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Research Article

Monitoreo de la supervivencia de una reforestación con especies nativas del matorral espinoso tamaulipeco

Monitoring of a reforestation survival with native species of the Tamaulipas thorn scrub

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Abstract

The *Tamaulipas* thorn scrub (TTS) is a highly diverse ecosystem that has been affected by anthropogenic activities. For its restoration, reforestation with native species has been carried out in search of greater survival. In 2018, a reforestation was carried out with 15 native species of the TTS in a property with previous agricultural use in an area of 15.43 hectares in *Los Ramones* municipality, *Nuevo Leon*. During the first two years after reforestation, protection (individual protectors and fencing) and maintenance activities (weed control and plant replacement) were carried out. The objective of this study was to evaluate the survival of reforestation for a three year - period. A sampling of 10 random and scattered lines was used, counting 30 continuous plants to evaluate the presence or absence of living plants. For 2019, 2020 and 2021, survival values of 80.67 %, 95.34 % and 28.7 %, respectively, were recorded. The species that most successfully survived were *Cordia boissieri* (16.43 %), *Prosopis glandulosa* (10.67 %), *Ebenopsis ebano* (7.56 %), *Diospyros texana* (5.89 %), *Ehretia anacua* (5.22 %), *Parkinsonia aculeata* (4.22 %), *Vachellia farnesiana* (4.11 %) and *Vachellia rigidula* (4.00 %). It is concluded that the climatic conditions affected the survival of the plantation, the selection of native species to be used determines the success of survival and that the protection and maintenance activities must be established according to the requirements of each species and maintained until the permanence of the plantation is ensured.

Key words: Environmental compensation, semi-arid forest ecosystem, native species, evaluation, maintenance, protection.

Resumen

El matorral espinoso tamaulipeco es un ecosistema con alta diversidad que está afectado por actividades antropogénicas. Para contribuir a su proceso de restauración se han realizado reforestaciones con especies nativas, cuyo propósito es lograr una mayor supervivencia. En 2018, se realizó una reforestación con 15 especies nativas en un predio con uso previo agropecuario en una superficie de 15.43 ha, localizado en el municipio Los Ramones, Nuevo León. Durante los primeros dos años posteriores a la reforestación se efectuaron acciones de protección (protectores individuales y cercado) y mantenimiento (control de maleza y reposición de plantas). El objetivo de este estudio fue evaluar la supervivencia por un periodo de tres años. Se utilizó un muestreo de 10 líneas aleatorias y dispersas, se contaron 30 plantas continúas para determinar la presencia o ausencia de plantas vivas. Para 2019, 2020 y 2021 se registraron valores de supervivencia de 80.67, 95.34 y 28.7 %, respectivamente. Las especies que persistieron con mayor éxito fueron *Cordia boissieri* (16.43 %), *Prosopis glandulosa* (10.67 %), *Ebenopsis ebano* (7.56 %), *Diospyros texana* (5.89 %), *Ehretia anacua* (5.22 %), *Parkinsonia aculeata* (4.22 %), *Vachellia farnesiana* (4.11 %) y *Vachellia rigidula* (4.00 %). Se concluye que las condiciones climáticas afectaron la supervivencia de la plantación, que la selección de las especies nativas por utilizar debe considerar las condiciones de degradación del sitio, y que las actividades de protección y mantenimiento se establecen de acuerdo con los requerimientos de cada especie y se efectúan hasta asegurar la permanencia de la plantación.

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Palabras clave: Compensación ambiental, ecosistema forestal semiárido, especies nativas, evaluación, mantenimiento, protección.

Introduction

The *Tamaulipas* thorn scrub (TTS) is a semi-arid ecosystem with a high diversity of tree and shrub species (Leal-Elizondo *et al*., 2018). During the last decades, the deterioration of this ecosystem has been increasing as a result of anthropogenic activities (Alanís-Rodríguez *et al.*, 2013). One way to reduce the environmental impacts caused to forest land is the application of environmental compensation measures (Cole *et al.*, 2021). Among these measures there are actions involved in ecological restoration, which consists of recovering the course of succession and resilience in an ecosystem that has suffered a disturbance (Gann *et al.*, 2019). This can be actively carried out by intervening in a site to accelerate its recovery, or passively, by stopping the disturbance and allowing the site to recover naturally (López-Barrera *et al*., 2016).

One of the actions applied in active restoration is reforestation (Sánchez *et al.*, 2005; Pequeño-Ledezma *et al.*, 2012), a non-natural process that consists of re-establishing forest vegetation induced by means of plantations in a determined area (Reyes *et al.,* 2019). Reforestation can focus on obtaining products for use or it can have the objective of ecosystem conservation, where the recovery of biodiversity is a priority, for which the use of native species is recommended (Cunningham *et al*., 2015).

In Mexico, the National Forest Commission (*Conafor*), the Secretary of National Defense (*Sedena*), state governments and social organizations have made great reforestation efforts. Between 1985 and 1998, an annual average of 78 500 ha year^{-1} was planted (Wightman and Cruz, 2003). From 2007 to 2012, *Conafor*, through the *ProÁrbol* program, achieved a national reforestation goal of 400 000 year^{-1}; and from 2013 to 2018 through the National Forest Program (*Pronafor*) a reforestation goal of 200 000 ha year^{-1} was accomplished (Prieto and Goche, 2016).

However, one of the greatest challenges has been to keep a survival level equal to or greater than that established by some national organizations such as *Conafor*, which usually requires a minimum 80 % survival of the plantation (Conafor, 2021). During the 2004 to 2016 period, external assessments to this institution showed annual percentages of survival by state and at the national level of different types of ecosystems, which yielded results between 30 and 53 %, with a general average of 43 % (Prieto *et al*., 2018).

Thus, it is important to monitor the survival of reforestation and communicate the experiences obtained in different types of ecosystems. This procedure consists of "a series of consecutive and periodic evaluations of quantitative and qualitative aspects of the vegetation of interest" (Prieto and Goche, 2016). The objective of these evaluations is to know the dynamics of the plantation in time and space, by determining parameters such as the number of living individuals and/or their phytosanitary status, as well as the technical circumstances that were not considered at the beginning of the plantation, in order to establish containment, protection and maintenance measures (Conafor, 2010).

These assessments can be carried out through censuses, however, due to the large amount of resources and time that this demands, it is recommended to measure a part of the population through sampling (Schreuder *et al*., 2006). A sample is taken to obtain representative data that demonstrates the existing variability in the population, with a level of reliability and estimation error (Ramírez, 2011).

Survival monitoring in a reforestation is usually applied annually and the period in which it is made will depend on the goal established for the project (Stein, 1992). For reforestation projects derived from an environmental impact condition, the Ministry of the Environment and Natural Resources (*Semarnat*) usually establishes periods of 5 to

10 years for maintenance and monitoring, although Conafor (2009) considers that the planted individuals are established when they have survived after three years. In the TTS, survival monitoring in reforestation with native species has been documented for direct planting in the field by seed and planting of plants from the nursery (Foroughbakhch *et al.*, 2001; Jurado *et al.*, 2006; García, 2011; Arias *et al.*, 2021).

Some of the studied reforestation conditions have been under dense and open scrub, different levels of water stress and temperatures below 0 °C, in competition with early successional weeds and with the use of individual tubular shelters (Foroughbakhch *et al.*, 2001; Jurado *et al.*, 2006; García, 2011; Alexander *et al.*, 2016; Arias *et al.*, 2021). Wide-ranging survival levels have been reported, from 0.4 % to 99 %, varying between the native species used and the natural or experimental conditions present. To date, the use of 18 native TTS species in reforestation has been published. The most frequently documented species are *Ebenopsis ebano* (Berland.) Barneby & J. W.Grimes, *Havardia pallens* (Benth.) Britton & Rose, *Senegalia berlandieri* (Benth.) Britton & Rose, *Vachellia rigidula* (Benth.) Seigler & Ebinger, *Senegalia wrightii* (A. Gray) Britton & Rose, *Cordia boissieri* A. DC. and *Prosopis glandulosa* Torr. None of these works has been carried out for reforestations greater than 3 600 individuals or a diversity greater than 10 native species.

The objective of this study was to evaluate the annual survival of a reforestation with 15 native species of the *Tamaulipas* thorn scrub during the three years after its establishment, as well as to examine its function within the ecosystem to counteract the impacts caused by the loss of vegetation.

Materials and Methods

Study area

The study area is located in the *Los Ramones* municipality at *Nuevo León* State, between 25°39'59.92" and 25°39'40.15" N and 99°27'27.35" and 99°27'24.99" W, at an average altitude of 185 m (Figure 1).

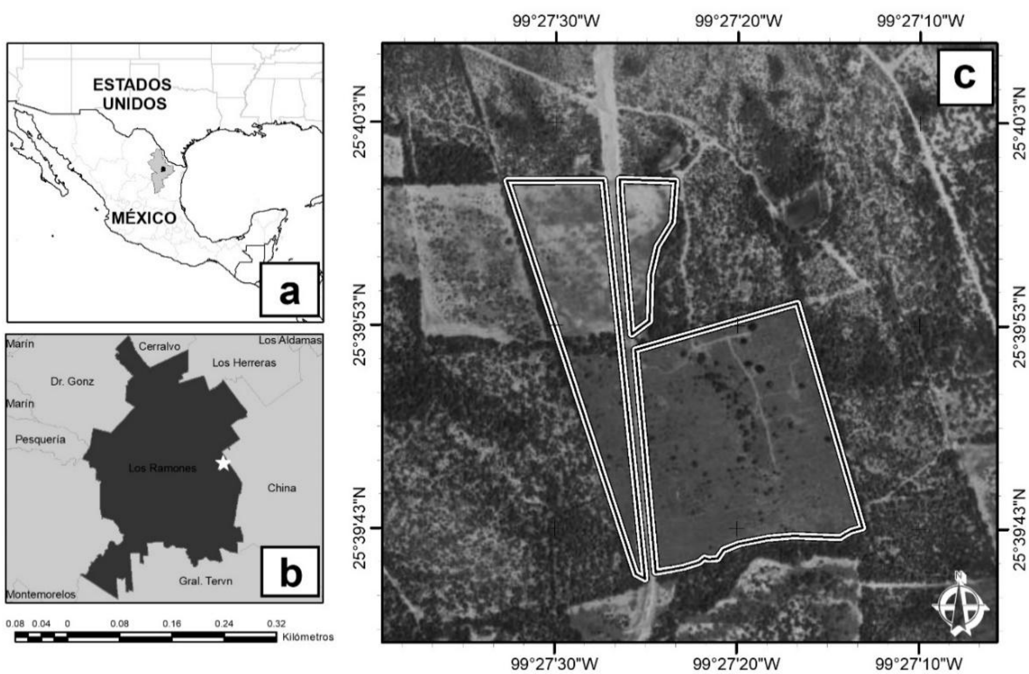

Figure 1. Study site: a) Representation of the state of *Nuevo León* in northeastern Mexico; b) Area of the *Los Ramones* municipality and location of the study area to the east; c) Satellite image showing the shape and size of the reforestation polygons.

The soils in the area are classified as Vertisol, Calcisol and Chernozem, with two types of texture, medium and fine. According to the Topographic Map G14C27 of the National Institute of Statistics and Geography (Inegi, 2019), the use of land and vegetation are recorded as Permanent Cultivated Pasture and Thorn Scrub. According to the classification of degrees of alteration of an ecosystem described by Conafor (2009), the site has a level II of alteration, since "it is significantly unbalanced, but there are still elements of the initial ecosystem that can be taken from reference to intuit which were the initial components of the system”. The climate is warm semi-arid from 22 to 24 °C, with rainfall between summer and winter greater than 18 % per year, according to Köppen's classification modified by García (2004).

Plantation establishment

In May 2018, the environmental impact resolution was issued for an electricity generation project in the *Los Ramones* municipality, *Nuevo León*. Among its conditions, it is specified to comply with a reforestation program, whose objectives were: “to compensate for the environmental impacts caused by the loss of vegetation, to restore possible nesting, shelter and feeding areas; as well as conserving and increasing the surface with vegetation”.

Based on the summer rainy season in the region (Figure 2), from September to December 2018, 12 596 plants of 15 native TTS species were planted (Table 1). The total reforestation area was 15.43 ha with a density of 816 plants per hectare, in a real frame design and a mixture of random species. The plantation area, number of individuals and species selection were determined according to those most frequently used, with high survival values in reforestation monitoring (Foroughbakhch *et al.*, 2001; Jurado *et al*., 2006; García, 2011; Alexander *et al*., 2016; Arias *et al.*, 2021).

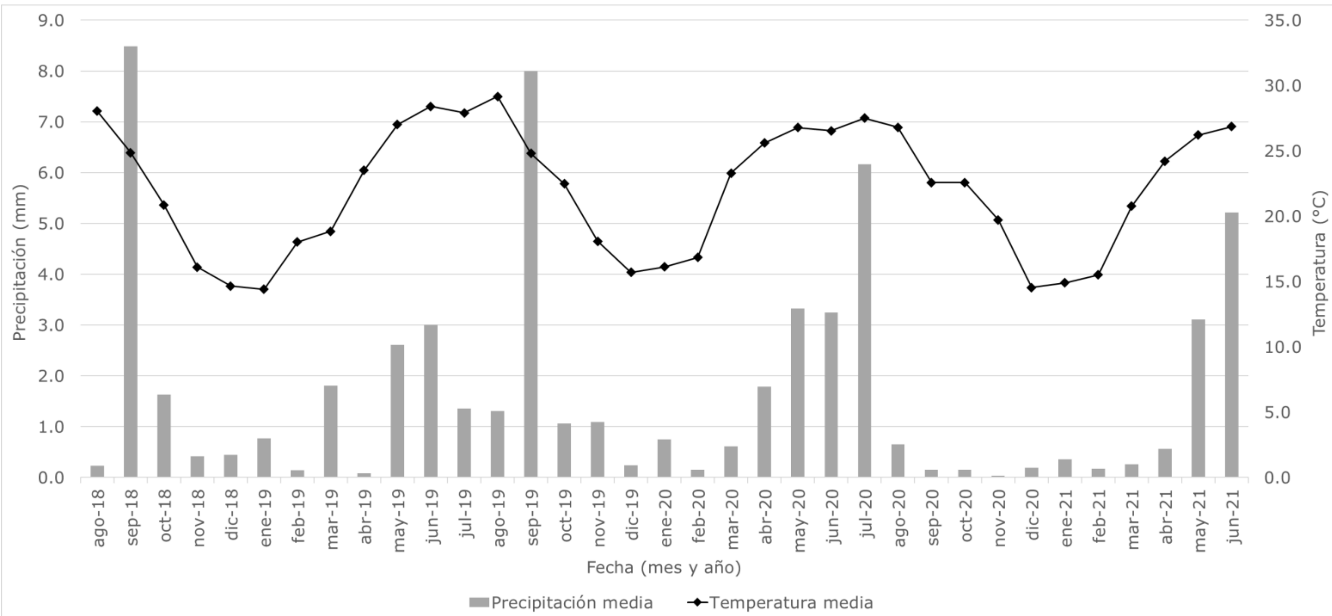

Figure 2. Monthly average temperature (°C) and precipitation (mm) in the reforestation and monitoring period (NASA, 2021).

Table 1. Native TTS species used in the reforestation essay in *Los Ramones, Nuevo León*.

Family	*Scientífic name*	*Common name*	*Established individuals*	*Surface (Ha)*
Cannabaceae	*Celtis pallida Torr.*	*Granjeno*	*512*	*0.63*
Rhamnaceae	*Condalia hookeri M. C. Johnst.*	*Brasil*	*378*	*0.46*
Boraginaceae	*Cordia boissieri A.DC.*	*Anacahuita*	*3 123*	*3.83*
Ebenaceae	*Diospyros texana Scheele*	*Chapote prieto*	*756*	*0.93*
Fabaceae	*Ebenopsis ebano (Berland.) Barneby & J. W.Grimes*	*Ébano*	*1 262*	*1.55*

Boraginaceae	*Ehretia anacua* (Terán & Berland.) I. M. Johnst.	*Anacua*	630	0.77
Fabaceae	*Erythrostemon mexicanus* (A. Gray.) Gagnon & G. P. Lewis	*Árbol de potro*	294	0.36
Fabaceae	*Havardia pallens* (Benth.) Britton & Rose	*Tenaza*	420	0.51
Fabaceae	*Parkinsonia aculeata* L.	*Retama*	848	1.04
Fabaceae	*Prosopis glandulosa* Torr.	*Mezquite dulce*	2 451	3.00
Fabaceae	*Senegalia berlandieri* (Benth.) Britton & Rose	*Guajillo*	596	0.73
Fabaceae	*Senegalia wrightii* (Benth.) Britton & Rose	*Uña de gato*	428	0.52
Fabaceae	*Vachellia farnesiana* (L.) Wight & Arn.	*Huizache*	504	0.62
Fabaceae	*Vachellia rigidula* (Benth.) Seigler & Ebinger	*Gavia*	50	0.06
Asparagaceae	*Yucca filifera* Chabaud	*Palma pita*	344	0.42
		Total	12 596	15.4301

Seedlings were produced in the forest nursery of the company GEMA S.C. in *Linares* city, *Nuevo León*. They were cultivated for six months in a 500 mL polyurethane bag, until they reached a minimum height of 0.30 m. They were planted inside circular holes 0.50 m deep x 0.35 m diameter, 3.5 m distant between them and 3.5 m between lines. Fine-grained agricultural hydrogel (Hydrogel MX) was added, based on the manufacturer's application recommendation of 3 g per 30 cm of plant height (Acua-Gel®, 2018), in order to prevent water stress in the face of the high temperatures of the region (Filio-Hernández *et al.*, 2019). Raizone-Plus Fax powder phytoregulator rooter (1.5 mg L^{-1}) was also used to promote vigorous root growth and recovery of possible wounds during the planting process (Fax México, 2018). Each individual was secured with 0.50 m wooden guides on its stem, and a high-density polyurethane perforated tubular protector 0.66 m long by 0.35 m high, fastened in a circular shape, was placed to avoid herbivory predation (Dick *et al.*, 2016; Mohsin *et al.*, 2021).

Maintenance activities

Based on the summer rainy periods in the region (Figure 2), during the months of October 2019 and August 2020, two maintenance activities recommended by Conafor (2010) were carried out: weed control and plant replacement. Weed control was carried out by manual removal of the invasive species *Cenchrus ciliaris* L., to facilitate the growth of the desired native species (Arias *et al*., 2021).

For the replacement of seedlings, the species identified with the highest mortality were replaced by species with the highest establishment success, in order to promote the highest possible survival of the plantation. In August 2020, the schedule of activities for the reforestation program ended, and so were the maintenance activities.

Sampling reliability

According to the methodology proposed by Stein (1992), the standard error of the total plantation population (s_p) and the confidence limits with a probability level of 80 % were determined; it was tested whether the sample size for the monitoring was statistically reliable by means of a two-tailed Student's t-test.

Survival anaysis

Three annual samplings were carried out to know the evolution of the plantation survival during September 2019, July 2020 and June 2021, based on the methodology proposed by the United States Department of Agriculture (USDA, 2018). Ten sampling lines distributed randomly and dispersed in each year were established; for each line 30 continuous plants were counted, recording their vigor and species (Mata-Balderas *et al.*, 2010). The following equation was used to calculate survival:

$$\% S = \left(\frac{pi}{p(N)}\right) * N$$

Where:

%S = Survival percentage

pi = Number of live plants

p(N) = Number of counted plants per each sampling line

N = Number of sampling lines

To standardize the replenishment dynamics during the first two years of reforestation and the year of monitoring without maintenance, the survival per species per year was calculated, followed by the average of the three years of monitoring per species. Likewise, the annual survival of the study area as a whole was analyzed and the survival of all species within each year of evaluation was added.

Results

For the reliability of sampling, a standard error of the proportion of 0.0262 was determined, with confidence limits of 0.287±0.04 for 80 % probability. The t-Student test yielded a sample size of 8.6 (n=8.6), below the 10 annual sampling lines that were made to assess survival (n=10), so the sample size is considered to be statistically reliable with a 0.20 level significance.

Survival

The survival of 15 native species of the TTS in a reforestation during the first three years of establishment was recorded from 1.11 to 16.43 % (Table 2). The species that recorded the highest survival were *Cordia boissieri* A. DC. and *Prosopis glandulosa* Torr. with 16.43 % and 10.67 %, respectively. Some species resulted in a range from 4.00 to 4.22 % such *as Vachellia rigidula* (Benth.) Seigler & Ebinger, *Vachellia farnesiana* (L.) Wight & Arn. and *Parkinsonia aculeate* L. The species with the lowest survival values were *Condalia hookeri* M. C.Johnst, *Senegalia berlandieri* (Benth.) Britton & Rose and *Senegalia wrightii* (A. Gray) Britton & Rose with values below 2 % and *Erythrostemon mexicanus* (A. Gray.) Gagnon & G.P. Lewis, *Havardia pallens* (Benth.) Britton & Rose and *Yucca filifera* Chabaud with values below 1 %.

Table 2. Mean survival values of the TTS native species used in reforestation in *Los Ramones, Nuevo León***.**

Scientific name	*%S mean ± e.e., n = 100*
Cordia boissieri A. DC.	*16.43 ± 6.11*
Prosopis glandulosa Torr.	*10.67 ± 5.21*
Ebenopsis ebano (Berland.) Barneby & J. W. Grimes	*7.56 ± 4.21*
Diospyros texana Scheele	*5.89 ± 4.12*
Ehretia anacua (Terán & Berland.) I. M. Johnst.	*5.22 ± 3.77*
Parkinsonia aculeata L.	*4.22 ± 1.44*
Vachellia farnesiana (L.) Wight & Arn.	*4.11 ± 2.23*
Vachellia rigidula (Benth.) Seigler & Ebinger	*4.00 ± 0.00*
Celtis pallida Torr.	*3.50 ± 0.5*
Senegalia berlandieri (Benth.) Britton & Rose	*2.44 ± 0.98*
Condalia hookeri M. C. Johnst.	*1.89 ± 1.16*
Senegalia wrightii (Benth.) Britton & Rose	*1.67 ± 1.08*
Havardia pallens Britton & Rose	*1.44 ± 1.06*
Yucca filifera Chabaud	*1.22 ± 0.75*
Erythrostemon mexicanus (A. Gray.) Gagnon & G.P. Lewis	*1.11 ± 0.71*

%S media = Mean survival; *e.e* = Standard error of the mean.

The reforestation annual survival percentage that was measured remained above 80 % during the first two years of establishment due to protection and maintenance efforts, resulting in 80.67 % for 2019 and 95.34 % for 2020. Once the protection and maintenance activities were suspended, a decrease was observed in the evaluated values of 2021 with 28.7 % survival (Figure 3).

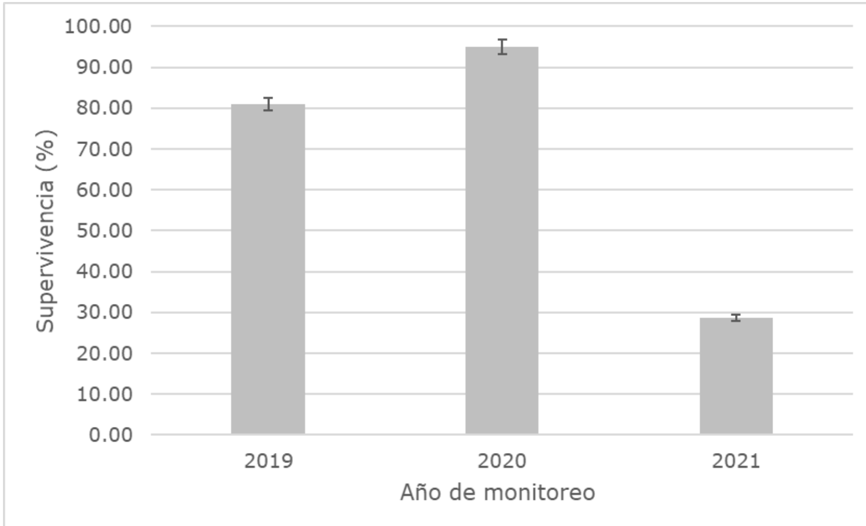

Figure 3. Total year reforestation survival at the TTS in Los Ramones, Nuevo León.

Discussion

In scrub reforestation of arid and semi-arid ecosystems, the survival of plantations is subject to extreme weather, herbivory and competition for resources (Alexander *et al*., 2016). Especially to weather events, such as the absence of rain or the incidence of drought or frost, which can significantly affect the plantation (Foroughbakhch *et al.*, 2011).

In northeastern Mexico in particular, frosts are repeated around every 10 years, and cause serious effects on TTS (Foroughbakhch *et al.*, 2011). In the frosts that impacted northeastern Mexico and southern Texas in 1983 and 1989, samples of *C. pallida* Torr, *H. pallens* and *E. ebano* (Berland.) Barneby & J.W. Grimes up to 6 m tall, suffered vigor loss from the base (Lonard and Judd, 1991). In the study area, from February 13th to 20th, 2021, there was a drop in temperature that reached -5 °C (AccuWeather, 2021), which is presumed to have adversely affected the plantation, since in the 2021 assessment, morphological damage was observed in several plant structures of the evaluated species from extreme minimum temperatures below the freezing point of water (0 °C) on seedlings; however, this was not tested experimentally. In the same way, García (2011) documented in dense scrub conditions that *E. mexicanus* (A. Gray.) Gagnon & G. P. Lewis*, C. pallida, C. boissieri* and *E. ebano* had higher survival values (3.7 – 6.6 %) for a year with rainfall of 716.8 mm. compared to a previous year with 154.8 mm.

On the other hand, the protection and maintenance activities during the first two years of the plantation were useful for the establishment of the species, but they did not seem to contribute greatly to the survival of the seedlings after their removal in 2021, since the percentage decreases drastically below the 80 % acceptable by Conafor (2021). For example, Mohsin *et al.* (2021) reported that *C. pallida* and *D. texana* Scheele had lower mortality a year after planting inside protective tubes, compared to other TTS species used in reforestation. These observations coincide with the study described here for *C. pallida*. González-Rodríguez *et al.* (2011) experimented with the water potential of four TTS species, and concluded that there are significant differences in their moisture content, which indicates that each species has a different tolerance to drought and therefore different irrigation requirements or use of supplements such as hydrogel.

It should be noted that no information was found related to the dynamics of the replacement of individuals that can occur in reforestation of the TTS, so it is suggested as an area of opportunity for future research.

In the same sense, a common mistake that is made in reforestation is that all species are given the same conditions for establishment and growth. Therefore, it is necessary to deepen the knowledge of the particular needs of the species to be used, especially during the first years of establishment, in order to propose maintenance activities specific to the characteristics of each species.

In regard to the composition of the species used, Domínguez-Gómez *et al.* (2013) refer that the good development of the *Fabaceae* family in the TTS is associated with its establishment ability in adverse environmental conditions. Foroughbakhck *et al.* (2011) points out the ability of this genus to fix nitrogen from the atmosphere to organic molecules. If the combination with trees that contain different levels of carbon and nitrogen concentration - such as *C. boissieri* (Maiti *et al*., 2016) - is added, a better humus quality in the ground is promoted, which in the long term, favors an improvement in soil structure; therefore, it is considered that this genus is essential to foster the plant succession process in the TTS.

Likewise, the highest importance values in the TTS in different areas with livestock and agricultural history are frequently supported by the species *V. farnesiana* (L.) Wight & Arn., *P. laevigata* and *Acacia amantacea* DC. (now *Vachellia rigidula*) (Pequeño-Ledezma *et al*., 2012; Alanís-Rodríguez *et al.,* 2013; Mora *et al*., 2013; Martínez *et al.,* 2014; Leal-Elizondo *et al.,* 2018; Sarmiento *et al.*, 2019). The regrowth of foliage, seeds and fruits of these species are usually highly consumed by livestock (Domínguez *et al*., 2012), which facilitates the scarification of the seeds through the digestive tract of the animals, which they are expelled back to the soil and create a reserve of seeds available for regrowth in the right weather conditions (Villarreal *et al.,* 2013; Rodríguez *et al.*, 2014). Particularly in the applied reforestation, *P. glandulosa*, *V. rigidula* and *V. farnesiana* maintained survival values between 4.00 and 10.67 %; therefore, for future reforestation projects in the TTS it is suggested to examine the available seed reservoir in the degraded areas to eliminate the possibility that these species could regrow with no assistance.

Meanwhile, *C. boissieri*, with greater establishment success, is not recorded in literature with the highest index of importance value in the composition of TTS; however, it is among the three most notorious species in areas recovered after livestock activity (Leal-Elizondo *et al*., 2018; Sarmiento-Muñoz *et al*., 2019).

The record of *P. glandulosa* with high survival values contrasts with the study by Foroughbakhch *et al.* (2001) that highlights *P. glandulosa* with the lowest survival percentage among 15 native species of the TTS evaluated under herbivore and pest conditions. Filio-Hernández *et al.* (2019) indicate that the use of *P. glandulosa* is recommended for restoration projects in arid zones, due to its ability to adapt to low water availability.

In some cases, the action of only excluding disturbance factors from an area is enough to recover the structure and functionality of the degraded ecosystem; however, this process is highly variable (Trujillo-Miranda *et al.*, 2018). Precisely, reforestation seeks to accelerate this regeneration for a greater diversity of timber plants and more advanced stages of succession in less time (Zahawi *et al.*, 2013). In this work we sought to reforest with a high diversity of TTS species and, although the most successful in the establishment (*C. boissieri* and *P. glandulosa*) are mentioned in stages of advanced succession of the TTS, not all species develop successfully. In this way, it is necessary to have greater knowledge about the area chosen to reforest, such as the characteristics of the soil, the seed reservoir and the presence of remnant vegetation.

The plantation must be incorporated into this dynamic, and the selection of species, as well as the management practices to be applied, must be chosen on time to obtain better results and, therefore, the absolute fulfillment of the committed environmental conditions.

Conclusions

According to the results of the reforestation assessments established in the TTS with 15 native species, the climatic conditions during the third monitoring (extreme minimum temperatures and low rainfall) affected the survival of the plantation. The selection of native species to be used must be made with respect to the degradation conditions of the site. Protection and maintenance activities must be established according to the requirements of each species and maintained until the permanent establishment of the plantation is ensured.

This evaluation offers valuable information on the stage of a reforestation project three years after being established in a TTS community.

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Conflict of interests

The authors declare no conflict of interest.

Contribution by author

José Manuel Mata Balderas: experimental design, plantation management and writing of the manuscript; Karen Alejandra Cavada Prado: data analysis, literature review and writing of the manuscript; Tania Isela Sarmiento Muñoz: writing of the manuscript, review of writing; Humberto González Rodríguez: review of data analysis and results.

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