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Article

# Factores ambientales y físicos que afectan la supervivencia de siete especies forestales en el Estado de México

# Environmental and physical factors affecting the survival of seven forest species in the State of Mexico

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**Resumen**

Esta investigación tuvo como objetivo evaluar el efecto de diferentes variables ambientales y físicas sobre la supervivencia de las siete especies más usadas para la reforestación en el Estado de México, durante el periodo 1997-2003. La evaluación se realizó a través de un muestreo de dos etapas de 757 plantaciones. En la primera, se seleccionaron aleatoriamente las plantaciones bajo un diseño completamente al azar. La segunda fase consistió en levantar sitios de muestreo de 100 m$^2$ elegidos de manera sistemática en cada una de las plantaciones seleccionadas, con una intensidad de muestreo de 5 % del área plantada. En los sitios se evaluó la supervivencia y un conjunto de variables de sitio. El análisis se realizó mediante un modelo *Probit*, en el cual se probaron todas las combinaciones de diferentes subconjuntos de variables de sitio y climáticas como variables de control. Los resultados mostraron que las plantaciones tienen una baja supervivencia (38 %), atribuible a la poca protección de las plantaciones, la rápida conversión a terreno agropecuario, así como a la desvinculación entre los requerimientos de cada especie y las características de los sitios de plantación. Se analiza y discute el efecto de las variables evaluadas por especie y se proporcionan recomendaciones de registro de información para las plantaciones.

**Palabras clave:** Evaluación, plantaciones forestales, *Probit*, restauración, supervivencia, variables de sitio.

**Abstract**

This research aims to assess the effect of different environmental variables on the survival of the seven species most used for reforestation in the State of Mexico along the 1997-2003 period. The evaluation was implemented through a two-stage sampling procedure in 757 plantations. In the first stage the plantations to be evaluated were chosen throughout a completely random design. In the second stage, a set of sites of 100 m$^2$ were systematically chosen in each selected plantation with a 5 % sampling intensity. Survival and a set of site variables were evaluated in each site. The analysis was performed through a Probit model by testing all combinations of different subsets of site and climate variables as independent variables. Results show low survival (38 %) in plantations, driven by low protection after plantations were established, the rapid conversion to agricultural land, as well as the disengagement between the environmental requirements of the species and the characteristics of the plantation sites. The effect of the environmental variables on each species is analyzed and discussed, and some suggestions for recording plantation information are highlighted.

**Key words:** Evaluation, forest plantations, Probit, restoration, survival, site variables.

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# Introduction

Restoration efforts in Mexico have been significant, both in terms of investment and in the diversity of strategies for promoting restoration activities (Carabias *et al*., 2007). However, most restoration incentive programs have had poor results (Burney *et al.*, 2015), either due to technical problems (species and site selection, plant quality, establishment technique or plantation management, among others), environmental problems (Carabias *et al.*, 2007, Sarukhán *et al.*, 2014), or the design of an appropriate incentive structure (amounts and dispersion of subsidies, indirect support, dispersion mechanisms, institutional design to manage incentives) to reduce cultural, economic or social barriers that limit the desirability and interest of the private sector to carry out restoration activities.

From a technical perspective, the success of forest plantation establishment depends on four factors: i) quality and relevance of the genetic material, ii) quality and type of vegetative material to be established in the field, iii) site characteristics and suitability for plantation establishment, and iv) care and management of the plant at the plantation site (Capó, 2001).

Although all four factors are important, most research attention in Mexico has focused on genetic material and plant quality, due to both the high cost of monitoring an established plantation and the misconception that reforestation work is concluded once the plantation has been established (Burney *et al*., 2015). Consequently, there is a wide variety of research results describing various morphological attributes (height, diameter and hardiness) of seedlings produced in different substrates, containers and conditions (Prieto, 2004; Prieto *et al.*, 2011) to achieve vegetative material with desirable attributes. In contrast, little work focuses on defining seedling production practices that align seedling and species quality with yield, survival and growth attributes at a given site (Mexal *et al*., 2002, 2008).

The effect of site conditions on the development of a plantation is usually determined by means of two methodological strategies. The most common is to set up a controlled experiment, in which different site conditions are tested within the spectrum of development of the species to be evaluated, usually limited to the conditions of a single locality. As a result, the extrapolation of results derived from these experiments is limited, since it is very difficult to find conditions similar to those of the place where the experiment is carried out.

However, the strategy can be efficient when testing for a limited number of factors with repetitions of the experiment in different locations. Examples of this site factor assessment methodology in Mexico include the work of Capó and Newton (1991); Román *et al.* (2007); Gómez-Romero *et al.* (2012); Yam-Chin *et al*. (2014); Sigala *et al.* (2015); Prieto *et al.* (2018); Barrera *et al.* (2018), and Muñoz-Flores *et al.* (2019).

The second strategy is the use of a natural experiment; that is, one or several already established plantations, where both the origin and characteristics of the seedling and the establishment technique are known. The procedure consists of taking samples with certain characteristics of randomness; this allows relating the site variables to the response variable under analysis. The procedure does not provide a direct line of causality, but helps to identify the plant and site variables most relevant to planting success. Examples of this site factor assessment methodology in Mexico include the work of Arteaga-Martínez (2000); Contreras and Rodríguez (2004); Muñoz *et al*. (2009; 2012); Montero *et al*. (2011), and Muñoz *et al.* (2011a).

The present study is a contribution to the identification of best practices for the establishment of forest plantations (Capó, 2001); its objective is the analysis of environmental and physical factors related to the survival of 5-10 year old plantations established in the State of Mexico. The work is important because it identifies the survival performance of seedlings of several species with similar physiological and morphological characteristics in different site conditions.

# Materials and Methods

## Sampling

The analysis of the factors affecting survival was based on the information derived from the evaluation of plantations established between 1997 and 2003 within the programs of afforestation, reforestation and commercial forest plantations of the Forest Protection Agency of the State of Mexico (*Protectora de Bosques del Estado de México,* Probosque). The sampling frame consisted of the beneficiaries of these programs (Figure 1), who were grouped into four regions of the State of Mexico: I *Toluca,* V *Atlacomulco*, VI *Coatepec Harinas*, and VII *Valle de Bravo*. The seedlings used in the reforestations came from six of the 18 nurseries that Probosque currently has.

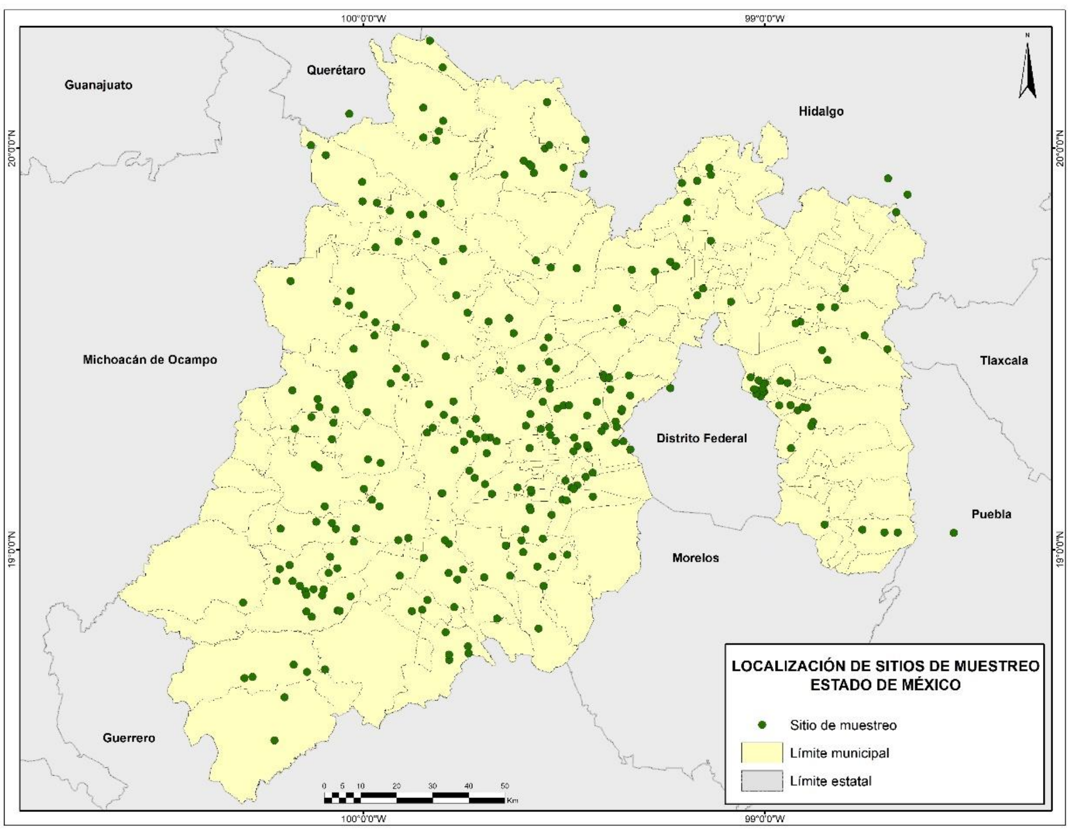


**Figure 1.** Distribution of plantations included in Probosque's benefit programs in the period 1997-2003.

The sample of the evaluated plantations was estimated based on a two-stage sampling design. In the first stage, the plantations to be evaluated were selected by simple random probability sampling, with a 95 % confidence interval. The area (ha) of the plantation was used as a variable indicative of the source of variation (mean = 2.16; standard deviation = 0.56). The sample size was 296 plantations out of a total of 757 (sampling fraction = 39 %) registered in the Probosque beneficiary register. In the second stage, each plantation was sampled systematically, with a sampling intensity of 5.0 % of the plantation area. Circular sampling sites of 100 $m^2$ (5.64 m radius) were used, with an East-West orientation (lines separated at 20 m and 100 m from site to site within each line). Table 1 shows the collected information.

**Table 1.** Information collected at each sampling site.

| Variable | Acronym | Categories |
|---|---|---|
| Survival | Surv | Living individuals / Total planted individuals |
| Tree Cover | Tree Cov | 1: 0-20 %, 2: 21-40 %; 3: 41-60 %; 4: 61-80 %; 5: 81-100 %; 0: Other |
| Erosion | Ero | 1: Not perceptible; 2: Light; 3: Intense; 4: Very intense; 0: Other |
| Exposure | Exp | 1: North; 2: South; 3: East; 4: West; 5: Zenithal; 6: Northeast; 7: Southeast; 8: Southwest; 9: Northwest; 0: Other |
| Physiography | Physio | 1: Valley; 2: Terrace; 3: Plain; 4: Ravine; 5: Plateau; 6: Slope; 7: Hills; 8: Lowland; 0: Other |
| Organic Matter | Org Matt | 1: Light, 2: Medium; 3: Thick; 4: Tepetate; 0: Other |
| Stoniness | Sto | 1: Light; 2: Medium; 3: Abundant; 0: Other |
| Slope | Slo | 1: 0-25 %; 2: 25-40 %; 3: Over 40 %; 0: Other |
| Soil depth | SoD | 1: 0-20 cm; 2: 21-40 cm; 3: Over 40%; 0: Other |
| Plantation protection | Plant Prot | 1: Close; 2: Vegetation; 3: Stone; 4: Other; 0: None |
| Soil texture | Text | 1: Fine; 2: Medium; 3: Coarse; 4: Other; 0: None |
| Vegetation type at the site | Veg Type | Other |
| | | **Climate information** |
| Precipitation (mm) | PP | 1: 50-100; 2: 100-150; 3: 150-200; 4: 200-300; 5: 300-400; 6: 400-500; 7: 500-600; 8: 600-800; 9: 800-1 000; 10: 1 000-1 200; 11: 1 200-1 500; 12: 1 500-1 800 |
| Temperature (°C) | T | 1: > 28; 2: 26-28; 3: 24-26; 4: 22-24; 5: 20-22; 6: 18-20; 7: 16-18; 8: 14-16; 9: 12-14; 10: 10-12; 11: 8-10; 12: 6-8; 13: 5-6; 14: 4-5 |
| Weather | W | 5: Cold; 4: Semi-cold; 3: Temperate; 2: Semi-warm; 1: Warm |

As a complement to the field information, climate data of the plantation sites —specifically, annual precipitation and average temperature— were obtained from Conabio's climate coverages for the State of Mexico (http://geoportal.conabio.gob.mx/descargas/mapas/imagen/96/clima500kgw). Table 1 shows the classification used in the analysis.

It is observed that the classification of the climate variables is aligned with the classification of the average temperatures.

## Analysis

The analysis assumes that the characteristics of the seedlings brought to the planting sites are similar for the species within each of the four selected regions in the entity. This is because the seedlings came from a limited number of nurseries, and the same production and plant management practices are applied in all the Probosque's regional nurseries involved. Therefore, the likely differential effect on survival that may be attributed to the quality of the seedlings can be approached using a model of fixed effects by region. This assumption may be very weak in a region such as *Toluca*, which has a larger number of nurseries; however, this is not the case for the remaining regions. For the analysis at species level, all sites with more than one taxon were eliminated in order to reduce the differential effect by species.

The first analysis was a characterization of the site factors associated with each species. For some variables a transformation was necessary in order to achieve a monotonic interpretation of the numerical value. Table 2 shows this recategorization of the qualitative variables, whose numerical interpretation is not direct and which had to be transformed into a new category.

**Table 2**. Transformations used in the analysis.

| Variable | Recategorization |
|---|---|
| Physiography | 1: Valley, Terrace, Plain, Plateau, and Lowland; 2: Hills; 3: Ravine and Slope; 0: Other |
| Exposure | -1: Southwest; -0.5: South, West; 0: Zenithal; 0.5: North, East; 1: Northeast; |
| Organic matter | *Tepetate* |

A second analysis consisted in determining the relationship between the survival of each species and the evaluated site factors, as well as the climate variables and the combinations of all variables. For this purpose, survival was considered as a variable with a 0 - 1 (0 - 100 %) interval and the following model was used to explore the effect of the site variables on survival:

$$s_{ik} = \sum \beta_j x_{ij} + \alpha_k D_k + e_i \qquad \forall\ i = 1, 2, ..n, j = 1,2, \dots 8,\ k = 1,2, \dots 8 \qquad \dots(1)$$

Where:

$s_{ik}$ = Survival of the *i^th^* site in the *k^th^* region of a particular species

$x_{ij}$ = Vector of *j* factors at the *i^th^* site

$\beta_j$ = Parameter vector characterizing each factor of the linear model

$D_k$ = Dichotomous variable associated with each region

$\alpha_k$ = Effect of each region (associated with difference in plant quality) and taking region I (*Toluca*) as a reference

$e_i$ = Random error

Given the characteristics of $s_{ik}$ (variable bounded to the interval 0-1), it was necessary to use a qualitative dependent variable model, such as the Probit model. This type of model allows predicting the probability of occurrence (interval 0-1) of a variable based on a set of independent variables. Since the probability is in an interval (0-1), as is the survival, the Probit model satisfies the requirement of a dependent variable within this interval, while reducing estimation biases derived from the use of transformations or restricted adjustments (Maddala, 1986). The analysis was carried out by evaluating all possible combinations of dependent variables in model (1), using the econometric package EViews® 11 (https://www.eviews.com/home.html). The selection of the best-fitting model was based on the likelihood ratio statistics, $\chi^2$, and parsimony of the model, as well as on the quality of the estimators, evaluated by their statistical significance.

# Results

## General statistics of the evaluated plantations

The evaluated plantations are composed of approximately 30 species distributed over a wide range of altitudinal, site and climate conditions. However, the analysis was carried out exclusively for taxa with a high frequency of sampled sites (more than 99 sites) and only where they were growing in pure form. The seven species that met these attributes were: *Cupressus lindleyi* Klotzsch ex Endl., *Pinus ayacahuite* Ehrenb. ex Schltdl., *Pinus greggii* Engelm. ex Parl., *Pinus michoacana* Martínez, *Pinus montezumae* Lamb., *Pinus patula* Schiede ex Schltdl. & Cham., and *Pinus pseudostrobus* Lindl. Table 3 summarizes the environmental characteristics of the sites evaluated for each selected species. The survival rate of *P. pseudostrobus* and *P. michoacana* stands out, being above 50 %, while that of *P. montezumae* and *P. greggii* is almost 33 %.

**Table 3.** Average environmental and physical characteristics of the evaluated sites.

| Species | No of sites | Surv | Alt | Veg Type | Tree Cov | Text | Ero | Slo | SoD | Sto | Plant Prot | Physio | Exp | Org Matt | PP | T |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Cupressus lindleyi* Klotzsch ex Endl. | 885 | 34.64 | 2 468.14 | 1.93 | 1.06 | 1.81 | 1.92 | 1.50 | 1.52 | 1.96 | 1.17 | 1.52 | -0.08 | 1.29 | 920 | 20 |
| | | (39.67) | (311.35) | (1.06) | (0.53) | (0.70) | (1.00) | (0.67) | (0.63) | (1.13) | (1.28) | (0.54) | (0.43) | (0.77) | (244.3) | (3.9) |
| *Pinus ayacahuite* Ehrenb. ex Schltdl. | 250 | 39.11 | 2 814.54 | 1.89 | 1.24 | 1.46 | 1.02 | 1.04 | 1.59 | 0.76 | 0.48 | 1.78 | -0.05 | 1.43 | 907 | 19 |
| | | (39.86) | (272.66) | (1.33) | (0.84) | (0.63) | (0.42) | (0.44) | (0.87) | (0.76) | (0.62) | (0.42) | (0.64) | (0.63) | (89.5) | (2.8) |
| *Pinus greggii* Engelm. ex Parl. | 330 | 31.45 | 2 629.36 | 1.82 | 1.21 | 1.66 | 1.74 | 1.29 | 1.47 | 1.64 | 0.45 | 1.67 | -0.18 | 1.38 | 879 | 18 |
| | | (38.21) | (414.10) | (1.13) | (0.87) | (0.68) | (1.16) | (0.60) | (0.85) | (1.08) | (0.81) | (0.47) | (0.46) | (0.71) | (140.2) | (3.1) |
| *Pinus michoacana* Mart. | 99 | 51.88 | 2 565.03 | 2.15 | 1.00 | 1.68 | 1.46 | 1.00 | 1.31 | 0.87 | 0.32 | 1.65 | -0.10 | 1.22 | 918 | 17 |
| | | (44.16) | (308.45) | (1.48) | (0.76) | (1.10) | (1.05) | (0.64) | (0.89) | (1.07) | (0.47) | (0.69) | (0.20) | (0.84) | (98.7) | (2.9) |
| *Pinus montezumae* Lamb. | 235 | 33.06 | 2 972.09 | 1.69 | 1.22 | 2.03 | 1.56 | 1.22 | 1.39 | 1.18 | 0.18 | 1.51 | -0.04 | 1.36 | 863 | 18 |
| | | (41.14) | (505.62) | (1.22) | (0.61) | (0.45) | (0.64) | (0.58) | (0.76) | (1.02) | (0.38) | (0.50) | (0.44) | (0.51) | (140.3) | (3.8) |
| *Pinus patula* Schiede ex Schltdl. & Cham | 361 | 44.20 | 2 845.73 | 1.77 | 1.01 | 1.62 | 1.56 | 1.28 | 1.30 | 1.39 | 0.33 | 1.76 | -0.20 | 1.35 | 897 | 17 |
| | | (41.04) | (357.95) | (1.22) | (0.41) | (0.71) | (0.90) | (0.66) | (0.77) | (1.04) | (0.59) | (0.45) | (0.61) | (0.65) | (180.3) | (3.6) |
| *Pinus pseudostrobus* Lindl. | 107 | 55.70 | 2 571.82 | 2.47 | 1.32 | 2.02 | 1.32 | 0.87 | 1.47 | 1.01 | 0.40 | 1.82 | -0.41 | 1.50 | 903 | 18 |
| | | (40.69) | (550.27) | (1.18) | (0.81) | (0.69) | (0.54) | (0.44) | (0.68) | (1.00) | (0.49) | (0.38) | (0.44) | (0.69) | (120.2) | (4.1) |

Surv = Survival; Alt = Altitude; Veg Type = Vegetation type; Tree Cov = Tree cover; Text = Soil texture; Ero = Erosion; Slo = Slope; SoD = Soil depth; Sto = Stoniness; Plant Prot = Plantation protection; Physio = Physiography; Exp = Exposure; Org Matt = Organic Matter; PP = Precipitation; T = Temperature. Values in parentheses are standard deviations.

Most of the plantations were established in grassland and shrublands with very low tree cover densities; only *Pinus pseudostrobus* was established in grassland and shrubland areas, with low to medium densities. Most of the soils had fine to medium textures. Only those on which *P. pseudostrobus* and *P. montezumae* grew had coarser textures.

## Factors that contribute to species survival

The effect of each environmental factor on survival differs by species (Table 4). The vegetation type (Veg Type) at the planting site consistently appears to have a positive (linear) relationship with survival; an increased presence of natural vegetation with a good cover improves survival (protective effect of the regrowth). The same applies to the physiography (Physio): sites with irregular physiographic conditions exhibited better survival rates.

**Table 4.** Correlation between the survival rates and environmental factors.

| Species | Alt | Veg Type | Tree Cov | Text | Ero | Slo | SoD | Slo | Plant Prot | Physio | Exp | Org Matt | PP | T |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Cupressus lindleyi* Klotzsch ex Endl. | 0.183 | 0.153 | 0.199 | -0.012 | -0.209 | -0.169 | -0.111 | -0.327 | -0.316 | 0.362 | -0.144 | -0.066 | 0.080 | -0.015 |
| *Pinus ayacahuite* Ehrenb. ex Schltdl. | -0.062 | 0.140 | 0.204 | 0.188 | -0.176 | 0.069 | 0.338 | -0.263 | -0.114 | 0.222 | 0.212 | 0.344 | -0.097 | -0.020 |
| *Pinus greggii* Engelm. ex Parl. | 0.041 | 0.151 | 0.165 | -0.061 | -0.135 | -0.180 | 0.025 | -0.220 | 0.079 | 0.033 | -0.210 | -0.126 | 0.056 | -0.041 |
| *Pinus michoacana* Mart. | -0.420 | 0.090 | -0.022 | -0.073 | 0.174 | -0.078 | -0.018 | -0.351 | -0.240 | 0.101 | 0.265 | 0.023 | -0.011 | -0.138 |
| *Pinus montezumae* Lamb. | -0.334 | 0.224 | 0.032 | 0.038 | -0.029 | 0.253 | 0.173 | -0.163 | 0.233 | 0.324 | -0.198 | 0.147 | -0.240 | 0.034 |
| *Pinus patula* Schiede ex Schltdl. & Cham | 0.159 | -0.067 | -0.239 | -0.310 | -0.147 | -0.340 | -0.040 | -0.319 | 0.019 | 0.024 | -0.247 | -0.111 | 0.032 | 0.070 |
| *Pinus pseudostrobus* Lindl. | 0.506 | 0.477 | 0.230 | -0.248 | -0.345 | -0.238 | 0.131 | -0.368 | 0.264 | -0.377 | -0.427 | 0.398 | 0.260 | 0.090 |

Alt = Altitude; Veg Type = Vegetation type; Tree Cov = Tree cover; Text = Soil texture; Ero = Erosion; Slo = Slope; SoD = Soil depth; Sto = Stoniness; Plant Prot = Plantation protection; Physio = Physiography; Exp = Exposure; Org Matt = Organic Matter; PP = Precipitation; T = Temperature.

The best fits of model (1) for the evaluated species are shown in Table 5. The overall performance of the various factors tested in relation to survival was as follows:

- The adjustments have a low predictive power; however, the estimators related to the variables with the greatest impact on the survival of each species were statistically significant.
- No regional differences in the survival rate of the evaluated species: variables related to regions are non-significant.
- The variables Precipitation, Mean Temperature, Stoniness, Tree Cover, Planting Protection, and Organic Matter Content did not show a statistically significant relationship with survival in the Probit model.
- There is a negative effect of altitude on survival for species established outside their natural altitudinal range.
- Increased natural cover at the planting site has a positive effect on survival.
- Increased erosion at the planting site has a negative effect on the survival of most species. This effect is reversed in sites with deeper soils.
- The physiography of low hills favors the survival of some species.
- The exposure of the plantation is closely linked to the tolerance of the species to shade; tolerant species show better survival in shaded exposures.

**Table 5.** Improved fits to the Probit survival model.

| Species | *Cupressus lindleyi* | *Pinus ayacahuite* | *Pinus greggii* | *Pinus michoacana* | *Pinus montezumae* | *Pinus patula* | *Pinus pseudostrobus* |
|---|---|---|---|---|---|---|---|
| Altitude | 0.001*** (0.000) | -0.001*** (0.000) | | -0.003*** (0.001) | | 0.001*** (0.000) | 0.003*** (0.001) |
| Vegetation type | 0.129*** (0.447) | 0.147*** (0.069) | | | | | |
| Soil texture | 0.200*** (0.069) | 0.463*** (0.161) | | | -0.708*** (0.244) | -0.686*** (0.119) | -1.400*** (0.353) |
| Erosion | 0.132*** (0.051) | -1.010*** (0.240) | -0.162*** (0.075) | -0.857*** (0.353) | 0.610*** (0.192) | | |
| Slope | | | -0.404*** (0.154) | | 0.377** (0.194) | -0.663*** (0.124) | -1.889*** (0.631) |
| Soil depth | | | | 0.545* (0.330) | 0.410*** (0.155) | | 1.765*** (0.737) |
| Physiography | | | 0.565*** (0.176) | 1.280*** (0.469) | | 0.807*** (0.174) | |
| Exposure | -0.330*** (0.105) | 0.423*** (0.136) | -0.478*** (0.159) | 4.240*** (1.783) | | -0.457*** (0.125) | |
| Region I | -1.955*** (0.425) | 2.231*** (0.822) | -0.153 NS (0.257) | 6.139*** (3.029) | 2.713*** (0.868) | -1.842*** (0.766) | -4.295*** (2.071) |
| Likelihood log | -543.140 | -150.555 | -212.082 | -53.166 | -142.036 | -185.470 | -30.910 |
| Prob > $\chi^2$ | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Pseudo $R^2$ | 0.050 | 0.090 | 0.071 | 0.187 | 0.128 | 0.229 | 0.457 |
| No. of observations | 889 | 250 | 330 | 99 | 235 | 361 | 107 |

Values in parentheses correspond to standard errors of the estimator. Consider significance according to: *** $p<0.01$, ** $p<0.05$, * $p<0.1$, NS = Not Significant.

The results at the species level (Table 5) were the following:

*Cupressus lindleyi*: survival is slightly better at higher altitudes, in sites with more natural cover, coarser soil textures and drier exposures; these results are similar to those obtained in other regions (Luoga *et al*. 1994). Interestingly, survival is better at sites with greater erosion than in sites with better soil condition. This last result may be associated with the greater number of eroded sites planted with this taxon (Table 3).

*Pinus ayacahuite*: survival improves when the species is planted at lower altitudes within its natural altitudinal range (1 600-3 600 m), on sites with a light vegetation cover, coarse-textured soils, little erosion, and shaded exposures. These sites that coincide with the requirements of the species (although there is a high variation) cited by several authors (Farfán *et al.*, 2002); however, the estimated survival was very low.

*Pinus greggii*: this species and *Cupressus lindleyi* were established in sites of lower quality (soil, erosion and higher altitudinal range). The natural habitat of the taxon is characterized by sites with altitudes ranging from 1 300 to 3 100 m, with thin, stony soils, usually poor in organic matter (Flores *et al.,* 2011b), and whose survival in conditions outside their range is outstanding (Gómez-Romero, *et al*., 2012). However, the results showed a low survival, compared to other sites in Mexico where it has exhibited a value above 50 % (Muñoz *et al.*, 2012). According to the present study, survival improves substantially in sites with low erosion, low slope, flat to hilly physiography, and dry exposures.

*Pinus michoacana*: survival improves in plantations established at lower altitudes within their natural altitudinal range (1 500-2 500 m), in locations with less erosion, greater soil depth, flat to undulating physiography and shaded exposures. Survival was highest at lower altitudes; this may be due to the higher temperatures, a variable that has an enormous impact on the survival of the species in *Michoacán*, particularly in locations with abundant humidity (Cázarez, 2017). However, the estimated survival is lower than that reported in other plantation evaluations (Gómez-Romero *et al*., 2012; Cázarez, 2017).

*Pinus montezumae*: Survival was favored in soils with more clayey textures, less erosion, moderate slopes, and deep soils. The observed survival is within the confidence limits indicated by other authors (Barrera *et al.*, 2018). Exposure turned out to have no significance on survival, as documented by Robles *et al.* (2017).

*Pinus patula*: survival improves at higher altitudes within the interval in which it was planted (2 100-3 500 masl), in sites with clayey textures and low slope, with hilly physiography and good sun exposure. However, it was significantly lower than the survival achieved in plantations in their natural habitat and with site conditioning treatments (Sosa-Pérez and Rodríguez-Trejo, 2003).

*Pinus pseudostrobus*: Survival improves at higher altitudes within the interval in which this species was planted (1 400-3 500 masl); this result is consistent with those obtained by Flores *et al.* (2011b), who report that the species has better survival at altitudes between 2 200 and 3 000 masl. Likewise, survival increases in sites with deep, clayey textures and with little slope, as pointed out by Flores *et al.* (2011b). The estimated survival rate is similar to that recorded in plantations in the state of *Michoacán* (Gómez-Romero *et al.,* 2012; Sigala *et al.,* 2015; Barrera *et al.,* 2018; Muñoz-Flores *et al.,* 2019).

## Discussion

The analysis showed that variables such as plantation protection and tree cover have a wide variation, which made convergence difficult in the estimation of the parameters of the Probit model that includes these variables. All models presented in Table 5 achieved convergence, acceptable statistical significance, and good quality estimators. However, the adjustments can only be used to characterize the relationships between environmental variables and survival, given that the adjustments lack a good predictive level, most likely due to a set of unobservable variables —quality, plant management, method and date of establishment—, which may have had an impact on the establishment of plantations, particularly in species like *Pinus greggii* and *P. patula*.

The variables precipitation, average temperature, stoniness, tree cover, planting protection, and organic matter content were not significant, although they are considered essential for the establishment of the plantation. This is attributable to the low variation of these variables within the evaluated plantations (Table 3), and to the fact that variables such as altitude seem to function as a regional proxy for temperature and precipitation.

The results show that the plantation protection variable is so low that it has no effect on plantation performance.

Slope had a negative sign in some species, which would seem illogical; however, it is a reflection of the strong effect of the immediate land use change from newly established forest plantations to agricultural use, as has been extensively documented by several authors (Mexal *et al*., 2008; Burney *et al.,* 2015). The relationship shows that land with low slopes is more desirable for land use change, and, therefore, better survival rates are achieved on steeper slopes and on hilly terrain.

The tree cover variable was not significant, most likely as a result of its high correlation with vegetation type, which was significant for the performance of shade-tolerant species. A similar correlation effect was observed with the organic matter content variable, which is related directly to soil depth and indirectly associated with erosion and slope.

The vegetation type variable showed a significant positive effect on the survival of *Cupressus lindleyi* and of *P. ayacahuite*; this suggests that a greater presence of other herbaceous or shrub species (according to the results) improves survival. The effect has been documented by other authors, in terms of seedling protection (Espinosa *et al*., 2008), or has been ascribed to the potential nurse-plant effect of certain shrubs or herbaceous (Ramírez-Contreras and Rodríguez-Trejo, 2009).

The dichotomous variables related to regional differences were not statistically significant, which indicates that survival is independent of region. If we consider that regions also have a diversity of site conditions, the likely source of uncontrolled variation would appear to be no different among the different regions of the entity.

This hypothesis implicitly suggests that the poor survival performance of the evaluated plantations can be attributed to poor plant quality, as well as to problems in the selection of planting sites and the method and date of planting (variables not included in the analysis). The two latter factors point to the limited compatibility that exists between the requirements of the species and the characteristics of the planting sites; this is very evident in the characterization of the environmental variables and in the evaluation of survival using the Probit model.

This hypothesis highlights the importance of including in plantation evaluations some indicator(s) of both plant quality (i.e., stem width, plant height, root characteristics, mycorrhizal quantity) and planting method, as well as seedling transport and in-field handling characteristics (i.e., shipment, type of transportation, unloading); as these variables have an impact on the performance of the plantations. Examples of these considerations are the works of Muñoz *et al*. (2013), Robles *et al*. (2017) and Prieto *et al*. (2018). The incorporation of these as control variables into a survival or growth analysis improves discrimination between the different effects of the environmental and post-planting management (plantation protection) variables.

Monitoring of the entire production chain in the establishment of a plantation is essential for carrying out good establishment practices. However, it requires capacity building among the various actors involved in the process, as well as the development of monitoring and reporting protocols, from seed collection / production to plant production to plant transportation to the establishment (date and method of planting) and management of the plantation. These actors must provide sufficient information so that the established plantations can be considered in the future as true natural experiments useful for evaluating the performance of different species under different site conditions. Such protocols will become increasingly important in the near future, as more and better information is needed to assess species adaptation in the presence of climate change (Galicia, 2017), as well as of changes in nutrient cycles and drastic modifications in the soils.

# Conclusions

Results show that plantations have a low survival rate (38 %), mainly attributable to the low protection of the plantations and the fast conversion to agricultural land. There are no differences by region that can be linked to differences in plant quality from different nurseries. However, there is a notorious lack of association between the basic requirements of the species in terms of altitudinal range, shade tolerance, soil type and depth, physiography and care of the plantation, and the sites chosen for planting. The success of future restoration actions will demand updated, relevant and evidence-based information in order to apply adequate public policy instruments to help improve the results of forest restoration programs, as well as basic technical information from plantation performance evaluation studies relating the requirements of the seedlings of each species in the field with the characteristics of the plantation sites.

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### Conflict of interest

The author declares no conflict of interests.

### References

Arteaga-Martínez, B. 2000. Evaluación dasométrica de plantaciones de cuatro especies de pinos en Ayotoxtla, Guerrero. Revista Chapingo: Serie Ciencias Forestales y del Ambiente 6(2): 151-157. https://revistas.chapingo.mx/forestales/?section=articles&subsec=issues&numero=22 (6 de junio de 2020).

Barrera R., R., R. López A. and J. Muñoz F. 2018. Survival and growth of *Pinus pseudostrobus* Lindl. and *Pinus montezumae* Lamb. on different planting dates. Revista Mexicana de Ciencias Forestales 9(50): 323-341. Doi:10.29298/rmcf.v9i50.245.

Burney, O., A. Aldrete, A., R. Álvarez R., J. A. Prieto R., J. R. Sánchez V. and J. G. Mexal.2015. México—Addressing challenges to reforestation. Journal of Forestry 113(4): 404- 413. Doi:10.5849/jof.14-007.

Capó A., M. Á. and M. Newton. 1991. Survival and growth of five species of *Pinus* seedlings after different approaches to competition control: bridging studies between Oregon and Mexico. New Forests 5:219-238. Doi:10.1007/BF00028113.

Capó A., M. Á. 2001. Establecimiento de plantaciones forestales: Los ingredientes del éxito. Dpto Forestal, UAAAN. Saltillo, Coah. México. 207 p.

Carabias, J., V. Arriaga y V. C. Gutiérrez. 2007. Las políticas públicas de la restauración ambiental en México: limitantes, avances, rezagos y retos. Boletín de la Sociedad Botánica de México (80): 85-100. Doi:10.17129/botsci.1759.

Cázarez, M. R. 2017. Afforestation with the Purpose of Restoring the Protected Natural Area "Cerro del Punhuato", Morelia, Michoacán. Modern Environmental Science and Engineering 3(9):653-660. Doi: 10.15341/mese(2333-2581)/09.03.2017/006.

Contreras, A. R. y D. A. Rodríguez T. 2004. Efecto de calidad de planta, exposición y micrositio en una plantación de *Quercus rugosa*. Revista Chapingo. Serie ciencias forestales y del ambiente 10(1):5-11. https://www.redalyc.org/pdf/629/62910101.pdf (17 de agosto de 2020).

Espinosa, U., J. F. Sánchez, L. G. Ramírez y R. I. Sánchez. 2008. Reforestación con especies nativas: el caso del mirador Estribo Chico, Pátzcuaro, Mich. Revista Latinoamericana de Recursos Naturales 4(2):248-255. http://revista.itson.edu.mx/index.php/rlrn/article/view/131 (5 de junio de 2020).

Farfán V., E. G., J. Jasso M., J. López U., J. Vargas H. y C. Ramírez H. 2002. Parámetros genéticos y eficiencia de la selección temprana en *Pinus ayacahuite* Ehren. var. *ayacahuite*. Revista Fitotecnia Mexicana 25(3): 239-246. https://www.redalyc.org/pdf/610/61025302.pdf (15 de junio de 2020).

Galicia, L. 2017. Tropical and highland temperate forest plantations in Mexico:pathways for climate change mitigation and ecosystem services delivery. Forests 8(12): 489. Doi:10.3390/f8120489.

Gómez-Romero, M., J. C. Soto-Correa, J. A. Blanco-García, C. Sáenz-Romero, J. Villegas y R. Lindig-Cisneros. 2012. Estudio de especies de pino para restauración de sitios degradados. Agrociencia 46(8): 795-807. http://www.scielo.org.mx/pdf/agro/v46n8/v46n8a5.pdf (27 de julio de 2020).

Luoga, E. J., Chamshama, S. A. O. and S. Iddi. 1994. Survival, Growth, Yield and Wood Quality of a Species and Provenance Trial of *Cupressus lusitanica, Cupressus lindleyi* and *Cupressus benthamii* at Hambalawei, Lushoto, Tanzania. Silvae genetica 43(4):190-195. http://www.sauerlaender-verlag.com/CMS/fileadmin/content/dokument/archiv/silvaegenetica/43_1994/43-4-190.pdf (12 de agosto de 2020).

Maddala, G. S. 1986. Limited-dependent and qualitative variables in econometrics. Vol. 3. Cambridge University Press. Cambridge, UK. 423 p.

Mexal, J. G., R. A. Cuevas R., P. Negreros-Castillo and P. Paraguirre L. 2002. Nursery production practices affect survival and growth of tropical hardwoods in Quintana Roo, Mexico. Forest Ecology and Management 168(1–3):125–133. Doi:10.1016/S0378-1127(01)00735-6.

Mexal, J. G., R. A. Cuevas R. and T. D. Landis. 2008. Reforestation success in central Mexico: factors determining survival and early growth. Tree planters' notes 53(1):16-21. https://agris.fao.org/agris-search/search.do?recordID=US201301607143 (12 de julio de 2020).

Montero S., F. M., J. I. Valdez Hernández, H. M. de los Santos P., V. M. Cetina A. y L.R. Sánchez V. 2011. Crecimiento inicial de especies arbóreas multipropósito en un terreno ganadero del norte de Veracruz. Revista mexicana de ciencias forestales 2(3): 53-68. Doi: 10.29298/rmcf.v2i3.631.

Muñoz, H. J., V. M. Coria Á., J. J. García S. y M. Balam C. 2009. Evaluación de una plantación de tres especies tropicales de rápido crecimiento en Nuevo Urecho, Mich. Ciencia forestal en México 34(106): 61-87. http://www.scielo.org.mx/pdf/cfm/v34n106/v34n106a4.pdf (15 de julio de 2020).

Muñoz F., H. J., G. Orozco G., V. M.Coria A., J. J. García S., Y Muñoz V. y G. S. Cruz, 2011a. Evaluación de *Pinus pseudostrobus* Lindl. y *Pinus greggii* Engelm. con dos densidades de plantación en Michoacán, México. Foresta Veracruzana 13(1):29-35. https://www.redalyc.org/pdf/497/49719786005.pdf (18 de julio de 2020).

Muñoz F., H. J., J. T. Sáenz R., J. J. García S., E. Hernández M. y J. A. Contreras. 2011b. Áreas potenciales para establecer plantaciones forestales comerciales de *Pinus pseudostrobus* Lindl. y *Pinus greggii* Engelm. en Michoacán. Revista Mexicana de Ciencias Forestales 2(5):29-44. Doi: 10.29298/rmcf.v2i5.585.

Muñoz F., H. J., V. M. Coria A., J. J. García S., E. Velasco B. y G. Martínez M. 2012. Evaluación de una plantación de *Pinus greggii* Engelm. con dos espaciamientos. Revista mexicana de ciencias forestales 3(11): 57-70. Doi: 10.29298/rmcf.v3i11.517.

Muñoz F., H. J., J. J. García M., G. Orozco G., V. M. Coria Á. y M. B. Nájera-Rincón, M. B. 2013. Evaluación de una plantación con dos especies tropicales cultivadas en diferentes tipos de envases. Revista mexicana de ciencias forestales 4(18): 28-43. Doi: 10.29298/rmcf.v4i18.387.

Muñoz-Flores, H. J., J. T. Sáenz-Reyes, R. Barrera-Ramírez, J. Hernández-Ramos, J. J. García-Magaña and D. Castillo-Quiroz. 2019. Planting dates and their influence on the development of *Pinus pseudostrobus* Lindl., in Michoacán, Mexico. Revista Bio Ciencias 6: e524. Doi:10.15741/revbio.06.e524.

Prieto R., J. A. 2004. Factores que influyen en la producción de planta de *Pinus* spp. en vivero y en su establecimiento en campo. Tesis Doctoral. Universidad Autónoma de Nuevo León. Monterrey, N.L., México. 131 p.

Prieto R., J. A., J. T. Sáenz R., M. Alarcón B., A. Rueda S. y J. D. Benavides S. 2011. Indicadores de calidad de planta en viveros forestales de la Sierra Madre Occidental. Capítulo II Materiales y Métodos. Campo Experimental Valle del Guadiana CIRNOC, INIFAP. Libro técnico Núm. 3. Durango, Dgo., México. pp. 23-30.

Prieto R., J. Á., A. Duarte S., J. R. Goche T., M. M. González O. y M. A. Pulgarín G. 2018. Supervivencia y crecimiento de dos especies forestales, con base en la morfología inicial al plantarse. Revista mexicana de ciencias forestales 9(47): 151-168. Doi:10.29298/rmcf.v9i47.182.

Ramírez-Contreras, A. y D.A. Rodríguez-Trejo. 2009. Plantas nodriza en la reforestación con *Pinus hartwegii* Lindl. Revista Chapingo. Serie ciencias forestales y del ambiente 15(1): 43-48. http://www.scielo.org.mx/pdf/rcscfa/v15n1/v15n1a5.pdf (5 de junio de 2020).

Robles V., F., D. A. Rodríguez T. and A. Villanueva M. 2017. Plant quality and survival in *Pinus montezumae* Lamb. Reforestation. Revista mexicana de Ciencias Forestales 8(42): 55-76. http://www.scielo.org.mx/pdf/remcf/v8n42/2007-1132-remcf-8-42-00055-en.pdf (6 de junio de 2020).

Román D., F., S. Levy T., H. Perales R., N. Ramírez M., D. Douterlungne y S. López M. 2007. Establecimiento de seis especies arbóreas nativas en un pastizal degradado en la selva lacandona, Chiapas, México. Ecología Aplicada 6(1-2): 1-8. http://www.scielo.org.pe/pdf/ecol/v6n1-2/a01v6n1-2.pdf (6 de junio de 2020).

Sarukhán, J., T. Urquiza-Haas, P. Koleff, J. Carabias, R. Dirzo, E. Ezcurra, S. Cerdeira-Estrada and J. Soberón. 2014. Strategic actions to value, conserve, and restore the natural capital of megadiversity countries: the case of Mexico. BioScience 65(2): 164-173. Doi:10.1093/biosci/biu195.

Sigala, R., T. González and R. Prieto. 2015. Survival of *Pinus pseudostrobus* Lindl. plantations in terms of the production system and pre-conditioning in the nursery. Revista Mexicana de Ciencias Forestales 6(30): 20-30. https://scholar.google.com/scholar?hl=es&as_sdt=0%2C5&q=Pinus+ayacahuite+plantation+survival&btnG= (16 de julio de 2020).

Sosa-Pérez, G. y D. A. Rodríguez-Trejo. 2003. Efecto de la calidad de planta en la supervivencia y crecimiento de *Pinus patula* en un área quemada. Revista Chapingo. Serie Ciencias Forestales y del Ambiente 9(1): 34-43. https://www.redalyc.org/pdf/629/62990104.pdf (14 de junio de 2020).

Yam-Chin, C., P. Montañez-Escalante y R. Ruenes-Morales. 2014. Crecimiento de plantas jóvenes de *Cordia dodecandra* (Boraginaceae) en tres etapas sucesionales de vegetación en Calotmul, Yucatán. Revista mexicana de biodiversidad 85(2): 589-597. Doi:10.7550/rmb.34996.

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