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Research article

Evaluación de una reforestación y regeneración del matorral espinoso tamaulipeco en el noreste de México

Assessment of a reforestation and a regeneration of the Tamaulipan Thorny Scrub at Northeastern Mexico

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Abstract

The ecosystems in northeastern Mexico have become degraded, and, therefore, it has been necessary to develop strategies to restore them. The objectives of this study were to estimate the survival and composition of a reforestation with native species three years after its establishment, as well as to assess the floristic composition and ecological parameters of the Tamaulipan Thorny Scrub (MET) 11 years after its reconversion for hunting use. Based on their ecological parameters, the regenerated vegetation was characterized into two strata, and their diversity indexes were calculated (Shannon-Wiener, Margalef, and Pretzsch). The survival and ecological parameters of the established species were estimated for reforestation purposes. The most important species within the regeneration were characteristic of early successional stages, following anthropogenic activities. The highest abundance of families and individuals was concentrated in the Fabaceae and Poaceae families; the former, represented by the same species successfully established in reforestation, and the latter, by invasive herbaceous taxa. Within reforestation, *Prosopis glandulosa*, *Diospyros texana*, *Cordia boissieri, Ebenopsis ebano, Vachellia rigidula*, and *Havardia pallens* had survival rates of 76.92, 50.0, 40.0, 38.46, 24.24, and 20.0 %, respectively; the rest of the species had 0 %. The results obtained are relevant for decision-making in forest management at the TTS, as well as for the monitoring of this community in its various successional stages.

Key words: Hunting activities, frost damage, desertification, diversity indexes, post-livestock, ecological restoration.

Resumen

Debido a la degradación en los ecosistemas del noreste de México, ha sido necesario desarrollar estrategias para restaurarlos. Los objetivos del presente estudio fueron estimar la supervivencia y composición de una reforestación con especies nativas, tres años después de su establecimiento, así como evaluar la composición florística y parámetros ecológicos del Matorral Espinoso Tamaulipeco (MET) a 11 años de su reconversión para aprovechamiento cinegético. Se caracterizó la vegetación regenerada a través de sus parámetros ecológicos en dos estratos, y se realizó el cálculo de sus índices de diversidad (*Shannon-Wiener*, *Margalef* y *Pretzsch*). Para la reforestación se estimó la supervivencia y parámetros ecológicos de las especies establecidas. Las especies con mayor importancia dentro de la regeneración fueron características de etapas de sucesión temprana, posterior a actividades antropogénicas. La mayor abundancia de familias e individuos se concentró en las familias Fabaceae y Poaceae, la primera representada por las mismas especies establecidas con éxito en la reforestación, y la segunda por taxones herbáceos de carácter invasor. Dentro de la reforestación, *Prosopis glandulosa*, *Diospyros texana*, *Cordia boissieri*, *Ebenopsis ebano*, *Vachellia rigidula* y *Havardia pallens* presentaron porcentajes de supervivencia de 76.92, 50.0, 40.0, 38.46, 24.24 y 20.0 %, respectivamente, y el resto de las especies registraron 0 %. Los resultados obtenidos son de relevancia para la toma de decisiones en el manejo forestal del MET, así como para el monitoreo de esta comunidad en sus diferentes etapas sucesionales.

Palabras clave: Actividades cinegéticas, daño por heladas, desertificación, índices de diversidad, posganadería, restauración ecológica.

Research article

Introduction

In Mexico, arid and semi-arid zones make up 60 % of its territory (Pontifes *et al*., 2018). The importance of studying them lies in the extreme conditions that affect their ecosystems, such as torrential rains, droughts, and frosts, which limit the growth and development of the flora (Filio-Hernández *et al.,* 2019). Among its plant communities, the Tamaulipan Thorny Scrub (MET, for its acronym in Spanish) stands out as the most abundant in the northeastern region of Mexico (Patiño-Flores *et al.*, 2021). It covers an area of approximately 125 000 km^2, distributed across the states of *Tamaulipas*, *Nuevo León* and *Coahuila* in Mexico, and south of Texas in the United States of America (Alanís *et al.*, 2013). It grows in warm and semi-warm climates, at altitudes of 200 to 500 m, on flat land, plateaus, and hills, in deep, clayey soils of the Vertisol type (Molina-Guerra *et al*., 2019; Alanís-Rodríguez *et al.*, 2021). The heterogeneity of edaphic and climatological conditions within the distribution area has given rise to a great variety of taxonomic assemblages, which become manifest in the diversity, richness, cover, height, and density among plant species (Pequeño-Ledezma *et al.*, 2017). Ecosystem services include carbon sequestration, erosion reduction, improved water infiltration, scenic beauty, and wildlife habitat (Molina-Guerra *et al.*, 2023).

The vegetation of the MET is harvested for timber, handicraft, ornamental, medicinal, and food purposes (Leal-Elizondo *et al.*, 2018), while most of the land is used for rainfed agriculture and both intensive and extensive livestock farming (Mora *et al*., 2013). Today, the area of land clearing has increased due to urbanization (Alanís-Rodríguez *et al.*, 2015), fuel and mineral exploitation (Marroquín-Castillo *et al.*, 2017; Molina-Guerra *et al.*, 2019), and installation of infrastructure for power generation (Mata *et al.*, 2022), among other factors.

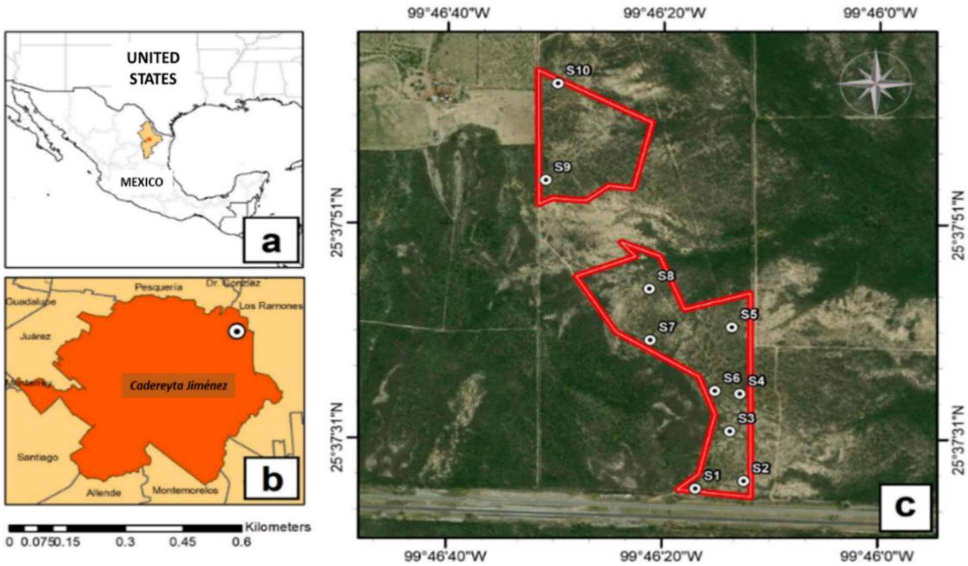
According to the National Forest Commission (Conafor, 2015), the clearing of forest land for the development of these economic activities has an impact on the ecosystem that must be balanced through ecological compensation actions. These measures can be implemented through reforestation with native species in areas that show some state of degradation, if established vegetation is maintained over the long term, it can lead to ecological succession and improve ecosystem conditions (Venegas, 2016). One way to increase their chances of permanence is to carry out reforestation in areas where low-impact economic activities are developed, and at the same time it is convenient for the owners to increase native vegetation (Martín *et al.*, 2022). An example of this is hunting activities (Serna-Lagunes *et al.*, 2013), which boomed nationwide in the first decade of the 2000s, mainly in the states of *Nuevo León*, *Coahuila*, *Tamaulipas*, *Sonora* and *Chihuahua* (Gallina-Tessaro *et al*., 2009). Specifically, the hunting exploitation of the white-tailed deer (*Odocoileus virginianus* Zimmermann) depends on a vegetative cover of at least 2.5 m in height for protection from predators and adverse weather conditions (Villarreal, 2014).

Research conducted at the MET for hunting purposes has focused mainly on the estimation of production indicators such as biomass, carrying capacity, and nutritional importance (Domínguez *et al.*, 2012; González-Saldívar *et al.*, 2014), as a result, studies aimed at assessing the vegetation composition within authorized wildlife conservation management units (UMA, for its acronym in Spanish) are scarce (Cantú *et al.,* 2011; Alanís *et al*., 2015). There are no documented cases regarding the assessment of reforestations in the MET with this type of harvesting. For this reason, the objectives of the present research were as follows: (1) To estimate the survival and composition of a reforestation site, as part of an environmental offset, three years after its establishment, and 2) To assess the floristic composition and ecological parameters of the MET 11 years after its reconversion for hunting use.

Materials and Methods

Study area

The study area is located in *Cadereyta Jiménez* municipality, *Nuevo León*. The location coordinates are 99°46'31.15" W and 25°39'3.27" N, and 99°46'31.26" W and 25°37'11.92" N (GPS model 10 eTrex®), at 252 masl, with an area of 22.66 ha (Figure 1). The climate is classified as warm semi-arid BS_1(h')w, with a mean annual temperature and precipitation of 22 to 24 °C and 600 to 800 mm, respectively (García, 2004; Cuervo-Robayo *et al.*, 2015a; Cuervo-Robayo *et al.*, 2015b). The soils are classified as *Kastañozem* and *Vertisol* (INEGI, 2013). The site has a history of logging of timber species (*Prosopis glandulosa* Torr., *Ebenopsis ebano* (Berland.) Barneby & J. W. Grimes, and *Helietta parvifolia* (A. Gray ex Hemsl.) Benth.) and extensive livestock farming (cattle). As of 2010, these activities ceased in order to make room for the hunting of the white-tailed deer (*Odocoileus virginianus*) and the collared wild boar (*Pecari tajacu* Linnaeus).



A = State of Nuevo León; B = Cadereyta Jiménez municipality, and location of the study site; C = Sampling sites.

Figure 1. Study site.

Reforestation activities

Reforestation activities were carried out as a result of the implementation of a reforestation program requested for environmental compensation for the establishment of a thermoelectric power plant in *El Carmen* municipality, *Nuevo León*. 16 woody species native to the MET were used to enhance diversity within the study site, having been selected based on taxonomic records of the municipality corresponding to primary and secondary vegetation (López and Pando, 2014; Rodríguez-Rojas *et al.*, 2017). Seeds were collected during the spring of 2017 and stored in airtight containers inside a refrigerator (model AT9007G, Acros®) at a temperature of 13 °C. Subsequently, in September 2017 they were germinated; for this purpose, polystyrene trays (Hidro Enviroment®) were used (capacity of 200 cavities of 15 cm^3 and caliber of 1 mm), the average sprouting time was 8 to 15 days. Germinated seedlings were transferred to 500 mL polyethylene bags, which were filled to 95 % of their capacity with a substrate mixture (70-30-10: natural soil, 22 mm pumice stone, and perlite mineral). The individuals were placed in beds under 40 % shade cloth; they were irrigated weekly for a period of 6 months. The seedlings were germinated and developed in the forest nursery of the company GEMA S. C., in *Linares* municipality, *Nuevo León*.

Planting was carried out in April 2018, considering the spring rains, prior to the summer temperature increase (ClimateData, 2023; Servicio Meteorológico Nacional, 2006). Planting density was 1 283 individuals per hectare with a random distribution within the entire area of the property (22.66 ha). A three-bowl design was utilized, this is a technique recommended to minimize soil dragging and at the same time take advantage of the runoff in the area (Conafor, 2010).

The seedlings used had an average height of 0.35 m (Conafor, 2010), therefore, they were placed inside circular stocks with a depth of 0.50 m and a diameter of 0.35 m. Previously, fine-grained agricultural hydrogel (Hydrogel MX) dissolved in water was added at a concentration of 3 g L^{-1}, following the supplier's recommendations (Maldonado-Benitez *et al.*, 2011). Furthermore, a phytoregulator rooting powder

(Raizone-Plus® Fax, 1.5 mg L^{-1}) was added to promote root growth and heal any wounds that may have been made during the planting process. At the end of planting, an initial irrigation of 25 L of water per individual was applied to allow the plant to adapt to the soil conditions. Each individual was secured with wooden stakes, and a 0.66 m long by 0.35 m high tubular protector made of high-density polyurethane was placed.

Quarterly maintenance activities, consisting in irrigation by pipe and hose (10 L per seedling) and replacement of dead plants at 100 %, were carried out from May 2018 to May 2020. In addition, herbaceous plants were removed monthly with a *machete* within 1 m^2 around the plant for a period of four months. The seedlings used for the substitution were developed under the same procedure as the original ones, until they reached a height range of 0.35-0.50 m. However, it was not possible to use the same species in all cases, and, therefore, the evaluation was made after the maintenance activities were completed.

Reforestation survival analysis

In August 2021, the survival of the plantation was evaluated based on the total number planted until May 2020. A sampling design adapted from Ramírez (2011) was used resulting in the establishment of 10 circular sampling plots (sampling fraction=1.19 %) with a surface area of 250 m^2 (radius of 8.92 m). The distance between sites was 150 m, estimated based on the equations of Schlegel *et al.* (2001). At each site, the survival and cover (N-S and E-W) of each of the planted individuals were assessed; they were found to differ from those obtained with natural regeneration due to the previous use of tubular protectors. Measurements were made with a 10 m Truper® flexometer. Survival, both overall and by species, was estimated with the Equation (1) (García, 2011):

$$\% S = \frac{Pv}{P} \quad (100) \qquad (1)$$

Where:

%S = Survival rate

Pv = Number of living individuals

P = Total number of live and dead plants

Assessment of natural regeneration of the MET

The same circular plots utilized for the survival analysis were used to characterize the natural regeneration of the MET. The vegetation was divided into two strata: the tall stratum, consisting of vegetation with woody stems ($D_{1.5}$≥1 cm), and Rosaceae and succulents counted within the 250 m^2 circular area. The low herbaceous stratum, which included herbaceous species, was counted in a 1 m^2 quadrat at the center of each circular plot. Stimates 9.1 software (Colwell, 2023) was used to verify that each stratum was fully sampled by means of species accumulation curves and through the evaluation of two non-parametric species richness estimators —Chao 2 and Jackknife 1— recommended for small sampling units (Hortal *et al.*, 2006). The completeness of each survey was calculated based on the ratio between the observed richness and the estimated total richness (Willott, 2001).

In both strata, the horizontal cover of each individual (N-S and E-W) and the height was measured using a 30 m tape (model TFC 30ME, Truper®). Plant species were identified with the help of flora catalogs and taxonomic keys (Alanís *et al*., 2011). The ecological parameters of the recovered vegetation were analyzed by calculating abundance, dominance, frequency in absolute and relative form, as well as the Importance Value Index (*IVI*) of Whittaker (1972) and Mueller-Dombois and Ellenberg (1974). Species diversity was evaluated through the Shannon-Wiener Index (*H'*) (Shannon and Weaver, 1949), which indicates the relative abundance of species. The Margalef index (D_{Mg}) (Clifford and Stephenson, 1975) was used to calculate the wealth of species. The vertical structure by sampling stratum was also analyzed using the Pretzsch Index, which categorizes the vertical structure into three strata: stratum I (high) refers to the interval between 80 and 100 %, in which 100 % is represented by the highest individual in the sampling stratum; stratum II (medium), to a 50-80 % interval, and stratum III (low), to a range of values of 0-50 % (Pretzsch, 2009).

Results and Discussion

Reforestation survival

In the survival assessment, 15 months after suspending maintenance activities in the plantation, the presence of 407 live individuals per hectare was estimated, which is equal to a 31.72 % survival rate, based on the initial plantation density. The successfully established species were *Prosopis glandulosa*, *Vachellia rigidula* (Benth.) Seigler & Ebinger, *Ebenopsis ebano*, *Cordia boissieri* A. DC., *Diospyros texana* Scheele and *Havardia pallens* (Benth.) Britton & Rose. The rest of the species (10) did not survive (Table 1).

Table 1. Values per hectare of planted individuals, live individuals per hectare, survival and cover in the reforestation area.

Species	Planted individuals ha^{-1}	Living individuals ha^{-1}	Survival (%)	Mean cover (m^2 ha^{-1})
Prosopis glandulosa Torr.	49	37	76.92	0.66±0.08
Diospyros texana Scheele	242	121	50.00	0.58±0.09
Cordia boissieri A. DC.	161	64	40.00	0.23±0.08
Ebenopsis ebano (Berland.) Barneby & J. W. Grimes	215	82	38.46	0.66±0.08
Vachellia rigidula (Benth.) Seigler & Ebinger	104	25	24.24	0.55±0.08
Havardia pallens (Benth.) Britton & Rose	62	12	20.00	0.66±0.08
Ehretia anacua (Terán & Berland.) I. M. Johnst.	189	0	0.00	0.00
Senegalia berlandieri (Benth.) Britton & Rose	87	0	0.00	0.00
Celtis pallida Torr.	42	0	0.00	0.00
Parkinsonia aculeata L.	38	0	0.00	0.00
Vachellia farnesiana (L.) Wight & Arn.	31	0	0.00	0.00

Erythrostemon mexicanus (A. Gray) Gagnon & G. P. Lewis	22	0	0.00	0.00
Senegalia greggii (A. Gray) Britton & Rose	18	0	0.00	0.00
Condalia hookeri M. C. Johnst.	12	0	0.00	0.00
Leucophyllum frutescens (Berland.) I. M. Johnst.	10	0	0.00	0.00
Yucca filifera Chabaud	1	0	0.00	0.00
Total	1 283	407	31.72	

This survival rate, which is lower than that obtained in other reforestations in the MET (Table 2), can be attributed to several factors, one of the main factors is the extreme weather prevailing in northeastern Mexico (Jurado *et al*., 2006).

Table 2. Previous survival assessment studies of the Tamaulipan Thorny Scrub (MET).

Authors and year of publication	Municipality and state	Objective of the study	Survival rate (%)	Establishment time
Jurado *et al.* (2006)	*Cd. Victoria*, *Tamaulipas*	Identification of species for ecological restoration	Presented in graphs by species	1 year
López y López (2013)	*Linares*, *Nuevo León*	Ornamental plantation	70.0	16 years
Foroughbakhch *et al.* (2014)	*Linares*, *Nuevo León*	Identification of species for ecological restoration	99.11	5 years
Vega-López *et al.* (2017)	*Pesquería*, *Nuevo León*	Identification of species for ecological	51.6	1 year

		restoration		
Gutiérrez-Barrientos *et al.* (2022)	*Pesquería, Nuevo León*	Use of drones for forest plantation monitoring	76.07	Not specified
Patiño-Flores *et al.* (2022)	*Pesquería, Nuevo León*	Reforestation of a degraded area	49.4	41 months
Mata *et al.* (2022)	*Los Ramones, Nuevo León*	Reforestation of a degraded area	28.7	31 months

Between February 13th and 20th, 2021, a temperature drop as low as -5 °C (Meteored, 2023) occurred over much of the southern United States and northern Mexico (Yang and Liu, 2023). Previous studies have reported negative effects on shrubland ecosystems due to frost (Lonard and Judd, 1991; Bojórquez *et al.*, 2021; Mata *et al.*, 2022); damage occurs inside the plant due to the formation of ice in the intercellular spaces, which causes the rupture or dehydration of the cell (Curzel and Hurtado, 2020).

Some MET species have developed adaptive mechanisms that allow them to survive the incidence of drought or frost (González *et al.*, 2004). Those individuals that managed to establish themselves in the reforestation, belonging to the species *Cordia boissieri* and *Diospyros texana*, have narrow ducts that prevent the cavitation process during the rise or fall of temperatures, and the water moves through them (Maiti *et al.*, 2016). *Prosopis glandulosa* exhibits a decrease in leaf area under water stress conditions (Qin *et al.*, 2018), as well as deep roots that allow it to reach groundwater (Johnson *et al.*, 2018).

Ebenopsis ebano has a thick cuticle that reduces water loss through transpiration (González *et al.*, 2017a), and its high content of chlorophyll a and chlorophyll b is associated with a high photosynthetic capacity during dry seasons (Maiti et al., 2016). Likewise, *Havardia pallens* increases its chlorophyll content, probably as an adaptation to the winter season (González *et al.*, 2017b). It has been shown that individuals of the species *Vachellia rigidula* cope with lack of moisture by increasing their water potential (González *et al.*, 2004).

In the study area, the cover of the herbaceous stratum had a higher dominance value than the tree-shrub vegetation of both the reforestation and the regeneration (tables 2 and 3). Similar results are presented by Albrecht *et al.* (2022) in an area invaded by exotic grasses, 23 years after its reforestation with MET species, where *E. ebano* and *P. glandulosa* had the lowest mortality. However, *E. ebano* and *H. pallens*, two of the species with the greatest cover, have been cited as taxa that prefer a closed canopy for growth (Jurado *et al.*, 2006).

Table 3. Ecological parameters of MET regeneration and their relative values.

Family	Scientific name	Abundance	Cover	Frequency	Relative Abundance	Relative Dominance	Relative Frequency	*IVI*
				High stratum				
Fabaceae	*Vachellia rigidula* (Benth.) Seigler & Ebinger	764	5.51	10	23.46	5.56	7.63	12.22
Scrophulariaceae	*Leucophyllum frutescens* (Berland.) I. M. Johnst.	344	4.73	9	10.57	4.77	6.87	7.40
Celastraceae	*Schaefferia cuneifolia* A. Gray	324	3.88	8	9.95	3.91	6.11	6.66
Rhamnaceae	*Rhamnus humboldtiana* Schult.	236	4.03	9	7.25	4.06	6.87	6.06
Fabaceae	*Cercidium macrum* I. M. Johnst.	120	7.80	8	3.69	7.87	6.11	5.89
Euphorbiaceae	*Jatropha dioica* Sessé ex Cerv.	272	1.87	9	8.35	1.89	6.87	5.70
Verbenaceae	*Lantana camara* L.	236	2.57	9	7.25	2.59	6.87	5.57
Fabaceae	*Eysenhardtia texana* Scheele	116	4.93	8	3.56	4.97	6.11	4.88
Cordiaceae	*Cordia boissieri* A. DC.	76	6.15	7	2.33	6.20	5.34	4.63
Solanaceae	*Lycium berlandieri* Dunal	124	3.75	8	3.81	3.78	6.11	4.57
Rubiaceae	*Randia*	136	4.09	6	4.18	4.12	4.58	4.29

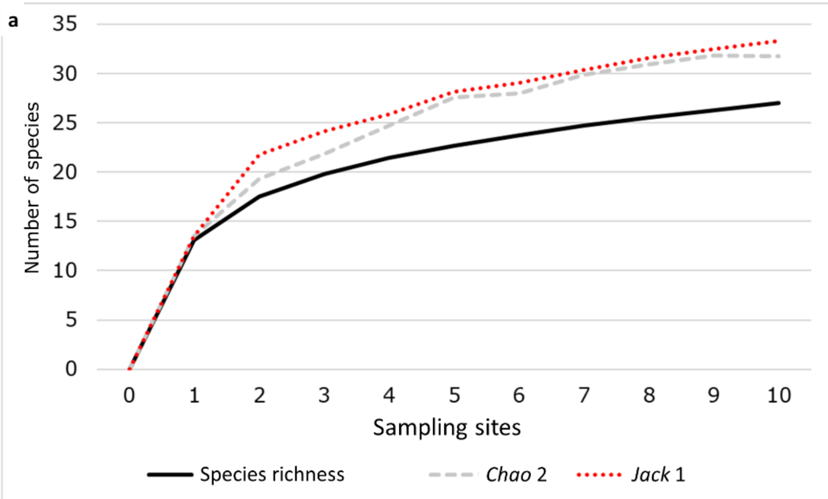
	rhagocarpa Standl.							
Oleaceae	*Forestiera angustifolia* Torr.	72	5.21	6	2.21	5.26	4.58	4.02
Asparagaceae	*Yucca filifera* Chabaud	44	6.47	4	1.35	6.53	3.05	3.64
Fabaceae	*Havardia pallens* (Benth.) Britton & Rose	32	5.46	4	0.98	5.51	3.05	3.18
Zygophyllaceae	*Guaiacum angustifolium* Engelm.	124	2.65	3	3.81	2.67	2.29	2.92
Cactaceae	*Cylindropuntia leptocaulis* (DC.) F. M. Knuth	64	2.13	5	1.97	2.14	3.82	2.64
Fabaceae	*Chamaecrista greggii* (A. Gray) Pollard ex A. Heller	20	3.03	5	0.61	3.06	3.82	2.50
Fabaceae	*Vachellia farnesiana* (L.) Wight & Arn.	16	4.85	2	0.49	4.89	1.53	2.30
Euphorbiaceae	*Bernardia myricifolia* (Scheele) S. Watson	8	4.10	1	0.25	4.14	0.76	1.71
Verbenaceae	*Lippia graveolens* Kunth	40	3.00	1	1.23	3.03	0.76	1.67
Fabaceae	*Prosopis glandulosa* Torr.	4	3.60	1	0.12	3.63	0.76	1.51
Euphorbiaceae	*Croton incanus* Kunth	40	1.59	2	1.23	1.60	1.53	1.45
Verbenaceae	*Aloysia macrostachya* (Torr.) Moldenke	8	3.20	1	0.25	3.23	0.76	1.41
Verbenaceae	*Lantana achyranthifolia* Desf.	4	2.00	1	0.12	2.02	0.76	0.97
Asparagaceae	*Agave lechuguilla* Torr.	4	1.80	1	0.12	1.82	0.76	0.90
Cactaceae	*Homalocephala texensis* (Hopffer) Britton & Rose	8	0.50	2	0.25	0.50	1.53	0.76
Cactaceae	*Ancistrocactus scheeri* (Salm-Dyck) Britton & Rose	20	0.24	1	0.61	0.24	0.76	0.54
	Total	3 256	99.14	131	100.00	100.00	100.00	100.00
				Low stratum				
Poaceae	*Bouteloua gracilis* (Kunth) Lag. ex	120 000	137.50	9	45.45	7.80	20.00	24.42

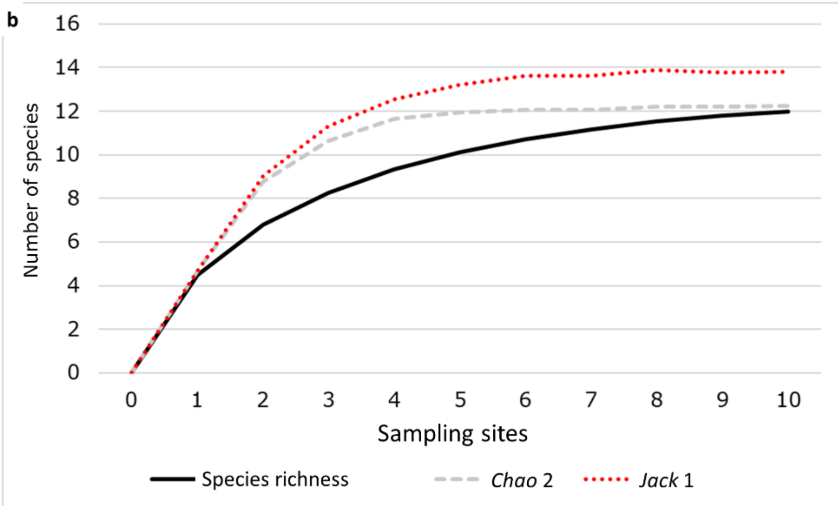
	Griffiths							
Poaceae	*Cynodon dactylon* (L.) Pers.	21 000	408.33	4	7.95	23.17	8.89	13.34
Acanthaceae	*Ruellia nudiflora* (Engelm. & A. Gray) Urb.	40 000	115.38	7	15.15	6.55	15.56	12.42
Convolvulaceae	*Evolvulus alsinoides* (L.) L.	32 000	80.16	7	12.12	4.55	15.56	10.74
Ehretiaceae	*Tiquilia canescens* (A. DC.) A. T. Richardson	15 000	235.00	4	5.68	13.33	8.89	9.30
Poaceae	*Melinis repens* (Willd.) Zizka	5 000	292.00	2	1.89	16.57	4.44	7.64
Malvaceae	*Meximalva filipes* (A. Gray) Fryxell	6 000	63.33	3	2.27	3.59	6.67	4.18
Heliotropiaceae	*Heliotropium angiospermum* Murray	1 000	165.00	1	0.38	9.36	2.22	3.99
Malvaceae	*Malvastrum* sect. *coromandelianum* (L.) Garcke	3 000	71.67	3	1.14	4.07	6.67	3.96
Asteraceae	*Thymophylla pentachaeta* (DC.) Small	8 000	76.25	2	3.03	4.33	4.44	3.93
Euphorbiaceae	*Euphorbia aleppica* var. *prostata* Kasapligil	12 000	47.92	2	4.55	2.72	4.44	3.90
Bixaceae	*Cochlospermum wrightii* (A. Gray) Byng & Christenh	1 000	70.00	1	0.38	3.97	2.22	2.19
	Total	264 000	1,763.54	45	100.00	100.00	100.00	100.00

Abundance (*N* ha^{-1}), Cover (m^2 ha^{-1}), Frequency (*N*) and Dominance (%) ranked from highest to lowest Importance Value Index (*IVI* %).

Characterization of the regenerated vegetation of MET

The species accumulation curves showed a non-asymptotic increasing trend, indicating that a higher number of taxa was expected in both strata (Figure 2). Sampling completeness varied between high and low strata (*Chao* 2=85.09 % and 98.12 %; *Jackknife* 1=81.08 % and 86.96 %), as well as estimated richness between estimators (*Chao* 2=32 and 12 species; *Jackknife* 1=33 and 14 species). There is no definitive estimator for all situations, but the *Jackknife* 1 estimator is the most commonly accepted (González-Oreja *et al*., 2010). Arboreal-shrub communities are the most studied for the MET, with richness records of 30 to 40 species (Alanís *et al*., 2015), which denotes that the sampling effort has been acceptable for this parameter.

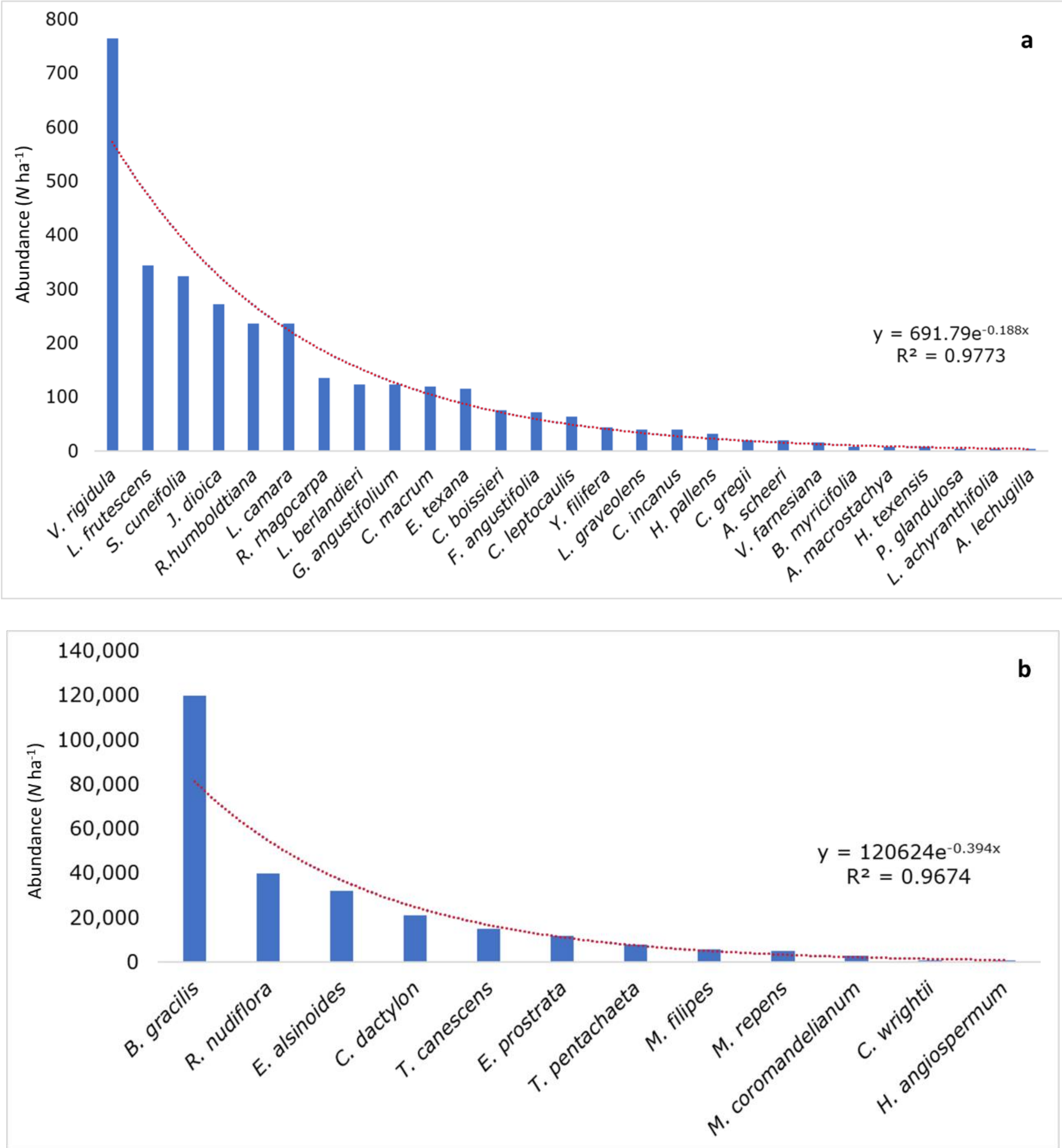




a = High stratum; b = Low stratum.

Figure 2. Species accumulation curves with two nonparametric estimators (*Chao* 2 and *Jackknife* 1).

The plant community of the high stratum in the study area is represented by 27 species distributed into 20 families (Table 3). Total abundance was 3 256 *N* ha^{-1} (Figure 3), with a coverage of 99.14 m^2 ha^{-1}. The abundance is similar to that of a conservation area (Yerena *et al*., 2014), which is higher than that existing in a silvopasture area (Patiño-Flores *et al*., 2021), but lower than that of a hunting ranch in the state of *Coahuila*, Mexico (Encina-Domínguez *et al*., 2020).



a = High stratum; b = Low stratum.

Figure 3. Species abundance interval (*N* ha^{-1}).

The family with the highest *IVI* was Fabacae, with 26.58 %. Its presence has been documented after anthropogenic activities, due to the tendency of the species to establish themselves in disturbed soils with low nutrient concentrations, as they can fix atmospheric N_2 (Alanís-Rodríguez *et al.*, 2018).

Vachellia rigidula (Fabaceae) was the most abundant species in the tree-shrub stratum, followed by *Leucophyllum frutescens* (Berland.) I. M. Johnst. (Scrophulariaceae) (Figure 3a). Both taxa are considered pioneers and have a high value of importance in subsequent assessments of different types of exploitation (Patiño-Flores *et al.*, 2022). Furthermore, they are identified as part of the diet of white-tailed deer (Lozano-Cavazos *et al.*, 2020), which contributes to the dispersal processes of these species.

The alpha diversity (2.63) and species richness (3.87) values for the high stratum are higher than those recorded for an UMA in the state of *San Luis Potosi*, where the white-tailed deer management is practiced (Dávila-Lara *et al.*, 2019).

A total of 12 species were registered for the herbaceous stratum, with an abundance of 264 000 *N* ha^{-1} (Figure 3b) and a cover of 1 762.53 m^2 ha^{-1}. The Poaceae family accounted for 45.39 %, registering the highest importance value index; the taxa with the highest *IVI* value were *Bouteloua gracilis* (Kunth) Lag. ex Griffiths (24.42 %), and *Cynodon dactylon* (L.) Pers. (13.34 %). The dominance of these and other species classified as invasive in the herbaceous stratum (Carrillo *et al.*, 2009) may be the product of a seed bank prevalent during the period of cattle ranching, an activity in which the use of fast-growing grasses is common (Jurado-Guerra *et al*., 2021).

Three strata were defined for the analysis of the vertical structure. In stratum I (high), 28 *N* ha^{-1} were recorded, only for *Yucca filifera* Chabaud; in stratum II (medium), there were 112 *N* ha^{-1} of the species *Cercidium macrum* I. M. Johnst., *Cordia boissieri*, *Havardia pallens*, *Schaefferia cuneifolia* A. Gray, and *Vachellia rigidula*, and in stratum III (low) all the species of the study were present, with a total of 4 084 *N* ha^{-1}, the most abundant species being *V. rigidula* and *B. gracilis*. It is important to highlight that the height of *Y. filifera* affected the results of this index, as it was the only one present in stratum I.

The Pretzsch index yielded a result of *Arel* (68.91 %) which is related to a mean diversity, as values close to 100 % indicate an equitable distribution of species between the three strata (Pequeño *et al.*, 2021). This value is lower than those indicated for a pasture with agroforestry use (Sarmiento-Muñoz *et al.*, 2019) and for a temperate forest (Silva-García *et al.*, 2021). This may be due to the fact that areas for agroforestry support not only grasslands but also tall woody species with a commercial value, while trees within a temperate forest are higher than those found in shrubland ecosystems (Vargas-Vázquez *et al.*, 2022).

Finally, all species surviving in the reforestation, with the exception of *Ebenopsis ebano* and *Diospyros texana*, are present in the regeneration of vegetation, and, therefore, contribute diversity to the ecosystem (Patiño-Flores *et al*., 2022).

Conclusions

The present study provides valuable information on the current status of the MET in the process of recovery and undergoing reforestation to provide structure and species diversity. The diversity of naturally regenerated vegetation is higher than in some MET conservation areas and can be attributed to the coexistence of flora taxa at different stages of succession. Those species with a higher value of importance are characteristic of sites with a history of exploitation and are part of the diet of the white-tailed deer; therefore, game fauna would be contributing to their dispersal. The taxa that managed to become established have been cited with optimal growth at a standard planting density, under a closed tree-shrub canopy, and with a high dominance and cover of herbaceous species. In addition, several studies indicate the adaptation mechanisms that these taxa exhibit in the face of the climatic conditions of the region. Therefore, their use is recommended for future reforestation with native species under conditions similar to those of the study site.

The results provide useful information for decision-making in the monitoring and reforestation of MET communities, for which purpose it is of utmost importance to know and study the various successional stages of an ecosystem before intervening in it.

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Conflict of interest

The authors declare that they have no conflict of interest.

Contribution by author

Jose Manuel Mata-Balderas: experimental design, planting management, and drafting of the manuscript; Carla Sofía González-Sánchez: data analysis, literature review, and drafting of the manuscript; Karen Alejandra Cavada-Prado: proofreading and drafting of the manuscript; Tania Isela Sarmiento-Muñoz: drafting of the manuscript and review of the data analysis and of the results.

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