Distribution and density of maguey plants in the arid Zacatecas Plateau, Mexico

M. Martínez-Salvador\textsuperscript{a,b}, R. Valdez-Cepeda\textsuperscript{c}, H.R. Arias\textsuperscript{b}, L.F. Beltrán-Morales\textsuperscript{a}, B. Murillo-Amador\textsuperscript{a}, E. Troyo-Díéquez\textsuperscript{a}, A. Ortega-Rubio\textsuperscript{a,*}

\textsuperscript{a}Centro de Investigaciones Biológicas del Noroeste, Mar Bermejo 195, Col. Playa Palo de Sta. Rita, P.O. Box 128, La Paz, B.C.S. 23090, Mexico
\textsuperscript{b}Instituto Nacional de Investigaciones Forestales Agrícolas y Pecuarias, Av. Homero 3744, Fracc. El Vergel, Chihuahua, Chih., 31100, Mexico
\textsuperscript{c}Universidad Autónoma Chapingo, CRUCEN, Carretera Zacatecas-Guadalajara Km. 3.5, El Oro, Zacatecas 98600, Mexico

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Abstract

The distribution and density of \textit{Agave salmiana} ssp. \textit{crassispina} within the state of Zacatecas, Mexico in the period from May 2001 to October 2002 is reported here for the first time. A field sampling was conducted based on a stratified random design. The resulting sample size was 154 plots, which were distributed randomly in three strata: high, medium, and low density. In each plot the following parameters were determined: latitude, longitude and number of agave plants that were classified into the following stages: juvenile; pre-reproductive; reproductive; and mature. The spatial data analysed using GIS showed that \textit{Agave salmiana} ssp. \textit{crassispina} is distributed over approximately 59,905 ha. Out of this total area, about 1142 ha were classified as high density, 51,529 ha as medium density, and 7234 ha as low density. The estimated density of agave plants in high-density strata was an average of 3125 individuals per hectare in comparison with 788 and 652 individuals per hectare for medium, and low density, respectively. It is recommended to protect the areas with higher density and to establish

\*Corresponding author. Tel.: +52 112 536 33; fax: +52 112 327 60.
E-mail address: aortega@cibnor.mx (A. Ortega-Rubio).
plantations in those with low density, but with the necessary conditions for the development and sustainability of this specie.

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1. Introduction and literature

All the species in the genus Agave are native to the south-western United States, Mexico, Central America, and the Canary Islands (Saluson, 2000). About 75% of these species live in Mexico, and 74% of them are endemic to this country (García, 1995; Martínez-Palacios et al., 1999). Agave’s greatest diversity is found in the Mexican Central Plateau (Gómez-Pompa, 1963; Saluson, 2000). Unfortunately, protection provided to these species by the Mexican authorities has been limited; hence, these ecosystems are being affected by destruction and changes to their habitat as a result of human activities such as urbanization, agriculture, livestock farming, road and dam construction, production of secondary products, as well as collecting of seedlings and mature specimens for ornamental uses (Franco, 1995). Some of the species of the Agavaceae and Nolinaceae families are preserved in 30% of state-protected natural areas (Franco, 1995). However, the local populations of many species in these families are endangered, among them Agave guiengola, A. impressa, and A. nizandensis (García, 1995; Franco, 1995).

In the Mexican state of Zacatecas, the most abundant agave subspecies is the green maguey (Agave salmiana Otto Salm Dick ssp. Crassispina (Trel.) Gentry). It includes wild plants with highly variable performance and phenotypes, but in general terms they have a central spiny body, which range from 80 to 120 cm high at maturity. Their relatively few leaves are narrowly lanceolate, 60–90 cm long, 16–25 cm wide, green to grayish, concave, rigid and acuminate, tipped with a subulada thorn 5–9 cm long (Tello, 1983). Agave salmiana reproduces mainly vegetatively by growing twigs or suckers around the mother plant, forming four to seven young agave plants, which will eventually become new established plants (Martínez-Morales and Meyer, 1985).

The wild populations of Agave in the study region occur on shallow soils derived from igneous lithologies. Records of 25 years of precipitation data in the area show that the mean annual precipitation is 450 mm and extreme temperatures may affect their propagation (Aguirre et al., 2001) even though maguey plants are classified as CAM plants and are able to withstand temperatures exceeding 55 °C (Nobel, 1996). In addition, human pressure as well as intensive livestock grazing have resulted in a remarkable decrease in the number of agaves. Therefore, it is evident that a rational management system is needed to protect these populations and to prevent their extinction (Aguirre et al., 2001). Moreover, the boom in tequila consumption and the resulting shortage of blue agave fuelled a continued strong demand for Agave salmiana ssp. Crassispina, an alternative/complementary source for producing this
alcoholic beverage. Consequently, harvesting of wild agave plants has considerably increased in the region, a situation that could lead to major alterations in the region ecosystem.

The present research is part of an ecological diagnosis of agave populations and forest communities in the study region. Little or no information is available about maguey distribution and density. The objective of this research was to evaluate distribution and density of maguey. A second objective was to determine the type of soils and landforms present in the area, using a spatial cartographic analysis. This knowledge may lead to a better understanding of the maguey ecosystems in the Zacatecas plateau of Mexico.

Concerning the originality of the present work, we are certain that it is very common to use GIS to analyse population distributions; nevertheless, this is the very first study, applying such techniques, analysing the current status of a commercial native plant (the agave), in a very poor and arid Mexican State (Zacatecas).

2. Materials and methods

This study was conducted from May 2001 to October 2002 in the southeast of Zacatecas, Mexico (Fig. 1). In this region Agave salmiana ssp. crassispina is naturally distributed. Climate can be classified as BSJKW(w) which corresponds to the least dry of the dry steppe type, with a mean annual temperature ranging between 12 and 18 °C, and an annual average precipitation of 450 mm (UNAM, 1970; Garcia, 1981). Most of the precipitation occurs from June to October, and fluctuations of wet and dry years are not as dynamic as on other regions of Zacatecas with less than 300 mm
of annual precipitation. The dominant soils in the area are Eutric Lithosols and Haplic Xerosols (according to the FAO soil classification system, modified by the CETENAL (1972) for Mexico's local conditions). The dominant plants in the area are xerophilous shrubs, which include several species of the family Cactaceae, such as *Opuntia* species (nopal) as well as thorny shrubs and other microphyll species, including *Larrea divaricata*, and *Jatropha dioica* (Rzedowski, 1978).

In order to determine the area of distribution of agave, the areas occupied by desert crass scrub (CR) a species typical of the communities in which the target agave populations occur, as well as their diverse associations, were identified using the Thematic Maps on Use of Soils (scale 1:50,000) of the study region (F14: A61, A62, A63, A71, A72, A73, A81, A82, A83) published by CETENAL (1970). The term F14 means the geographic region of UTM and the term A61 represents the specific place of the thematic map. Having identified these communities, we conducted photogrammetric analyses and field surveys to produce an updated map of the area of distribution of *Agave salmiana* ssp. *crassispina*. According with the photogrammetric results, we decided to identify three environmental units where agave is the main commercial species: high density when the observed vegetation cover was greater than 40%; medium density when the vegetation cover was in a range of 20–40%, and low density when the vegetation cover was lower than 20%. The collected data were mapped in a GIS system (ArcView), and a digital database based on the area of distribution of agave was created using a UTM projection.

Using the soil and topographic maps (scale 1:50,000) developed by the CETENAL (1972), two thematic maps of the distribution area of green maguey were digitized in ArcView. The surface area of the main soils and landforms where its populations occur was estimated based on these maps. Finally, we created a map of these areas integrating the major soil and topographic features suitable for establishing agave plantations in the regions with medium and low density.

With the specific objective of estimating the agave density in number of plants/ha, a field sampling was conducted based on a stratified-random design. The sample size was calculated from the following equation (Freese, 1969):

$$n = \frac{L\sum_{h=1}^{L} N_h S_h^2}{N^2 D^2 + \sum_{h=1}^{L} N_h S_h^2},$$

where $n$ is the sample size; $L$ is the number of strata; $N_h$ is the total size (number of units) of each stratum $h$ ($1, 2, \ldots, L$); $D$ is the desired standard error of the mean; $S_h$ is the stratum $h$ standard error; and $S_h^2$ is the stratum $h$ variance.

The appropriate sample size was determined using the variance in *Agave salmiana* ssp. *crassispina* density, with a confidence level of 95%. This calculation was performed after a preliminary survey in circular plots of 250 m². With this size, the number of species within the plots do not vary when applying the methodology of the nested sites (Franco, 1989). The resulting sample size was 154 plots (plots sampled in the preliminary survey were not included), which were randomly allocated in three strata or environmental units (high, medium, and low density). The latitude and the longitude were considered at each plot to recognize each plot. In
addition, agave plants were classified into one of the following stages, suggested for Granados (1993): (1) juvenile, suckers that emerge from the roots of the mother plant, establish themselves within a maximum radius of 2 m, and will eventually reach about 30 cm in height; (2) pre-reproductive, agaves older than the juveniles, independent from the mother plant, but that have not entered the clonal reproduction stage; (3) reproductive, plants that have already initiated the vegetative reproduction stage by producing suckers from their roots, they will eventually produce seven descendants or more; this stage ends as soon as they initiate sexual reproduction; and (4) mature, plants that have entered the sexual reproduction stage, evidenced by the production of the floral stalk, which is an unquestionable sign of the final stage of the plant life cycle.

With the specific objective for estimating the density of green maguey in each of the study environmental units, the data obtained from the field sampling was entered into a digital database, using Arc View software.

3. Results and discussion

According to the spatial data analysed using GIS and a mean comparison using tukey's test (0.05 significance level), Agave salminana ssp. crassispina is distributed over about 59,905 ha. Approximately 1142 ha, representing 1.91% of the total area was occupied by high-density populations. Medium, and low-density populations were noted in 51,529 and 7234 ha, respectively (Fig. 2) coexisting with different plant communities, such as nopal (Opuntia) groups, thornless and thorny shrubs. The estimated density of agave plants was an average of 3125 individuals per hectare in the high-density area (Table 1), whereas in the other two areas, the estimated numbers of individuals per hectare were considerably lower (Table 1). It was evident that agave density gradually decreases with age, so the number of mature agaves was much lower than that of the juveniles. This pattern was noted in the four categories (Table 1). It would seem reasonable to suggest that this effect was due to different disturbances such as frequent droughts or overgrazing that is a common practice in the study region. Furthermore, the utilization of agave plants for commercial purposes such as the sale of young plants, their exploitation as an alternative forage, and for the production of mezcal and liquor beverages are additional factors contributing in the decline in the number of individuals that eventually will reach maturity.

Agave populations in the study area occur mainly on Eutric Lithosols (61.18%), Haplic Xerosols (20.34%), Eutric Fluvisols (7.30%) and Calcaric Fluvisols (7.26%); the remaining populations were found on other soil types like Phaeozem, Haplic castañozem, and luvic xerosol. Lithosols and Xerosols represents the type of soils that are very shallow, but they have a superficial thin layer of organic matter, and a calcareous phase (Fig. 3). These soils dominate the hills and the bottom of mountains where the slopes are greater than 13%, as well as the erosive valleys. Eutric Lithosols are better suited for growing agave with high sugar contents (Aguirre et al., 2001). However, it is generally accepted that Xerosol offers the
biological optimum for agave production and development. These areas represent a viable option for the establishment of plantations designed to protect and preserve agave populations, conserve and rehabilitate fragile soils, and protect biodiversity in these ecosystems (Fig. 3).

Green maguey is found mainly at the bottom of mountains, on hillsides and valleys with gentle slopes of less than 13% (Fig. 4). These landforms cover 72.5% of the total distribution area. Agave density tends to decreases as the slopes increase, so
on hills and mountains with slopes greater than 13%, it accounts for 20.43% of the total distribution area. Agave is also found, although at a lower density, on erosive valleys. This landform account for only 7.02% of the total distribution area. It
represents the area where the main impacted area is due to human disturbances with easy accessibility. The lower portions of the area, with gentle slopes, are suitable for establishing agave plantations on areas where this species has been displaced or on those with low density of agaves.

The estimated area with the potential for establishing agave plantations is 28,185 ha, which is distributed in the three municipalities where this study was conducted (Fig. 5). As shown in Table 2, the largest area (27,026 ha) corresponds to the present moderate density populations. And finally, the area with the lowest density covers 1159 ha. This is the area where new plantations are urgently needed for re-establishing agave species in the study area.

In Zacatecas, Mexico *Agave salmiana* ssp. *crassispina* occupies a total area of 59,905 ha, distributed in the municipalities of Pinos, Villa Hidalgo and Noria de Angeles; however, high-density populations occur in only 1142 ha. Hence, harvesting and use of this resource in the study area should be planned and performed using the appropriate methods, including thinning and selective harvesting of young plants for transplanting on the low density environmental units with appropriate characteristics (Fig. 5). In all the environmental units, it is advisable to harvest a maximum of 70% of the mature individuals, and to protect the remaining 30% so that they continue to reproduce, which will preserve the species. The survival of juvenile, pre-reproductive and reproductive individuals should be ensured through promotion and support of agave plantations and re-establishment programs for the regions with the lowest density but with adequate characteristics.

Fig. 5. Potential area for *Agave salmiana* ssp. *crassispina* plantations, in southeast Zacatecas, Mexico.
Table 2
Potential area for *Agave salmiana* ssp. *crassispina* plantation establishment, in the southeast of Zacatecas, Mexico

<table>
<thead>
<tr>
<th>Municipalities</th>
<th>Average of annual precipitation (mm)*</th>
<th>Average of annual temperature (°C)*</th>
<th>Surface ha</th>
<th>Medium density</th>
<th>Low density</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pinos</td>
<td>375</td>
<td>16</td>
<td>23,067</td>
<td>1159</td>
<td>24,226</td>
<td></td>
</tr>
<tr>
<td>Villa Hidalgo</td>
<td>400</td>
<td>16</td>
<td>3805</td>
<td>0.00</td>
<td>3805</td>
<td></td>
</tr>
<tr>
<td>N. Angeles</td>
<td>400</td>
<td>16</td>
<td>154</td>
<td>0.00</td>
<td>154</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>27,026</td>
<td>1159</td>
<td>28,185</td>
<td></td>
</tr>
</tbody>
</table>


In 98% of its distribution area in Zacatecas, agave occurs at medium and low densities (788 and 652 individuals per ha, on average), hence, it is critical to develop and implement more efficient programs and actions to facilitate the establishment of new agave plantations that may constitute the foundation of environmentally sound systems for the commercial production of agaves. In this work, we determined which are the optimal areas for establishing agave plantations. Most of the appropriate areas exhibit low densities, which are caused by the current over-exploitation of this arid plant.

In the studied zone, certainly it is not possible to analyse the history of the human disturbances on the *Agave* populations. There are no any kinds of records. There are no special licenses to exploit natural populations in the field. You can understand it, because it is a very poor and chaotic Mexican State. Indeed the state of Zacatecas is the poorest in Mexico. Despite such lack of records of human disturbances on agave populations, we can infer, through the ecological information presented in this paper, which zones currently classified as Low Density zones- have the propitious conditions as to be considered as High-Density zones. According with our ecological and plant population analysis we can then conclude that these currently Low Density zones, have been suffered a high historic human disturbance.

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