Population Structure of Maguey (*Agave salmiana* ssp. *crassispina*) in Southeast Zacatecas, Mexico

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A study was performed from May 2001 to October 2002 to assess density and morphological characteristics of maguey, *Agave salmiana* ssp. *crassispina*, in five districts of the state of Zacatecas, Mexico. A random stratified sampling procedure was used, where each area with different maguey densities (high, moderate, low, and very low) was treated as an independent stratum. Then, 154 randomly distributed sites covering an area of 250 m² were evaluated obtaining the following data: number of individuals by age class (juvenile, prereproductive, reproductive, and mature), height, crown width, and basal diameter. Thematic maps as well as aerial photos and field visits were utilized to produce a base map, which was digitized, vectorized, and georeferenced using GIS tools. The total area occupied by maguey populations was 59,905 ha. Mean densities were as follows: 1,142 ha with 3,064 magueys per ha; 17,441 ha with 892 magueys per ha; 34,088 ha with 725 magueys per ha; and 7,234 ha with 653 magueys per ha. There were differences in age class, height, crown width, and basal diameter between strata as well among strata. The data suggested that different management programs must be used to ensure sustainability of this resource.

**Keywords** desert plants, density, phenology, morphological characteristics

The name “Agave” stems from a Greek word meaning “admirable, noble, illustrious, pleasant, magnificent” (Reyes, 1987; Granados, 1993; Nobel, 1998), and it represents the genus of plants commonly known as magueys. All species in the genus agave are native to Mexico, the Canary Islands, and southwestern United States (Slauson, 2000), although 75% of these species occur in Mexico, and 74% are endemic to Mexico (García–Mendoza, 1995; Martinez-Palacios et al., 1999). Agave species have been highly appreciated in Mexico since the pre-Hispanic era. They have long been used by Mexican Indian people as a source of food, forage, fibers, poultices for wounds, and fermented liquor (Gentry, 1980; Colunga–García & May–Pat, 1993; Franco, 1995). Unfortunately, the maguey populations in this country have been affected by destruction of their habitat, as a result of human activities such as urbanization, agriculture, livestock grazing, road and dam construction, production of

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secondary products, as well as the collection of seedlings and adult specimens from the wild for decorative purposes (Franco, 1995).

Maguey verde (Agave salmiana) is adapted to different habitats, including steep, rocky hills and slopes, and it grows well, both as individuals and as populations, on medium textured soils with a neutral to slightly acidic pH (Martínez, 1985). Maguey verde is a vigorous plant that grows up to 1.8 m tall. Its leaves form a succulent rosette, and their fresh weight can be up to 250 kg. Its stem is fibrous, short, and thick. When the plants’ flower, stalks emerge, the stems grow in thickness and, together with the leaf bases, form a carbohydrate storage organ known as “piña.” Maguey has a shallow fibrous root system, with abundant, dark red roots. The roots extend in a radial pattern all around the plant, and penetrate no more than 30 cm into the ground (Martínez, 1985; Tello, 1988; Martínez, 1988). The life cycles of Maguey species range from eight to 20 years and flowering occurs at the end of this cycle, after a long vegetal growth period.

The purpose of the current study was to estimate the density and morphological characteristics of maguey, Agave salmiana Otto ex Salm-Dyck ssp. crassispina (Trel. ex L.H. Bailey) Gentry, populations in the southeastern state of Zacatecas, Mexico. In this region, maguey has been historically used for mescal production and forage for livestock in intensive grazing systems. Therefore, it is crucial to know the population structure and morphological characteristics, in order to establish management programs that favor the preservation of young maguey populations, and to ensure the appropriate utilization of adult plants as an option to preserve the structure of maguey populations in this Mexican state.

Materials and Methods

The study was conducted from May 2001 to October 2002 in a region southeast of Zacatecas, Mexico, comprising five local government areas identified as municipios; Pinos, Villa Hidalgo, Noria de Ángeles, Loreto, and Villa García (see Figure 1), in which Agave salmiana ssp. crassispina (maguey) is naturally distributed. The area of distribution of this species in Zacatecas is located between about 21° 49' and 22° 43' N and between 101° 18' and 102° 08' W. Climate in this region corresponds to BS1 kw (w) (García, 1964; UNAM, 1970) that identify a dry region, temperate, warm summer, and an annual average temperature between 12° and 18°C. The precipitation annual average is 450 mm. According to the FAO/UNESCO classification, as modified by CETENAL (FAO/UNESCO, 1968) the predominant soils are Eutric Litosols, that is, medium textured soils with a mean depth of 10 cm, with coarse gravel in the soil profile (Ortiz, 1990). These soils are commonly found on gently rolling topography with slopes greater than 6%. Another soil present in the area is the Xerosol Haplico, which is typical of areas with high calcium carbonate content and with duripans or fragipans, located on rolling areas and valleys. The type of dominant vegetation in the area is xerophytic scrubs, which coexist with species of the family Cactaceae, such as Opuntia, and shrub species with small leaves and, occasionally with spines.

A cartographic characterization of maguey distribution was performed using thematic maps (F14-A61, F14-A62, F14-A63, F14-A71, F14-A72, F14-A73, F14-A81, F14-A82, F14-A83) with a scale of 1:50,000 (CETENAL, 1970; CETENAL, 1972). The term F14 means the geographic region of UTM and the term A61 represents the specific place of the thematic map. These maps include the term “matorral cracirrosulifolio espinoso” to identify the areas of distribution of
maguey. According to Rzedowski's classification (1978), magueys are found in association with other vegetation communities such as matorral espinoso, inermey subinerme, Opuntia cacti scrub, mesquite shrubs, and natural grasslands. The distribution surface was checked for errors based on aerial photos and field visits to produce a base map of maguey distribution, which was digitized, vectorized, and georeferenced using GIS (Geographic Information System) tools. Finally, the collected data were analyzed in ArcView version 3.2, where the surface occupied by maguey was estimated by converting the vector map into UTM coordinates. Four study areas were identified on the basis of maguey density (number of magueys/ha) as high, moderate, low, and very low density.

In order to determine the population structure and morphological characteristics of Agave salmiana ssp. crassispina, an inventory was carried out, using a random-stratified sampling design (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: \( n \) = sample size; \( L \) = number of strata; \( N_h \) = total size (number of units) of each stratum \( h(1,2,\ldots,L) \); \( D \) = desired size of the standard error of the mean; \( S_h \) = stratum standard error \( h \) and; \( S_h^2 \) = stratum \( h \) variance.
For estimating the sample size, a variance of the density of the sample size of *Agave salmiana* was used at presampling sites. The sample size was estimated, with a significance level of 95% and a maximum acceptable error of 5%. For the sampling procedure, each area with different maguey density was treated as an independent stratum. Finally, 154 randomly distributed sites covering an area of 250 m² were evaluated (Franco, 1989). The following variables were measured at each site: number of individuals by age class, height, crown width, and basal diameter.

The maguey individuals found at the sampling site were classified into the following age classes: (1) Juvenile: suckers up to 35 cm tall that emerged from the parent plant, and established themselves within a maximum radius of 2 m around the parent plant; (2) Prereproductive: magueys older than the juveniles, that live independently from the parent plant, but have not entered the reproductive stage (by suckers from the root system); (3) Reproductive: those that have initiated the vegetative reproduction stage by producing seven suckers or more that emerge from the rhizomes, a stage ending as soon as the magueys initiate sexual reproduction; and (4) Mature magueys: those magueys that have entered the sexual reproduction stage as evidenced by the production of the flower stalk, an unquestionable sign of the final stage of the maguey life cycle.

**Results**

The GIS data analysis indicates that the total area occupied by populations of this species in the region is 59,905 hectares (13%). The five municipios cover an area of about 459,000 ha. The density of maguey populations differed in the four areas of interest, hence a small area of 1,142 ha is dominated by maguey; whereas in 58,763 ha, the species is found as a codominant population, coexisting with different vegetation communities such as shrublands composed of thorny and/or thornless shrubs, *Opuntia* cacti scrub, and mesquite shrub.

The results for the area with a high maguey density, together with the maguey characteristics evaluated by stages are shown in Table 1. This data clearly indicate that the number of individuals per hectare decreases with age. Individual height, crown width, and basal diameter were measured. In this stratum, there was a higher frequency of magueys ranging from 0.23 m to more than 1.0 m in height (in the four stages). Dimensions of individuals showed differences in individual size for the different stages, for all cases, it was estimated a coefficient of variation lower than 25% for all variables. The juvenile individuals showed the greatest variation, whereas mature magueys were the least variable. With the exception of juvenile magueys, in the rest of the age classes the variation in basal diameter was greater than that in height and crown width, although it was minimal. The homogeneity of maguey density and morphological characteristics is likely to be due to the dominance of magueys in this stratum, since their high density reduces competition from other plant populations, contributes to capture of rainfall and reduced soil erosion, and finally, favors production of new generations with relatively homogeneous characteristics.

The results for the morphological characteristics exhibited by magueys in this study area are shown in Table 2. The dimensions and size of individuals were lower than those for magueys in the area with high density, and the morphological features had a high variability, although magueys reproduce mainly vegetatively by rhizomes. As for the stratum where maguey is present as a codominant species with moderate...
Table 1. Population structure of *Agave salmiana* ssp. *crassispina* in the stratum with high density

<table>
<thead>
<tr>
<th>Age classes</th>
<th>Number of individuals</th>
<th>Height</th>
<th>Crown width</th>
<th>Basal diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>St. dev.</td>
<td>Mean</td>
<td>St. dev.</td>
</tr>
<tr>
<td>Juvenile</td>
<td>993</td>
<td>66</td>
<td>23</td>
<td>5</td>
</tr>
<tr>
<td>Prereproductive</td>
<td>828</td>
<td>67</td>
<td>52</td>
<td>4</td>
</tr>
<tr>
<td>Reproductive</td>
<td>697</td>
<td>49</td>
<td>74</td>
<td>4</td>
</tr>
<tr>
<td>Mature</td>
<td>607</td>
<td>34</td>
<td>108</td>
<td>7</td>
</tr>
</tbody>
</table>

1Population structure of magueys in 1,142 ha with high density, summarizing the morphological features evaluated, by age class.

density, Table 2 shows that density of individuals per hectare decreases as the plants develop, thus, just as in the case of the last stratum, the number of juvenile magueys is greater than that of mature magueys. In this particular case, low density combined with high variability indicates that, in this stratum, maguey populations have a more heterogeneous spatial distribution, and they occur in groups as separated patches. This makes them vulnerable to high intensities of utilization, so it will be necessary to establish management schemes for juvenile, prereproductive, reproductive, and mature populations in order to preserve this resource.

The density of maguey populations for the stratum with low density is shown in Table 3. In this case, the number of maguey individuals per hectare was 725 and, as in the other cases, it can be noticed that the number of individuals decreases gradually as the plants mature. The coefficient of variation for maguey density ranged from 30 to 40%, indicating that magueys are distributed heterogeneously in separated patches. Also, it can be seen that the number of reproductive magueys is lower than that of mature ones. Morphological characteristics of magueys in this area also showed differences and variation in individual sizes (Table 3). The dimensions of the plants showed a variation greater than 20% for each age class, which may be related

Table 2. Population structure of *Agave salmiana* ssp. *crassispina* in the stratum with moderate density

<table>
<thead>
<tr>
<th>Age classes</th>
<th>Number of individuals</th>
<th>Height</th>
<th>Crown width</th>
<th>Basal diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>St. dev.</td>
<td>Mean</td>
<td>St. dev.</td>
</tr>
<tr>
<td>Juvenile</td>
<td>268</td>
<td>69</td>
<td>17</td>
<td>4</td>
</tr>
<tr>
<td>Prereproductive</td>
<td>212</td>
<td>44</td>
<td>46</td>
<td>6</td>
</tr>
<tr>
<td>Reproductive</td>
<td>274</td>
<td>65</td>
<td>70</td>
<td>4</td>
</tr>
<tr>
<td>Mature</td>
<td>138</td>
<td>47</td>
<td>83</td>
<td>37</td>
</tr>
</tbody>
</table>

1Population structure of magueys in 17,441 ha with moderate density, summarizing the morphological features evaluated, by age class.
Table 3. Population structure of *Agave salmiana* ssp. *crassispina* in the stratum with low density

<table>
<thead>
<tr>
<th>Age classes</th>
<th>Number of individuals</th>
<th>Height</th>
<th>Crown width</th>
<th>Basal diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>St. dev.</td>
<td>Mean (cm)</td>
<td>St. dev.</td>
</tr>
<tr>
<td>Juvenile</td>
<td>209</td>
<td>66</td>
<td>16</td>
<td>5</td>
</tr>
<tr>
<td>Prereproductive</td>
<td>187</td>
<td>70</td>
<td>40</td>
<td>15</td>
</tr>
<tr>
<td>Reproductive</td>
<td>160</td>
<td>63</td>
<td>68</td>
<td>13</td>
</tr>
<tr>
<td>Mature</td>
<td>169</td>
<td>53</td>
<td>98</td>
<td>21</td>
</tr>
</tbody>
</table>

Population structure of magueys in 34,088 ha with low density, summarizing the morphological characteristics evaluated, by age class.

...to intraspecific competition, since maguey populations grow in separate patches or small colonies in this stratum. Therefore, it is advisable to establish repopulation programs including thinning techniques and transplanting of juvenile and prereproductive magueys.

A summary of the characteristics of the target maguey populations in the stratum with very low density is shown in Table 4. In this region, the shrub community is dominated by associations such as *Opuntia* cacti scrub and matorral micrófilo subinerme (*Jatropha dioica*, *Opuntia leucotricha*, *Opuntia robusta*, *Larrea divaricata*, *Mimosa biuncifera*, *Fluorencia cernua*, *Opuntia imbricata*, *Acacia vernicosa*, *Acacia shaffinerti*). In this case, the density of *Agave salmiana* ssp. *crassispina* was 652 individuals per hectare.

As in the strata with high, moderate, and low density, in this stratum, the density of *Agave salmiana* ssp. *crassispina* decreases as growth stage advances. The greatest variations were found in this study area. The coefficients of variation for all four variables was greater than 30%, which indicates that there is a high variability in dimensions, even though magueys, as explained earlier reproduce vegetatively.

Table 4. Population structure of *Agave salmiana* ssp. *crassispina* in the stratum with very low density

<table>
<thead>
<tr>
<th>Age classes</th>
<th>Number of individuals</th>
<th>Height</th>
<th>Crown width</th>
<th>Basal diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>St. dev.</td>
<td>Mean (cm)</td>
<td>St. dev.</td>
</tr>
<tr>
<td>Juvenile</td>
<td>199</td>
<td>67</td>
<td>17</td>
<td>7</td>
</tr>
<tr>
<td>Prereproductive</td>
<td>161</td>
<td>63</td>
<td>39</td>
<td>20</td>
</tr>
<tr>
<td>Reproductive</td>
<td>163</td>
<td>57</td>
<td>66</td>
<td>18</td>
</tr>
<tr>
<td>Mature</td>
<td>130</td>
<td>45</td>
<td>85</td>
<td>41</td>
</tr>
</tbody>
</table>

Population structure of magueys in 7,234 ha with very low density, as well as the morphological characteristics evaluated, by age class.
Discussion

Maguey populations in southeast Zacatecas, Mexico are distributed in four regions with different density levels. The current mean densities in the four study areas were as follows: 1,142 ha with 3,064 magueys per ha; 17,441 ha with 892; 34,088 ha with 725; and 7,234 ha with 652. In each of the studied areas, there was a decrease in the number of magueys as they reach greater maturity. The fact that the number of maguey plants decreases with age may be explained due to increased mortality from disturbances such as prolonged droughts, overgrazing in the region, or human-induced effects. On the other hand, the use of maguey plants for commercial purposes, such as the sale of suckers, their utilization as forage, and for mescal production, are other factors that may be contributing to maguey population decline. The variation in the density of magueys in the high density stratum was less than 8% for all cases, which indicates that their spatial distribution is relatively homogeneous.

The prereproductive, reproductive, and mature magueys represent 85%, 85%, and 68%, respectively, in relation to the total number of existing juvenile magueys. These data show the mortality rate or utilization of the species in the intermediate stages of growth, and evidence the fragility of maguey populations. On this regard, Nobel (1998) reported that production of mescal using agaves from spontaneous populations could have serious ecological consequences. In the case of the region of study, the use of immature individuals for mezcal production and overgrazing reduces reproduction by seeds and adversely affects asexual reproduction since, although all the plants have the ability to produce suckers, medium-size plants produce the greatest percentage because of their high density (Tello, 1988).

It was estimated that there were about 12 million magueys in the reproductive stage, and about 9 million mature magueys, so there was 21 million magueys able to generate suckers. In this respect, Martínez (1988) noted that production of suckers would be sufficient to replace adult plants that are collected from the wild. However, there is a high mortality rate among juvenile plants in these populations, and this may create serious problems in the future. Therefore, it would be necessary to implement an adequate thinning and transplanting program to encourage and to promote the long-term conservation of this resource. These crop management practices would be of great importance, since, according to Martínez (1985), vegetative production by suckers is crucial to maintain maguey populations. It is the only means to ensure production of plants, given that germination of seeds is very low; under normal conditions only one seed out of 500,000 to 1,000,000 germinates and grows to maturity (Gentry, 1982).

In the area where maguey populations are dominant, variation in density is less than 8% for the four age classes evaluated, which indicates that there is a homogeneous distribution of the species in this area. However, in the regions where magueys are found as a codominant species, associated with other shrub populations, the density by age class had a minimum coefficient of variation of 20% and a maximum of 40%. These results indicate that maguey is heterogeneously distributed, in colonies or separate patches. Notwithstanding, maguey plants continue to be used in this irrational manner. It will be necessary to implement appropriate management programs including the establishment of plantations in regions with lower density, and an efficient thinning program in the high density areas, in order to ensure the sustainable use and conservation of this resource.
Conclusions

The results suggest that the maguey communities are heterogeneously distributed according to region. We found areas with more than 3,000 maguey plants per ha in contrast with areas that exhibited about 600 plants per ha. In addition, most maguey plants, no matter the density level in which they are classified, are in juvenile and prereproductive level. We acknowledge that this research was exploratory; thus, we recommend that a dynamic study be carried out to understand the synergistic effects (human-natural resource-climate) in order to offer management strategies of maguey populations in a sustainable system.

The approach outlined in this study might be replicated in other environments as well as in other plant species in order to have a better understanding of communities differences. However, it might produce different results.

References


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