A Demographic Study of Maguey Verde (Agave salmiana ssp. crassispina) Under Conditions of Intensive Utilization

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Abstract

In western San Luis Potosi, Mexico, wild populations of Maguey Verde *(Agave Salmiana* Otto ex Salm-Dyck ssp. *crassispina* (Trel.) Gentry) are intensively utilized, especially as raw material for production of the distilled liquor mezcal. A demographic approach was used to investigate possible explanations for recent population decline. The effect of overgrazing on the survival of young plants (offsets) was found to be a major problem. Harvest of sexually mature plants for mezcal aggravates the problem by leaving both soil and offsets exposed. But, in itself, this harvest seems to constitute a reasonable long-term use for wild populations, even though seed production is halted.

Introduction

In the semi-arid steppe country of western San Luis Potosi, Mexico, maguey verde *(Agave salmiana* ssp. *crassispina* (Trel.) Gentry) is a common and conspicuous component of the natural vegetation. It is an economically important plant whose multiple uses include the commercial manufacture of the distilled liquor mezcal. Raw material for local mezcal manufacture comes exclusively from wild populations.

The Altiplano Potosino is only marginally suited for rainfed agriculture, with an average annual rainfall of 350-400 mm and marked year-to-year variation. As a consequence, the burden of supporting the growing rural population falls heavily on the natural vegetation, which is utilized both through direct collection and through grazing. With the intensification of land use in recent years, natural ecosystems are experiencing visible and possibly irreversible degradation. One result has been a decline in the supply of raw material from wild maguey populations. The object of this study was to try to understand why maguey populations are declining and how they could be managed for sustained long-term yield.

Maguey verde is one of the more spectacular agaves of semi-arid Mexico, reaching rosette heights of 1.8 m and fresh weights of over 250 kg. As mentioned by Gentry (1982), it propagates freely of offsets and also sets abundant seed. It is adapted to a variety of habitats, including rocky hillsides, but it reaches its maximum development, both in population and individual terms, on broad plains with reasonably deep soils. It often shares this habitat with grassland vegetation, occurring in clumps dispersed in a grassland matrix. The grassland today is composed mostly of species tolerant to grazing and trampling.

Tello-Balderas (1983) has described the local utilization of maguey verde. Use of the flowering stalk as human food and in construction prevents seed production, but the bulk of the rosette is left in place. Harvest for mezcal production (for details see Tello-Balderas and Garcia-Moya, this issue of *Desert Plants)* involves the removal of entire plants once they have initiated the process of sexual reproduction. This halts seed production and also implies removal of resources and of the protection offered by the dead post-flowering rosette. Harvest of submature plants for cattle forage, in addition to having the above effects, may also interfere with offset production. Any form of intensive exploitation effectively eliminates the option of reproduction from seed.

Methods and Materials

The La Tinaja Study Site is typical of much of the 'magueyera' of the region (Figure 1). It is located about 10 km ESE of the town of Salinas de Hidalgo, San Luis Potosi, at 22° 35′ north latitude, 101° 38′ west longitude, and at an altitude of about 2280 m (for regional map, see Tello-Balderas and Garcia-Moya, this issue of *Desert Plants)*. The almost level plain supports extensive maguey-grassland vegetation. The soil, a neutral sandy clay loam with a calcareous hardpan at (0-) 30-90 cm, is rich in potassium but poor in phosphorus and iron (Lagunes-Espinosa, 1985). The land is managed under the 'ejido' system, a type of communal ownership, as open range with intensive grazing by all classes of livestock.

Table 1. Damage to offsets and soil compaction (measured as resistence to penetration in kg/cm^2), in relation to position with regard to other agaves, based on a sample of 200 randomly selected offsets. Contingency table analysis shows highly significant departures from expected values per position for each type of damage, for damage in general, and for degree of soil compaction ($p < .005$ in each case).

	Offset Position					
	Within-Clump Protected	Within-Clump Exposed	Clump Edge Semi-Protected	Clump Edge Exposed	Open Grassland	General
% Total Offsets	24	28	32	16	0	100
Damage (% Total Offsets)						
Overall	12	71	61	82	-	56
Trampling	0	11	9	21	-	9
Predation	4	27	29	36	-	24
Insects/Pathogens/Stress	8	55	35	36	-	34
Soil Compaction (kg/cm^2)						
% ≤ 1	65	33	20	3	0	-
% 1.1-2.0	27	27	23	26	0	-
% 2.1-3.0	8	11	28	29	4	-
% 3.1-4.0	0	16	21	18	10	-
% > 4.0	0	13	8	24	86	-

Harvest for mezcal is carried out under contract with a local factory, while small-scale harvest for other uses is continual.

In designing the study, we took the clump as the basic population unit, and considered factors which might affect its size (area), its size-class structure, and its potential productivity. We proposed that, within an agave clump, there ought to exist a critical value for biomass/area, above which the effects of crowding might be expressed as reduced growth rate, smaller size at flowering, or the supression of offset production. At biomass/area below this critical value, the advantages of cohabiting with other agaves, such as protection from trampling and access to better soil microsites, should outweigh the disadvantages. We considered that, given time and environmental homogeneity, agave clumps should continue to expand and should eventually merge with each other. That this has not happened implies either heterogeneity in terms of soil or topographic factors or decreased survivorship at clump edges due to biotic interactions. We also considered that plant size at flowering in this monocarpic perennial should provide a good index of site quality, integrating biotic and abiotic factors.

To obtain accurate estimates of biomass/area, we excavated a series of eight individuals of different sizes and used regression analysis to relate field size parameters to dry weight. The size of an individual expressed as its height × diameter in square meters was related to its dry weight in kilograms by the following equation:

$$\text{dry weight} = 11.44\ (\text{height} \times \text{diameter})^{1.32}\ (R^2 = .98).$$

To estimate the former size of harvested plants, the stem diameter in meters was related to the product of height × diameter in square meters by the following equation:

$$(\text{height} \times \text{diameter}) = 67.4\ (\text{stem diameter})^{2.03}\ (R^2 = .97).$$

Non-destructive sampling of 52 agave clumps was carried out in the most homogeneous and least degraded part of the general study area. Clump area, soil depth inside and immediately outside the clump, and size-class structure for living, dead, and harvested agaves were among the parameters. Size class categories used the height × diameter (square meters) criterion as follows:

Class	Size Range
1	0.01-0.05
2	0.06-0.10
3	0.11-0.20
4	0.21-0.40
5	0.41-0.60
6	0.61-0.80
7	0.81-1.00
8	1.01-1.20
9	1.21-1.40
10	1.41-1.60
11	1.61-1.80
12	1.81-2.00
13	2.01-3.00
14	>3.00

Offset production by size class was examined by excavating 150 potential parent plants. To look for plants propagated from seed, we excavated 150 small offsets; their rhizome connections were also traced.

We looked at damage to offsets by sampling 200 individuals, noting type and degree of damage, position with regard to other agaves, and degree of soil compaction (Soiltest pocket penetrometer). Types of damage noted were trampling, predation, and a combination of the effects of abiotic stress, pathogens, and boring insects. Offset position was recorded as within-clump and protected, within-clump but exposed, clump-edge and semi-protected, or clump-edge and exposed.

We carried out an extensive survey of 360 plants in flower in order to relate plant size at flowering to the living agave biomass within a 1.5 m radius of the center of each plant. Flowering plants were classified by the height × diameter criterion as small (<1.00 m^2), medium (1.00-2.00 m^2), or large (>2.00 m^2), while agave neighbor dry weight biomass was defined as low (<20 kg), medium (20 to 40 kg), or high (>40 kg).

Figure 1. *View of the study site near Salinas de Hidalgo, San Luis Potosi, Mexico, showing maguey verde clumps in a matrix of degraded grassland vegetation. Offsets exterior to the clumps are subject to trampling and predation (see example at right) as well as soil compaction.*

The data were analyzed statistically using contingency table analysis. Further detail regarding the sampling methodology may be found in Martinez-Morales (1985).

Results and Discussion

A theoretical maximum value for biomass/area in this population of Maguey Verde is about 20 kg/m^2, based on a calculation for continuous cover by very large plants. Figure 2 shows how the 52 sampled clumps compared with this value. Over 90% of the clumps showed values equal to or less than 10 kg/m^2, while over two-thirds showed values equal to or less than 5 kg/m^2.

There was no correlation, either positive or negative, between offset density and biomass/area. Mean density was 0.4 offsets per square meter, and there was no great clump-to-clump variation. Thus there was little evidence either for the suppression of offset production or for enhanced offset survival in high biomass/area clumps. This may be because of lower survival rate in areas of higher production. Within-clump heterogeneity in terms of biomass distribution may also have obscured the results.

Results of the extensive sampling of sexually mature plants (Figure 3) show that most of the plants were surrounded by relatively little agave neighbor biomass, as

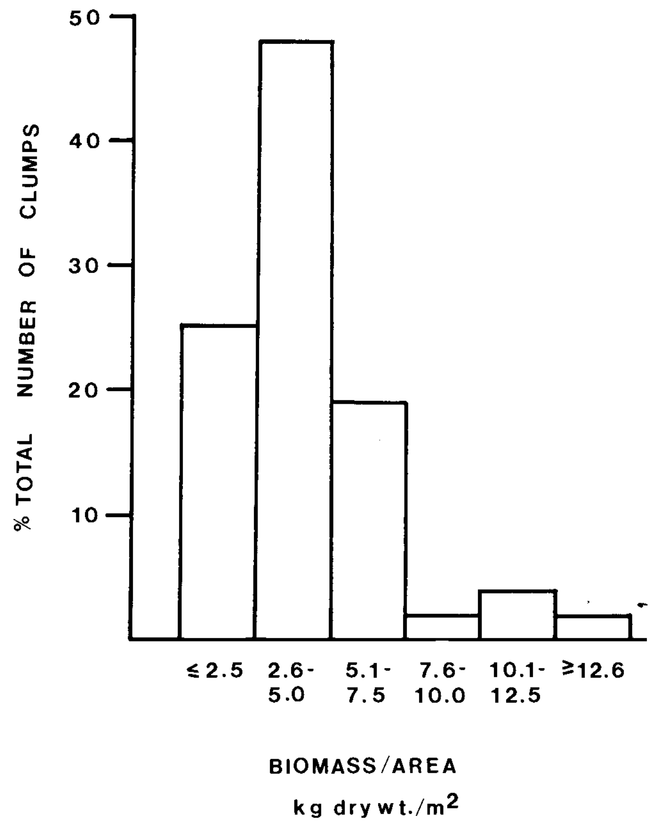

Figure 2. *Frequency distribution showing the proportion of nondestructively sampled clumps in each of six dry weight biomass/area categories.*

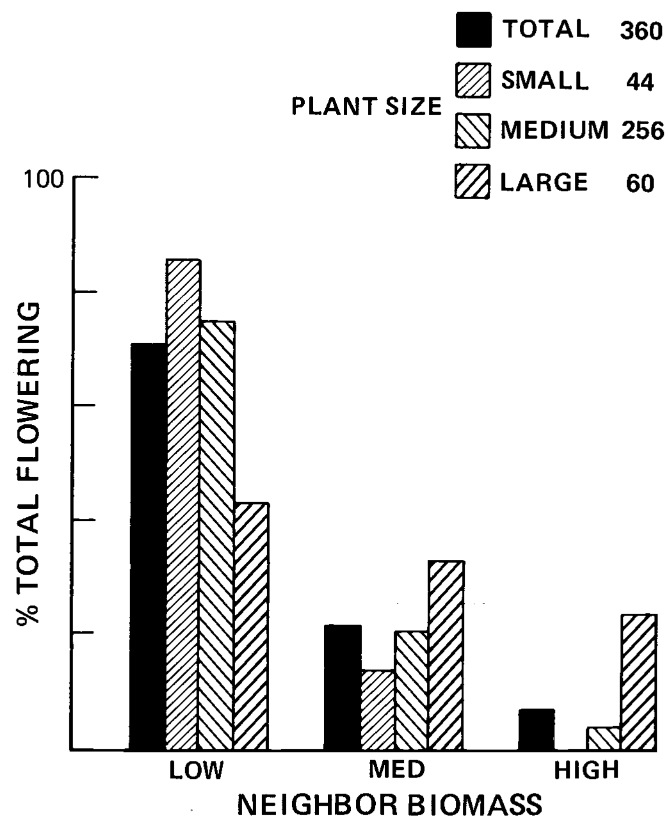

Figure 3. *The relationship between plant size at flowering and agave neighbor biomass, from an extensive sample of 360 sexually mature plants. Large flowering plants are significantly underrepresented in low neighbor biomass locations and overrepresented in medium and high neighbor biomass locations ($x^2 = 46.5$, $p < .005$).*

would be expected from the general biomass/area data. But in areas with medium or high neighbor biomass, large flowering plants were significantly overrepresented. This suggests not only a lack of competition but a positive intraspecific interaction. The growth advantage in dense groups seems to be related to improved soil conditions.

The biomass in an agave clump may be very unevenly distributed among its members, and the flowering and death of a large individual can lower the overall value considerably. Variation in time is therefore to be expected and different clumps would be at different stages in this cycle. But the low biomass/area in the groups with values less than 5 kg/m^2 is only partially explained by size class structure. Some other factor seems to be operating to keep the overall biomass/area low. The critical step may involve the production and survival of young plants.

We found no evidence of successful reproduction by seed, not a surprising result in view of the almost non-existent seed production under current management practices. Reproduction from seed could be important in the reestablishment of extinct clumps on a local scale as well as in the colonization of new areas and the maintenance of genetic diversity.

Vegetative reproduction by offsets seems to be a potentially adequate mechanism for the maintenance of already-established clumps. The mean density of 0.4 offsets/m^2 was obtained in late summer, at the end of the main period of production. If there were no subsequent mortality and no further recruitment, this value could ultimately result in nearly continuous cover by large flowering agaves. But the evidence suggests that both year-by-year recruitment levels and offset mortality levels are high under present conditions. The size-class distribution of the overall population (Figure 4a) shows that new offsets (Size Class 1) constituted over 25% of the individuals present, while the subsequent size class contributed only 10%. Given a time-stable size-class distribution, this suggests high mortality for offsets.

Plants of virtually all size classes are capable of producing offsets (Figure 4b). In practice, however, most offsets are produced by plants of intermediate size classes, in spite of the somewhat higher production per plant in larger individuals (Figure 4c). The functional rhizome connection with the parent plant is short-lived, rarely persisting in offsets with a fresh weight of over 1 kg.

Possible causes of offset mortality were examined indirectly by assessing offset damage (Table 1) six months after the end of the season of maximum production. Over

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Conclusions

Probably the greatest advantage of agave as a potential agricultural crop in Arizona is the multiplicity of uses for which it might be cultivated. A number of products from agave are illustrated in Table 7. At present the economic return from sale of steroidal sapogenins is sufficient to encourage establishment of plantations and the possibility of additional income from the remainder of the plant following extraction exists. Likewise, the climate in some agricultural areas of southern Arizona appears ideal for the cultivation of the Tequila Agave (*Agave tequilana* Weber) which would support the establishment of an industry for the distillation and sale of spirits derived from agave fermentation. The increasing sales of tequila worldwide suggest the success of such an enterprise.

With millions of acres in the Southwest suitable for agave plantations an enormous potential production is possible. Agave, by reason of its shallow root system and perennial growth habit, should act to stabilize desert soils and control erosion during the several years of growth before harvest. The agronomic attributes of agave make it a plant of choice for effective biological energy conversion in the arid Southwest.

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half the offsets showed at least one type of damage. But only 12% of the within-clump protected offsets were damaged, compared with over 80% for clump-edge exposed offsets. Damages due to trampling, predation, and stress/pathogens/insects were all significantly lower for protected offsets. Offsets in within-clump exposed positions generally suffered damage similar to that suffered in clump-edge semi-protected positions.

Data on soil compaction (Table 1) show clearly that a major soil difference between protected positions in agave clumps and open degraded grassland is at least a fourfold increase in resistance to penetration in the open grassland soil. Resistance to penetration decreased progressively in the following order: open grassland, exposed edges, semi-protected edges, exposed within-clump positions, protected within-clump positions. This pattern helps to explain the increase in stress-related damage to offsets outside the immediate protection of other agaves. There was also a mean 10% decrease in soil depth in open grassland when compared to adjacent agave clumps, irrespective of absolute depth. These differences in soil depth and degree of compaction appear to be due to the differential effects of overgrazing on open grassland versus agave-protected soil. Clump area may be restricted both by direct biotic interactions (trampling and predation) at edges and by soil heterogeneity that itself seems to have been induced by overgrazing.

In order to evaluate plant size at flowering as an index of site deterioration, we examined three size class distributions. Figure 5a shows the distribution for plants in the nondestructively sampled clumps which reached sexual maturity during the study, while Figure 5b is based on the dead plants in the same clumps. Both show a preponderance of the largest size classes, and the two are statistically not distinguishable. This suggests that, at least in the relatively favorable environment of the nondestructively sampled area, there has been no major change in plant size at flowering within the last ten years (the estimated persistence period for dead plant remains). In contrast, Figure 5c shows the distribution for the more extensive sample of living plants, which included more obviously degraded areas with hardpan showing at the surface. Modal plant size in this sample was Size Class 10, while modal size in samples from the less-degraded area was Size Class 13. Plant size at flowering is clearly plastic and appears to

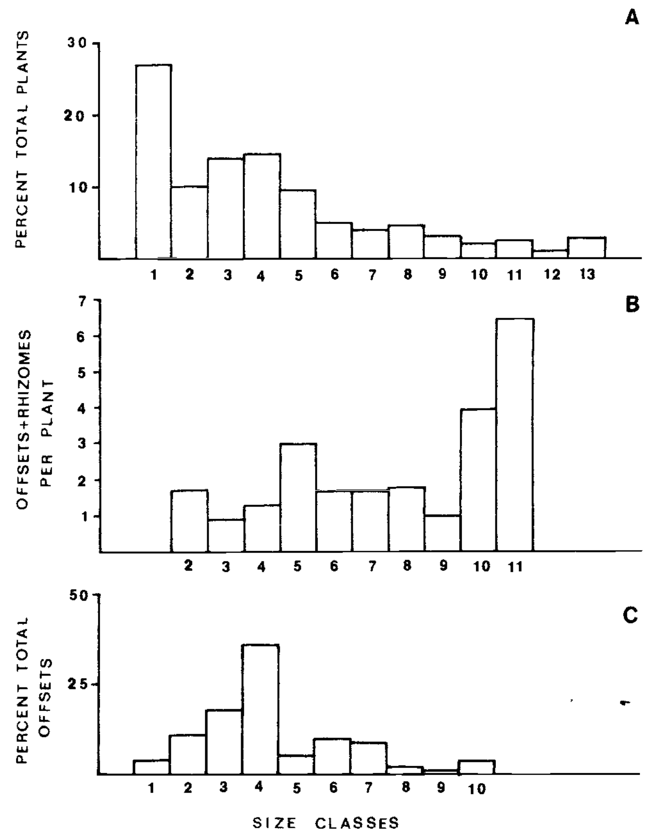

Figure 4. *(a) Size class distribution for the overall population, based on data from the 52 nondestructively sampled clumps. (b) Mean potential offset production (current connected offsets + developing rhizomes) by plants of different size classes, based on the excavation of 150 potential parent plants. (c) Actual offset production by parent size class, based onthe excavation of 150 randomly selected offsets. See text for class size details.*

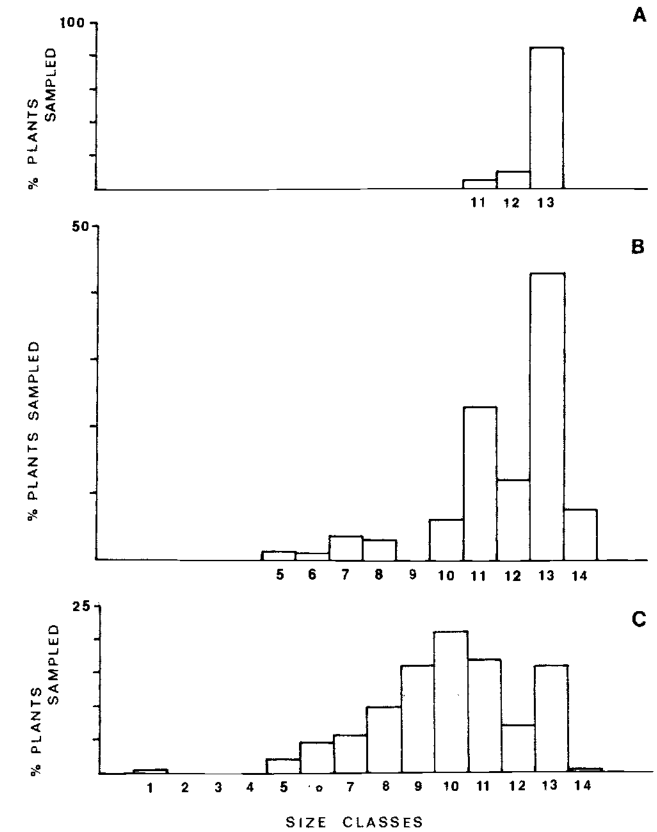

Figure 5. *Size class distributions for sexually mature plants. (a) Living plants in nondestructively sampled clumps (n = 21). (b) Dead plants in nondestructively sampled clumps (n = 414). (c) Living plants in a more extensive sample which included more severely degraded habitat (n = 360). See text for class size details.*

represent a direct response to integrated stress, making it a good potential parameter for site quality evaluations. In this case the abiotic stress related to soil conditions appears to be more important than the effects of crowding.

Conclusions

The evidence generated in this study suggests that under present conditions the agave biomass/area in clumps at the study site is often below the critical value. Evidence for the negative effect of crowding is weak, while the case for the positive effect of cohabiting with other agaves is quite strong, in terms of both apparent offset survival and improved conditions for the growth of large plants. Agave clumps offer protection against the direct negative effects of grazing and also have deeper, less-compacted soils than areas outside clumps. Clump area may be restricted by negative biotic interactions at clump-edges and by soil heterogeneity which seems to be grazing-induced. Clumps appear to be contracting, as areas formerly occupied by large agaves are negatively impacted by grazing following the removal of plants for mezcal production. Under current conditions, offset production is high, but apparent offset mortality is also very high.

The harvest of sexually-mature plants *per se* does not seem to be the cause of the population decline, although it aggravates the effects of overgrazing by leaving both soil and offsets exposed. Harvest for mezcal could probably be considered a rational long-term use of the wild maguey verde resource, if it were carefully managed and if the problem of grazing could be brought under control.

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