
Guaiacum angustifolium Engelm.	55	1.8	3.5	0.4	0.13	0.01
Sum	2090	2.20	6.94	24.00	14.82	6.67
Ash scrub 2						
Cercidium macrum I.M. Johnst.	11	4.7	14	4	1.10	1.31
Leucophyllum frutescens (Berland.) I.M. Johnst.	622	1.9	3.8	1.9	2.45	1.30
Baccharis salicifolia (Ruíz & Pav.) Pers.	817	5.2	3.7	2.9	2.49	1.12
Acacia rigidula Benth.	33	2.4	4.5	2.1	0.08	1.10
Cordia boissieri A. DC.	28	2.4	9.4	2.3	2.90	0.78
Acacia farnesiana (L.)Willd.	94	3.9	18.5	2.4	1.74	0.50
Eysenhardtia texana Scheele	111	2	3.1	1.5	0.18	0.46
Prosopis glandulosa Torr.	6	3.9	17	3.9	0.17	0.31
Karwinskia humboldtiana (Schult.) Zucc.	594	1.4	3.1	1.4	1.01	0.28
Havardia pallens (Benth.) Britton & Rose	106	2.7	5.8	2.2	0.18	0.16
Yucca filifera Chabaud	56	7.2	37.5	1.6	0.36	0.11
Forestiera angustifolia Torr.	383	2.3	3	1.4	0.63	0.08
Croton cortesianus Kunth	1300	1.1	3	0.8	2.89	0.08
Diospyros texana Scheele	11	3.4	15	3.4	0.68	0.08
Celtis pallida Torr.	11	2.3	4	2.3	0.24	0.04
Zanthoxylum fagara (L.) Sarg.	11	2.2	4	2.6	0.04	0.02
Sum	4194	3.06	9.34	36.70	17.16	7.72
Mature scrub 3						
Prosopis glandulosa Torr.	150	4.3	14.4	4	2.44	3.09
Acacia rigidula Benth.	1480	3.7	4.5	1.5	6.02	2.71

The three species with the greatest dimensions in this research are also those with the highest value index values in areas of MET regenerated naturally after agricultural and livestock activities (Alanís *et al.,* 2008; Jiménez *et al*., 2009). Several studies suggest that the importance of Fabaceae in MET is attributable to the wide range of reactions they have to support and tolerate limiting factors, such as ecophysiological responses to water stress (González and Cantú, 2001; López *et al*., 2010; González *et al*.; 2011a, b).

In the specific case of *A. farnesiana*, it is a species of rapid establishment in disturbed areas forming dense associations known as *huizachales* (Estrada *et al*., 2004; Leal *et al*., 2018); *P. glandulosa* dominates areas of secondary vegetation, it is abundant in overgrazed areas, abandoned crop fields (Estrada *et al*., 2014) and in the lower parts of the basins (Alanís *et al.,* 2017); while *C. macrum* is characteristic of the northern region of the state, in plains and mountains (Estrada *et al*., 2005).

Conclusions

The plant communities of the Tamaulipan thorny scrub of the *Ternium* ecological reserve, *Pesquería*, have high variability in carbon storage, values in recently planted areas of 2.51 Mg ha^{-1} up to high values in mature communities established in the lower part of the basin (46.1 Mg ha^{-1}). In general, the *Ternium* ecological reserve area stores 1 228.09 Mg of carbon, which is equivalent to an average of 12.76 Mg ha^{-1}. The species with the highest total biomass and stored carbon were the Fabaceae: *P. glandulosa, A. farnesiana* and *C. macrum* with 34.96 % of the total biomass.

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Conflict of interests

The authors declare no conflict of interests.

Contribution by author

Ana María Patiño Flores: conceptualization of the research, review of the database, data analysis, writing of the original draft; Eduardo Alanís Rodríguez: conceptualization of the research, review of the database, review of the data analysis, writing of the methodology and review and editing of the manuscript; Víctor Manuel Molina Guerra: conceptualization of research, coordination in field work, review of data analysis and of the manuscript; Humberto González Rodríguez: database review, data analysis and review and editing of the manuscript; Enrique Jurado: conceptualization of the research, review of the database and review and editing of the manuscript; Oscar Alberto Aguirre Calderón: database review, data analysis and review and editing of the manuscript.

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