Plant Communities as Indicators and Regulators of Degradation in the Manix Basin

A Senior Thesis

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Abstract. *Plant cover and soil salinity data were collected in various places in the Manix Basin as a preliminary exploration of land degradation occurring on abandoned fields there. A classification of perennial plant communities based on Larrea tridentata and Atriplex polycarpa abundance was proposed. Correlations between soil salinity and plant community characteristics were found. Salt levels elevated by ~30% over the surrounding undisturbed soil were documented on an abandoned field. A tentative model of degradation for the Basin in which plants help to regulate salinity was proposed that involves wind erosion, salinization, and ecology.*

Introduction

While commonly thought of as unproductive and economically useless, arid regions are used worldwide as crop and grazing land. Local economies are highly dependent upon the agricultural productivity of arid regions in many places. Degradation of these regions represents a serious threat to the Earth's agricultural productivity: it is estimated that "over the past 45 years, about 11 percent of the Earth's vegetated soils became degraded to the point that their original biotic functions are damaged," (World Resources Institute, 1992) these soils occurring in arid, semi-arid, or dry sub-humid areas. In many cases, recovery of this land is impossible or economically unfeasible on time-scales of less than a few centuries. For this reason, it is important to understand the causes and signs of degradation.

Arid region land degradation, otherwise known as desertification, is defined by Schlesinger as a redistribution of biotic productivity, either in amount or in species composition. The causes of degradation may involve a complex interaction of a number of factors. They typically include wind or water erosion. Redistribution of soil nutrients may be involved (Schlesinger, 1996). Another problem can be elevated soil salinity. Often, the only obvious aspects of degradation are mobilized sand and changes in plant communities, and this only after the degradation has occurred.

The Manix Basin

The Manix Basin is located near Barstow, California, approximately 70 miles northeast of Los Angeles. It is situated on the western edge of the eastern Mojave Desert, on the site of a large perennial freshwater Pleistocene lake that drained catastrophically about 15000 years ago. Today, the Mojave river flows beneath the ground through the Basin. The area studied lies between the Calico Mountains on the west, Coyote Dry Lake on the north, an alluvial fan originating in the Alvord mountains on the east, and the Mojave River on the south. Also in the north is a playa. This entire area is around 34°58’N latitude 116°42’W longitude.

Barstow received an average of 9.65 cm of precipitation between 1951 and 1977 (National Climate Data Center, 1986). The average daily maximum temperature was 80.3° F for the same period. The area is subject to frequent erosive winds, typically blowing from the west (Ray, 1995).

The native flora is dominated (in undisturbed regions) by creosote bush, in this case, *Larrea tridentata.* This shrub is an evergreen covered with small, dark leaves. A common perennial shrub is the white bursage, or *Ambrosia dumosa.* This shrub has characteristically differentiated leaves with a light gray-green color. In the region studied, the other major shrub species was *Atriplex polycarpa.* Its leaves are also lightly colored during dormancy, green when active, and simple in geometry. The species is known to be salt tolerant. (Andy Sanders, personal communication)

The area first underwent irrigation between 1884 and 1902, and reached its peak in irrigated acreage by 1951. Since then, total irrigated acreage has held fairly steady at around 7200 hectares (Tugel and Woodruff, 1986). From around the late 1950’s until the 1970’s, the primary form of irrigation was flooding from buried pipes. After this, sprinkle irrigation systems gained prominence. The circle-pivot irrigation system was almost exclusively the type of sprinkle system used. (Ray, 1995)

Center-pivot irrigation is a system which employs circular fields with a suspended sprinkler pipe that runs along a radius of the field. As water is pumped through the pipe, the assembly rotates about the center to deliver water to the entire field. This form of irrigation is very economical and has been used to cultivate crops in arid regions throughout the world.

Beginning in the early 1970's, these center-pivot fields began to be abandoned in the study area (Ray, 1995). Interviews with local residents suggest water retrieval became too expensive to continue irrigation. Satellite imagery and the memories of residents allow the active times for these fields to be estimated or constrained (Ray, 1995). Circular fields were often cultivated over old rectangular flood irrigated fields.

Figure 1 is a SPOT panchromatic-enhanced LANDSAT Thematic Mapper image of the study area taken on July 28, 1985. The image is taken from Terrill Ray's thesis. Four of the fields are numbered according to the identification scheme found in Ray's work.

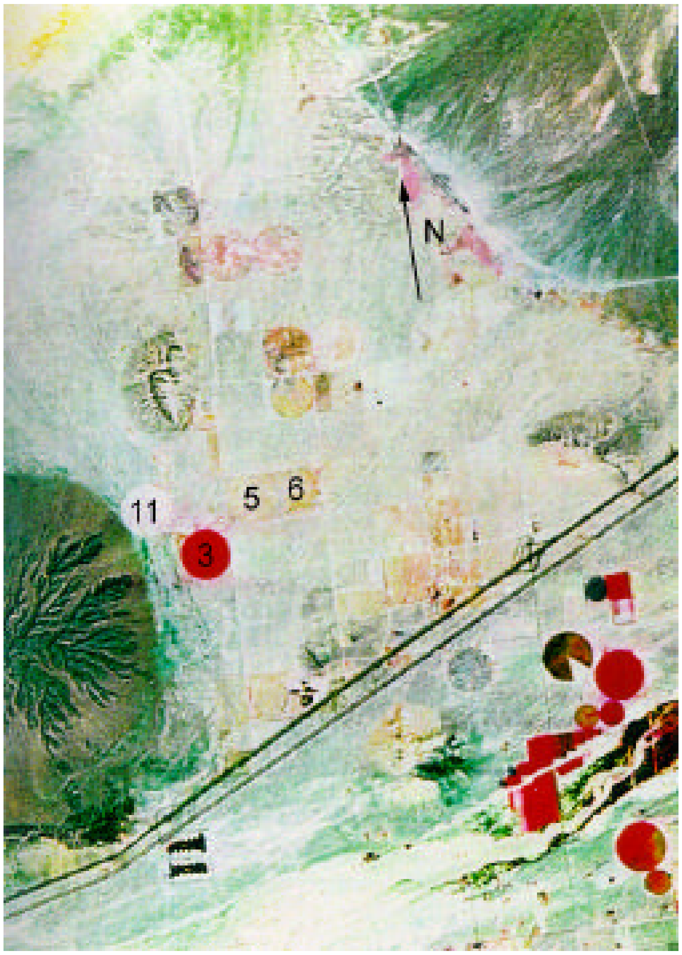

Figure 1. LANDSAT TM image of study area taken on July 28, 1985. Fields undergoing cultivation at the time the image was taken appear red. Currently there are no active circular fields north of Interstate 15 (the parallel dark lines crossing the image).

Goals of Research

The principle goal of this research was to conduct a preliminary investigation into the nature of the degradation occurring in the Manix Basin. As a part of this goal, a characterization of the plant communities in the Manix Basin was attempted. Furthermore, a preliminary investigation of soil salinity was attempted by analyzing soil samples collected in and around an abandoned field. Finally, a synthesis of the observations made during the project was constructed to form a tentative model of the land degradation process in the Manix Basin.

Methods

Two lines of investigation were pursued. To characterize the plant communities, plant cover data were collected from many locations within the study area. Next, because the plants invading the abandoned fields (*A. polycarpa*) are known to be salt tolerant, plant cover and soil salinity data were collected along a single transect including 1) undisturbed land, 2) an abandoned field, and 3) land downwind of the abandoned field.

Characterization of Perennial Plant Cover

The plant cover data were collected on April 20, 1997 and on May 21, 1997. 44 sites were selected from just north of the entrance road leading from Interstate 15 to an area north of the study site. At each site, a 5 m radius circle was drawn. Each plant within the circle was identified and measured. Only *L. tridentata*, *A. polycarpa*, *A. dumosa*, “Mormon tea,” and cholla were recorded, because these were judged to be the major large perennials. The number and type of plants within each of four size classes (0 - 2 ft, 2 - 4 ft, 4 - 6 ft, and > 6 ft of canopy diameter) were recorded.

On the May 21 trip, the 32 sites were arranged as eight groups of four neighboring sites. In each case, a location was preselected. A rock was thrown in a random direction from this location, and the landing point served as the center for the first of the four sites. This approach was used to minimize unconscious bias in site selection. The next site in the group of four was located by pacing 20 m to the north. The next was 20 m to the west, and the last was 20 m to the south. In this way, four sites lying roughly on the corners of a 20 m square were examined. This procedure was intended to examine local variability as well as to aid in future efforts to identify plant communities by AVIRIS images, which have a roughly 20 m pixel size.

The areas examined fell into six basic categories: (1) south of the fields, (2) in an old flood irrigation field, (3) north of the fields, (4) downwind of the transect field, (5)inside abandoned circular fields, and (6) west of the transect field on the base of an alluvial fan. The location of each site was measured with a hand-held GPS unit to an accuracy of about 20 m (accuracy was determined by multiple measurements of a landmark). Figure 2 shows the locations of the sites on the LANDSAT image from Figure 1.

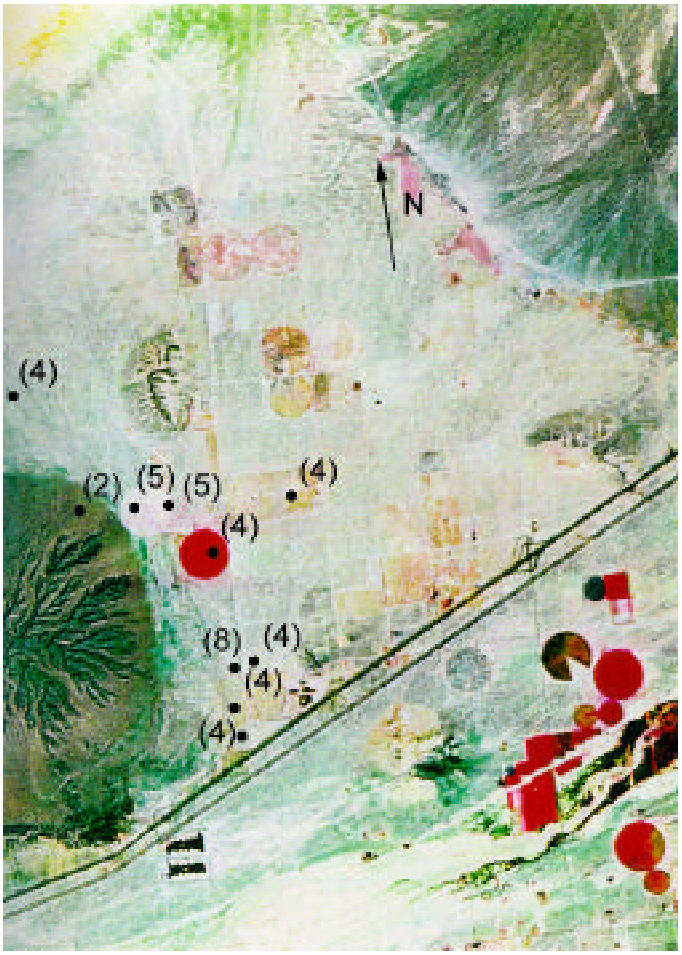

Figure 2. Locations of survey sites. The number next to each point is the number of sites at that point. Four sites do not appear because they are too far west to fit on the image.

Perennial Plant Cover and Salinity Measurements

Field 11 (see Figure 1) was chosen for a transect because of its proximity to undisturbed desert and to a variety of drainage and plant distributions. Satellite imagery suggests the existence of a drainage wash on the western half of the field, which Meek's soil map confirms. In addition, it was in some ways less disturbed than other areas. In particular, field 11 sits on the western-most edge of the valley, and so is subject to no downwind effects from other fields (Ray). Furthermore, the western half of the field was probably never subjected to flood irrigation.

The transect along which the measurements were taken was directed from west to east through the center of the field as determined by the base of the center-pivot irrigation system. The field was determined to be ~800 m in diameter; the transect was 1500 m long, which included 350 m off either side. All measurements were taken within a 5 m wide strip along the transect. The transect was done on August 7 and 8, 1996, a time when most plant species were dormant.

Plants were catalogued by species and size as measured by the average of their long and short canopy diameters. For these measurements, the plants were put in to 10 cm increment size classes. All plants were counted in 10 m increments along the transect (for a total of 50 m^2 per transect pixel). Soil samples from the top 5 cm were taken from the center of every third transect pixel (for a spacing of 30 m between each sample). Samples were stored in sealed plastic bags for transport to Caltech.

Soil samples were dried by heating at over 100° C for one hour. 10 g of each sample was mixed with 10 ml of distilled water by shaking for one hour. The resulting mixture was then centrifuged until a clear liquid separated on top, and 5 ml of this liquid was collected and diluted with 15 ml of distilled water. The conductance of this solution was then measured in order to estimate soil salinity. The conductance measurements took four days to complete. During this time, the conductance of a standard KCl solution was measured four times with a coefficient of variation of ~3%. There was no trend in this calibration data. To further ensure that no instrument drift would affect comparisons between different regions of the transect, samples were measured in random order. This 1:1 extraction procedure was suggested by Dr. Jim Wood of the USGS Soil Salinity Laboratory in Riverside, CA.

Analysis

Plant abundance data were converted to percent coverage (including bare ground) by assuming that the plants had circular cross sections with diameters equal to the average of there long and short diameters. The fractional contribution to total plant coverage (excluding bare ground) was then computed for each species. The data were then examined for identifiable groupings of communities, and correlations to the type of location in which they were found. The abundance data from the transect were processed in the same way.

Salinity data were collected in units of the conductance of a dilute solution. From this, the equivalent concentration of the salt ions present in solution was estimated, as if they came from KCl salt, by use of a standard conductance curve calculated from dilute KCl solutions (see Appendix). All salinities were expressed in mmol_c[*] per kg of soil. Average salinities were calculated for both areas off the field (west and east), and for the field itself. The data were checked for significant linear dependencies (as judged by the t-statistic for the slope) on transect position in each area.

Finally, for each species, the salinity data were regressed against the plant data and examined for significant linear relationships. Points were only used if there was a plant of the particular species (of any size) present in the pixel to prevent the data from being flooded with points with no plants, and to try to eliminate other factors which might influence local plant density (such as vicinity to parent populations).

Results

The most abundant species in most of the locations surveyed was either *L. tridentata* or *A. polycarpa.* For this reason, these two species were chosen to characterize the sites studied. The average communities for each of the eight site groupings are included in Appendix B. Figure 3 is a ternary plot which represents the communities from each site by the fraction of plant cover that is *L. tridentata* and the fraction of plant cover that is *A. polycarpa.* Most of the communities fall along the *L. tridentata* axis; these typically come from sites west of field 11, south of the fields, or on the old flood field south of field 3. In these communities, *L. tridentata* dominates over *A. polycarpa.* Some

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[*] 1 mmol_c = 1 meq

lie at the top of the *A. polycarpa* axis; the majority of these come from inside abandoned fields. In these communities, the dominant of the pair is *A. polycarpa*. Finally, some points lie in the triangle between the axes; these communities come from sites either to the north of the fields or in the downwind region of field 11. In these communities, neither species has clear dominance.

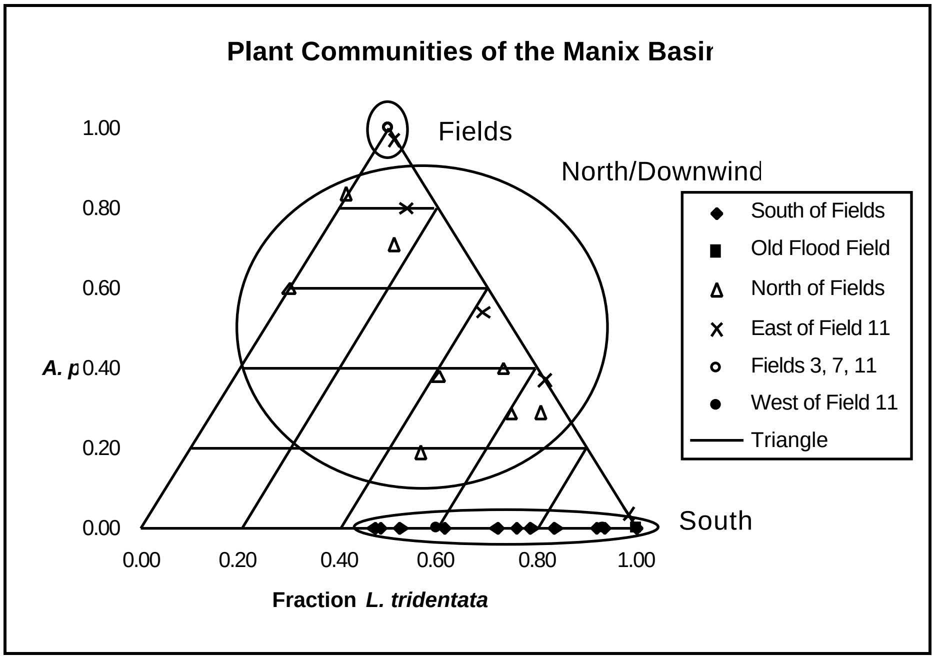

Figure 3. Plant communities characterized by relative abundances of *L. tridentata* and *A. polycarpa*. Disturbed areas tend to fall on the top of the *A. polycarpa* axis, areas downwind of disturbed areas and areas north of the fields fall in the triangle between the axes. Areas south of the fields tend to be mostly *L. tridentata*.

Other species occur more infrequently. Cholla, for instance, never fell inside a site. Mormon tea occurred in some of the southern and northern sites, but not frequently enough to make comparison between occurrences very meaningful. *A. dumosa* was typically the rest of the cover that was neither *L. tridentata* or *A. polycarpa*.

The plant populations found along the transect were analyzed in the same way. Figure 4 is the equivalent ternary plot for the transect data. Once again, the communities divided between *L. tridentata* dominance over *A. polycarpa* (west of the field), vice-versa (on the field), or some split (east/downwind of the field).

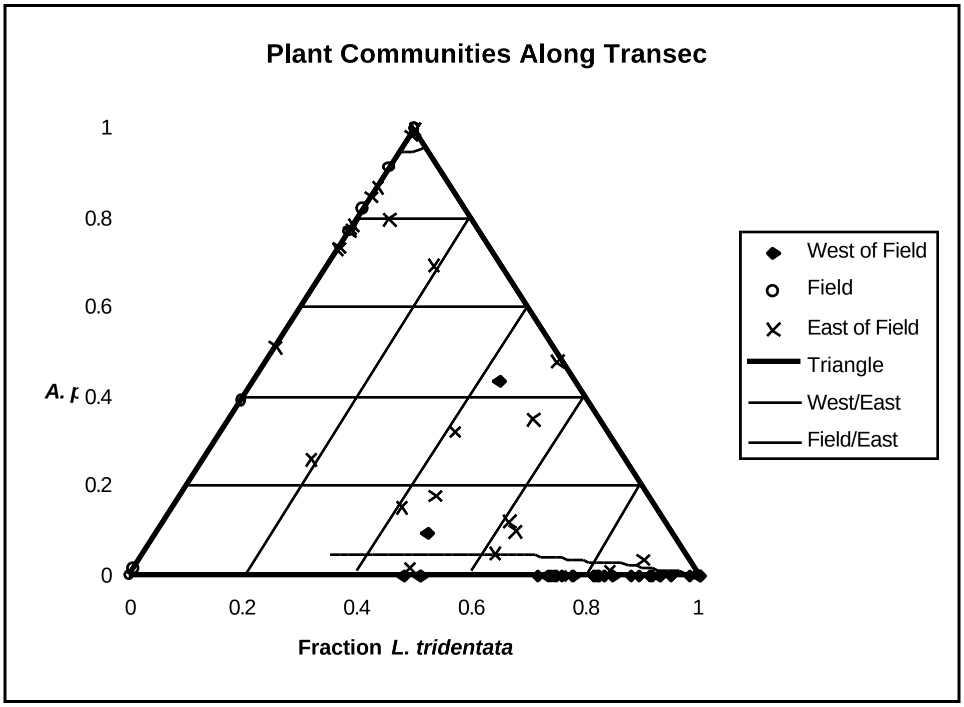

Figure 4. Plant communities along the transect characterized by relative abundances of *L. tridentata* and *A. polycarpa*. 80% of the western points fall on the bottom of the triangle. 47% of the field points fall on the tip of the triangle; 37% of the field points had none of the survey shrubs in them and appear on the origin. 66% of the eastern points fall in the triangle; 11% of the eastern points had either none of the survey shrubs or had only *A. dumosa*, and appear on the origin.

Figure 5 illustrates the plant distribution along the transect as percent cover. Negative distances are west of the center of the field; positive distances are east. The field edges lie at ±400 m. It is readily apparent that vegetation changes drastically, not only in density, but also in composition as the field is traversed, as seen before in Figure 4. In general, on-field vegetation in the transect is limited to a large patch of *A. polycarpa* on the eastern half. This is true of the rest of the field as well, although there are some patches to the north and south of the transect on the western half. On the western off-field region, *L. tridentata* dominates. The eastern off-field region is far more heterogeneous.

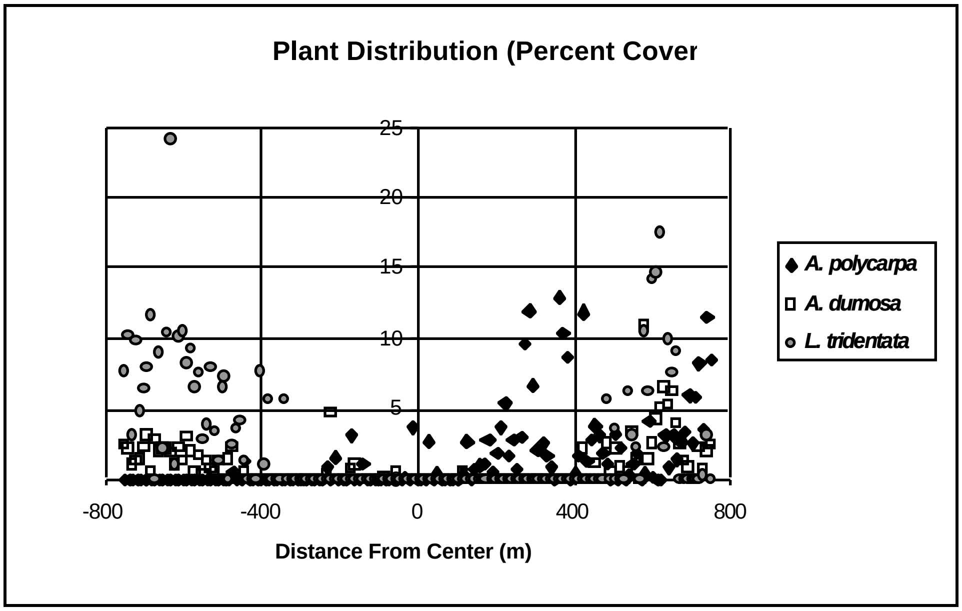

Figure 5. Plant cover across an abandoned field (11). The field boundaries are at ±400 m.

Figure 6 illustrates the salt distribution along the transect. Also plotted are the mean salinity values for each major region (west off-field, field, and east off-field) together with error bars showing the sample standard deviations. Note that the error bars are not the standard errors on the estimations of the means; even though the plotted bars overlap, the means are still significantly different* . The large spike at +500 m was not incorporated into this analysis. The mean salinities on the west off-field, field, and east off-field regions were 2.44 ± 0.14** , 3.15 ± 0.14, and 2.70 ± 0.12 $\text{mmol}_c\ \text{kg}^{-1}$, respectively. To determine if the mean salinities in these regions were significantly different, a t test was performed on the null hypothesis H_0 = “the mean salinities are equal.” The differences in means between the off-field regions and the field were significant ($P < 0.001$ for the west and $P = 0.02$ for the east). The difference between the two off-field regions was not significant at the 95% confidence level ($P = 0.15$). The salinity measurements had no significant linear relationship to transect position in any region.

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* Standard deviation is an estimate of the variance of data; given enough data, it provides a measure of the natural spread about the mean. Standard error is an measure of certainty for a statistical estimate; with an increasing amount of consistent data points, standard error will tend to decrease, representing increasing confidence that the estimated mean is close to the true mean.

** ± 1 standard error

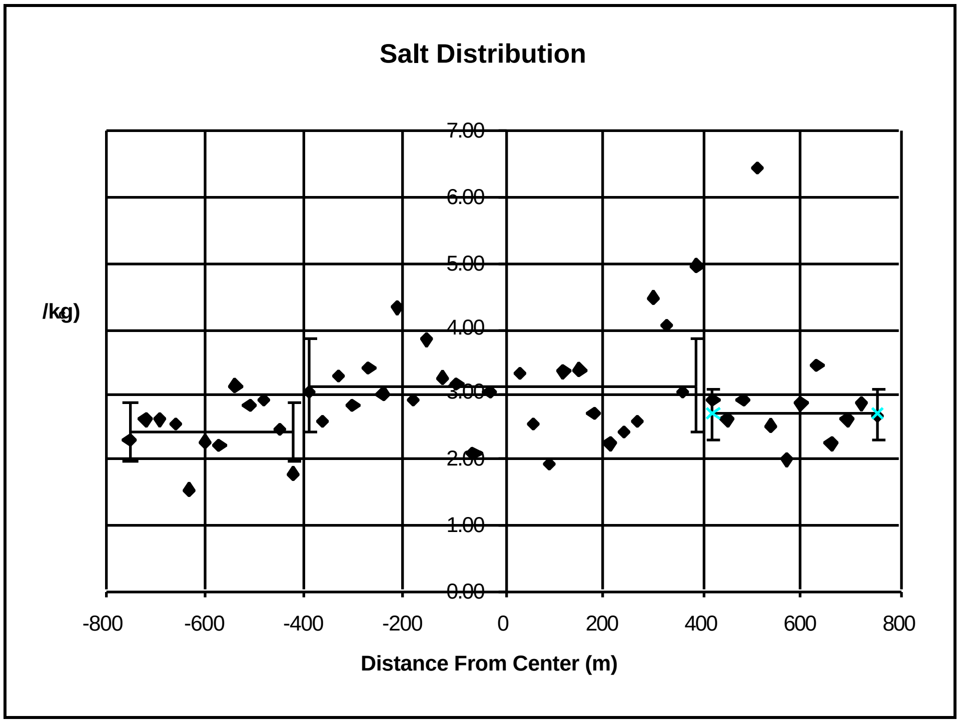

Figure 6. Salinity across an abandoned field (11). The field boundaries are at ±400 m.

A significant linear relationship between soil salinity measurements and *L. tridentata* cover was found in the transect data. Figure 7 illustrates this. The slope of the regressed line is significantly different from zero (P = 0.02 by a t test), and this difference remains significant at the 95% confidence level even if the regression is performed without the right-most point. The possibility that salinity might be limiting populations of *L. tridentata* (that the observed correlation reflects a causal relationship) is reinforced by the observation that shrubs of that species frequently appear salt burnt on the east side of field 11. However, this correlation (and the other plant-salinity relationships examined in this section) can be considered only suggestive of a true causal relationship until further experiments are performed over a wider range of regions in the Basin.

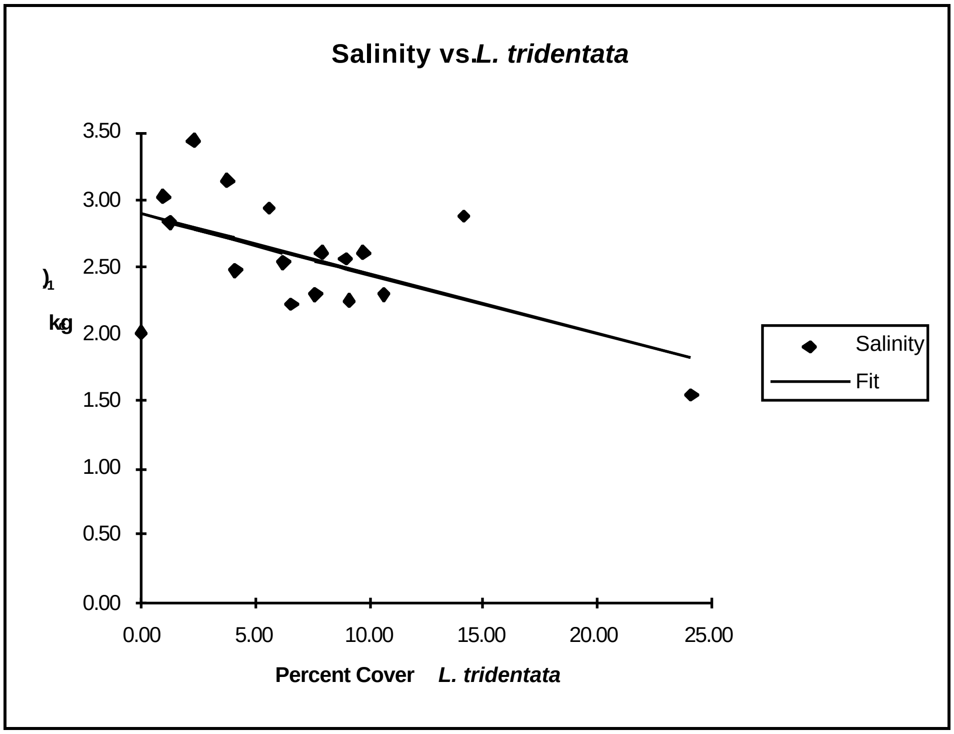

Figure 7. Negative relationship between *L. tridentata* and salinity measurements. The slope is significant at the 95% confidence level. A = (-0.044 ± 0.016)t + (2.88 ± 0.16)

A. polycarpa also displays a negative correlation with salinity measurements. Figure 8 illustrates this. However, note that *A. polycarpa* are still detected at higher salt concentrations than *L. tridentata*. One way of quantifying this is to examine the intercepts of the fitted lines: the intercept for *A. polycarpa* is a significantly higher at the 95% confidence level by a t test.

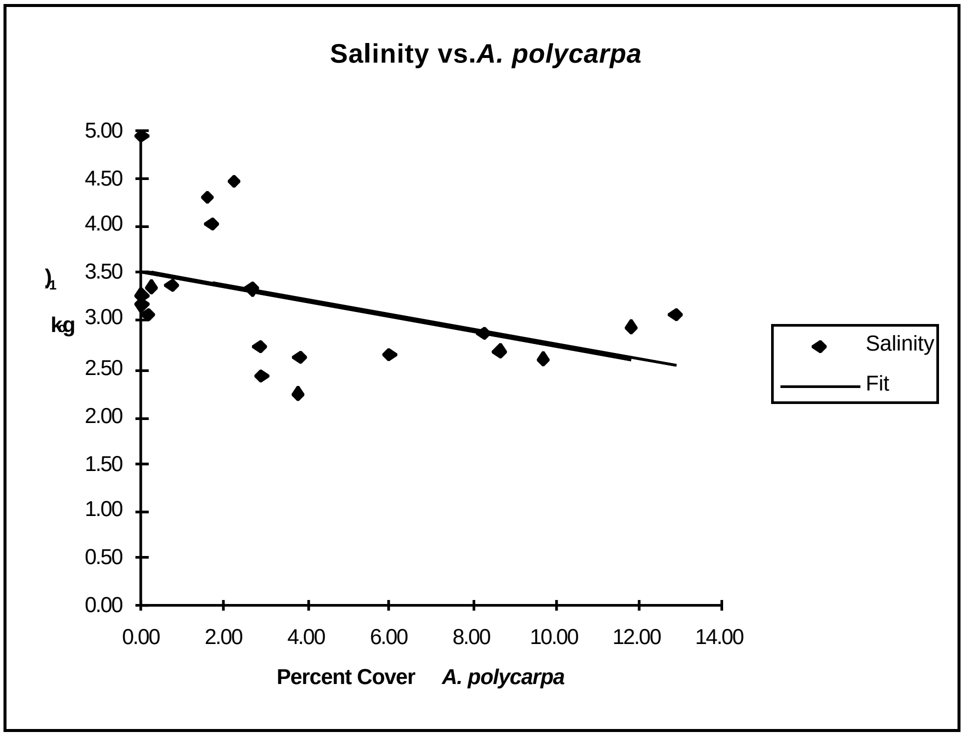

Figure 8. Negative relationship between *A. polycarpa* and salinity. The slope is significant at the 95% confidence level. A = (-0.078 ± 0.037)p + (3.51 ± 0.21)

Regression reveals no significant correlation between salinity measurements and *A. dumosa* cover (Figure 9). This would seem to indicate that there are other factors more important than salinity determining where this shrub grows.

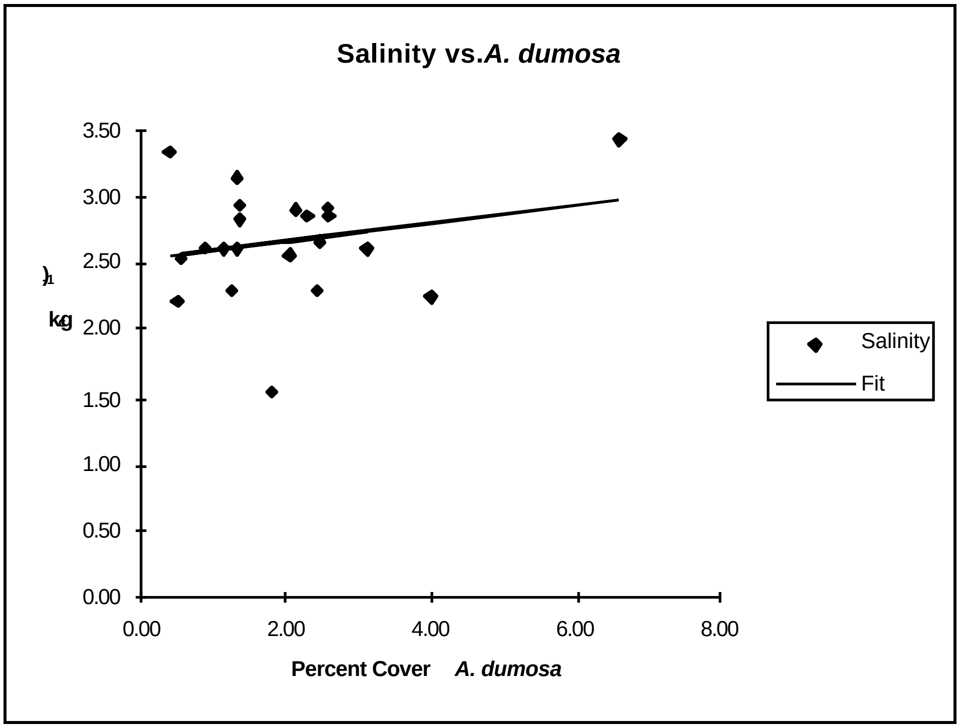

Figure 9. There is no significant relationship between soil salinity and *A. dumosa* cover. A = (0.069 ± 0.067)d + (2.53 ± 0.16)

A final analysis was performed to explore the effect of soil salinity upon community composition, as represented by the relative fractions of *L. tridentata* and *A. polycarpa*. First, the fraction of *L. tridentata* and *A. polycarpa* cover that was *A. polycarpa* was calculated:

$$f = \frac{A.\ polycarpa \text{ cover}}{A.\ polycarpa \text{ cover} + L.\ tridentata \text{ cover}}$$

f is a number that varies from 0 (all *L. tridentata*) to 1 (all *A. polycarpa*). Communities for which $f = 0$ would appear on the horizontal axis on a graph like Figure 4. Communities for which $f = 1$ would appear on the vertical axis, and communities for which $0 < f < 1$ would appear in the triangle between the axes. Figure 10 shows f plotted against salinity.

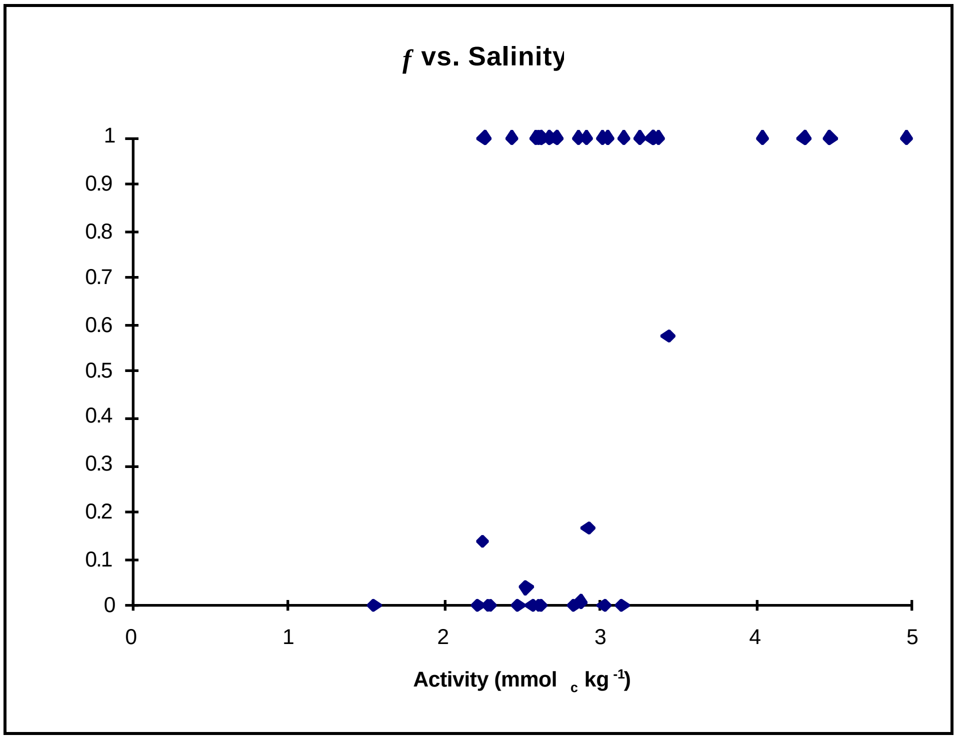

Figure 10. The fraction of *A. polycarpa* cover + *L. tridentata* cover that is *A. polycarpa* plotted against soil salinity.

These points do not suggest any smooth curve. However, it appears that low values of *f* are more frequent for low activities, while higher values are more frequent for high activities. This suggests that some sort of salinity-dependent frequency may be calculated. Thus, the data was divided into salinity “bins” of equal size, and the frequency of communities in each bin for which *f* > 0.5 was calculated. Table 1 shows the result.

Salinity (mmol$_c$ kg^{-1})	Number of Sites	Number of Sites with *f* > 0.5	Frequency of *f* > 0.5
2.2 - 2.4	5	1	0.20
2.4 - 2.6	5	2	0.40
2.6 - 2.8	6	4	0.67
2.8 - 3.0	5	2	0.40
3.0 - 3.2	6	4	0.67
3.2 - 3.4	4	4	1.00
3.4 - 3.6	1	1	1.00
3.6 - 3.8	0	0	-
3.8 - 4.0	0	0	-
4.0 - 4.2	1	1	1.00

4.2 - 4.4	1	1	1.00
4.4 - 4.6	1	1	1.00
4.6 - 4.8	0	0	-
4.8 - 5.0	1	1	1.00

Table 1. Frequency of *A. polycarpa* dominance over *L. tridentata* for ranges of soil salinity.

Another way to interpret this data is as the probability that *A. polycarpa* will dominate *L. tridentata* in an area given its soil salinity. In that sense, a probability function of salinity has been estimated. This function is shown in Figure 11. The probability of *A. polycarpa* dominance can be seen to increase with increasing salinity.

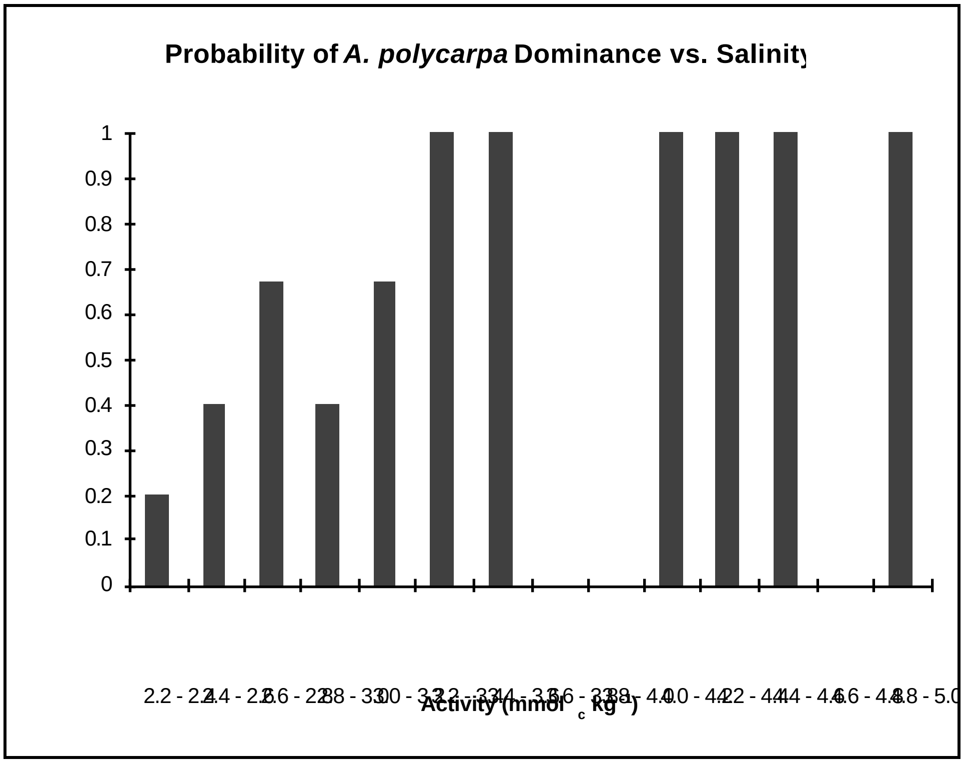

Figure 11. Frequency data interpreted as a probability function. Probability increases with increasing salinity.

Discussion

The data collected for this study suggest several important hypotheses for further testing about the plant communities and soil chemistry of the Manix Basin: 1) plant communities are well classified by the relative coverage of *L. tridentata* and *A. polycarpa*, 2) soil salinity plays a major role in determining what communities will inhabit different areas, and 3) soils in abandoned fields and their downwind regions have higher salinities than nearby regions. Moreover, these hypotheses can be connected to provide a preliminary model of the degradation process operating in the Basin.

Classification of Plant Communities

Figures 3 and 4 suggest that plant communities might be classified into groups by considering the relative cover of *L. tridentata* and *A. polycarpa*, and that these tend to correlate with groupings based on location within the Basin. In particular, the plant cover on abandoned fields is almost entirely dominated by *A. polycarpa*. Plant cover in relatively undisturbed regions in the southern portion of the study area and on the alluvial fan to the west is almost entirely dominated by *L. tridentata*. Plant cover in the downwind area of field 11 and in the undisturbed areas in the northwest portion of the study area is typically a mix of both. Figure 12 summarizes this classification in a ternary diagram.

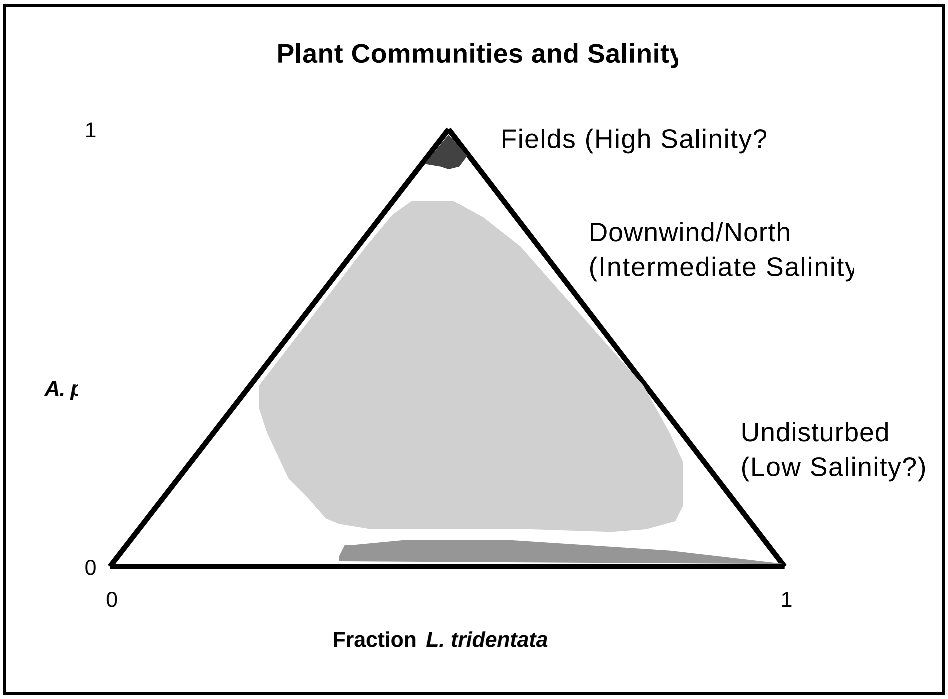

Figure 12. General classification of Manix Basin plant communities.

The other major plant species were not used for classification because they were either too poorly represented in the data (Mormon tea, cholla) or they didn't add significantly to the classification (*A. dumosa*). In particular, *A. dumosa* was represented in nearly all of the samples, but did not appear to help distinguish between the regions any more than did *L. tridentata* and *A. polycarpa* already.

It seems slightly strange that the undisturbed communities from north in the study region should appear the same as the downwind sites of field 11. In fact, this is one instance in which Mormon tea might be useful for classification, since the downwind area didn't have any while the northern sites sometimes did. Beyond that, it is still fair to ask how *L. tridentata* and *A. polycarpa* can coexist when nearly everywhere else they are separate. It is possible that the answer to this question involves soil salinity; there might be a salt gradient approaching the playa to the north that drives the plant communities into a mixed composition (see below).

Salinity and Plant Communities

Figures 7 and 8 demonstrate statistically significant correlations between soil salinity measurements and the percent coverage of *L. tridentata* and *A. polycarpa.* These correlations suggest direct cause and effect relationships. For instance, the *L. tridentata* in the downwind area of field 11 appear burned, a common appearance for plants that are undergoing salt stress. This could indicate that elevated soil salinity levels are inhibiting the growth of the shrub in that area. Moreover, a negative salinity measurement-percent cover correlation suggests that might be one of the limiting factors in *A. polycarpa* growth. *A. polycarpa* is not significantly correlated with any other shrub, implying that inter-specific competition was probably not the major control of the populations examined. Finally, *A. polycarpa* appear to decrease in abundance with vicinity to the playa, where the soil salinity must be much higher (at some points, evaporites are visible on the soil surface). Instead, *Atriplex canescens* takes its place. *A. canescens* is known to be more salt tolerant than *A. polycarpa.*

Assuming that *L. tridentata* and *A. polycarpa* are both limited at some point by soil salinity, it is seems likely that *L. tridentata* is limited at a lower salinity level. This is suggested by the significantly lower intercept found for *L. tridentata* in the salinity regressions. Moreover, the fit for the *A. polycarpa* regression was not nearly as good, suggesting that other factors may have similar magnitudes of control over distribution of the shrub. For instance, since *A. polycarpa* are frequently observed growing in clusters oriented about the principle wind direction, it seems likely that the species is limited by a need for wind nursing. It should be noted, however, that the slopes can not be distinguished statistically. Thus, for each species, if soil salinity is increased in their limiting range by 0.10 $\text{mmol}_c\ \text{kg}^{-1}$, it might be expected that shrub concentrations would decrease on average by about

$$\Delta cover = \frac{0.10\ \text{mmol}_c\ \text{kg}^{-1}}{-0.05\ \text{mmol}_c\ \text{kg}^{-1}\ \%\text{cover}^{-1}} = -2\%$$

As an example of the kind of scale of change that this is, on a 2 m by 2 m plot of soil, this change in cover is about equivalent to the loss of a small plant (30 cm diameter).

Finally, Figure 11 suggests that salinity had an influence in determining what plant community was present in points along the transect. Thus, salinity might be a controlling factor in both species composition and abundance along the transect. It is conceivable, although not directly tested here, that salinity is a controlling factor for the plant communities throughout the Basin. It might even be possible to estimate soil salinity simply by examination of the plant species present. For instance, given an area in which both *L. tridentata* and *A. polycarpa* are present but *A. polycarpa* is the more dominant of the two, Figure 11 would estimate a likely lower limit for salinity of ~2.8 $\text{mmol}_c\ \text{kg}^{-1}$. Note that this salinity lies between the estimated intercepts of the shrub/salinity correlation regressions (Figs. 7 and 8). This number was obtained by a separate analysis of the same data, which indicates some degree of internal consistency to this analysis. This is certainly a hypothesis that needs to be tested, because it has implications for low-cost surveying of local land for salinity and for remote sensing of the area (assuming that plant species may be distinguished by remote sensing data).

Salinity Distribution

The transect of field 11 shows a ~30% increase in soil salinity on an abandoned field over that of the undisturbed land nearby. A strict statistical analysis of the downwind area can not distinguish an elevated salinity above the undisturbed region with the data collected for this study. However, there are good reasons to expect such an elevation, and to believe that it exists. First, erosive winds should transport dust with high salt content off of the field and into the downwind region. Second, the mixed plant community in the downwind region is suggestive of a soil salinity higher than the *L. tridentata* dominated community upwind. Why, then, is such a difference not detected?

One part of the explanation lies in the fact that there are simply less points to compare between the upwind and downwind regions than with the field. This drives the standard errors on the estimated means for the off-field regions higher than on-field, making comparison more difficult. Another possible explanation has to do with the mechanism by which the salt would have reached the downwind region. It was blown there, so it would have been concentrated about the best wind blocks; assuming that region was originally also dominated by *L. tridentata*, the best blocks would have been the large shrubs. This is evidenced by the long mounds of sand built up around *L. tridentata* east of field 11. This would lead to an extremely heterogeneous distribution of salinity, making changes in mean values difficult to detect. Unfortunately, the heterogeneous distribution hypothesis can not be conclusively proven or disproven with the data collected since the number of points taken does not sufficiently constrain the estimated variances for any of the regions of the transect. Another contributing factor to the inability to detect the hypothesized salinity difference is noisy experimental technique.

Sources of Variance

Variance in the salinity data is the result of two processes: these are experimental error and natural variation. In order to estimate the fraction of the variance that results from experimental error, three locations on the transect were tested for salinity in three samples each. Thus, considered as groups of three, there were 27 different groups of samples. For instance, one group might contain the first sample from the first location, the second sample from the second location, and the first sample from the third location. Each group contained one sample from each location. The variances for each group were calculated and averaged. Finally, the variances for each location were calculated and averaged. The ratio of the average location variance to the average total variance was ~45%, suggesting that nearly half of the variance seen in the data was a result of experimental error. While this does not invalidate the results of this paper, it does suggest that much could be done (such as shaking the dry samples and sorting out the larger particles before conducting measurements) to improve precision, and possibly distinguish between different regions of salinity.

Limitations of the Conductance Method

The conductance of a solution may be estimated from the equivalent conductances and the molar concentrations of the dissolved electrolytes by the following formula:

$$\Lambda \approx \sum_i n_i \lambda_i [\mathrm{E}_i],$$

where n_i is the valence and λ_i is the equivalent conductance of salt E_i. It is impossible, however, to invert the equation to obtain some measure of total dissolved salts if there is more than one species of salt in solution. In order to do this, some knowledge of the relative abundances of the dissolved species would be necessary. While it is possible to guess that salts containing Fe, Cl, Ca, K, etc. are probably important in the samples collected for this study, all analysis was done without information about the relative abundance of these species. Thus, all equivalent concentrations quoted in this paper should be considered only as a convenient way of reporting the conductance of a sample solution. In other words, what is really meant by the statement “Sample X contained 2.0 $\mathrm{mmol_c\ kg^{-1}}$ of salt,” is “A 1:1 extract of sample X produced a solution with enough salt in it to yield a conductance equal to that of a solution containing 2.0 $\mathrm{mmol_c\ L^{-1}}$ KCl.” At most, the concentrations reported here may be regarded as order-of-magnitude estimates of the equivalent concentrations of soil salt.

Furthermore, this paper is partially concerned with relationships between soil salinity and plant distributions. The really interesting thing about soil salt, in the context of this report, is its toxic effects on plants. What would be truly useful is some “toxicity” function of salt concentration in soil:

$$toxicity = T([\mathrm{E}_1],[\mathrm{E}_2],\ldots[\mathrm{E}_i],\ldots)$$

There is no particular reason to expect this hypothetical function to be correlated to conductance:

$$\Lambda \approx \sum_i n_i \lambda_i [\mathrm{E}_i]$$

Thus, even if salinity has a significant effect on plant distribution, there is no a priori reason to expect to see this effect reflected in conductance data such as those presented in this paper. Conversely, a correlation between conductance and plant distribution does not necessarily reflect salt toxicity effects. Further experiments need to be conducted to determine the major salts in the Manix Basin soils.

A Preliminary Model of Degradation

The hypotheses presented above can be tied together to form a tentative model of degradation for the abandoned fields in the Manix Basin. This model appears to fit the observations made for this project, and is probably the first model to be proposed for this particular system. What follows may be considered a "story" reconstructed from the hypotheses formulated during this preliminary exploration.

The process of degradation begins when land is first converted for cultivation. At this point, the native cover of *L. tridentata* and desert armor is removed to make way for the field. In removing the *L. tridentata*, the element that excludes other species is removed (McAuliffe 1994, Mahall and Callaway abstract, 1991). In removing the armor, the element that holds soil in place against wind erosion is removed.

The next step occurs during cultivation. In the Manix Basin, it is possible that the water used to irrigate the fields was saline (interviews with local residents suggest that this might have been true). In any case, irrigation in an arid environment will almost certainly lead to salinization of the soil. For the transect field, this portion of the degradation process happened extremely rapidly. Remote sensing constrains the time of active cultivation to just three growing seasons between 1975 and 1977 (Ray, 1995).

When a field is abandoned, the first plants to invade are grasses (Ray, 1995). At this step, it may be that a critical point is reached. Since the field has high salinity, *L. tridentata* cannot begin to recolonize it. However, a few *A. polycarpa* might be able to take advantage of the small protection from the wind that the grass offers to begin to invade. Several things may interfere with this: *A. polycarpa* might simply have a year during which seed production is especially low, the soil might have been compacted to the extent that *A. polycarpa* cannot invade, or *A. polycarpa* may not hit its seeding season at the same time as the grasses. Depending on whether or not the shrub is able to invade quickly, two routes might be followed from here.

If *A. polycarpa* manages to establish itself in areas throughout the field, then the next growing season it will have wind-nurses to aid in invasion. The rate of colonization of the field will increase, even after the grasses have used up the remnant nutrients from the cultivation and are no longer able to thickly cover the ground inside the field. A moderate amount of soil will be eroded off of the field, but the *A. polycarpa* community will eventually stabilize the surface simply by covering most of it. In this way, the *A. polycarpa* community actually helps to regulate the salinity of the field.

If *A. polycarpa* does not establish itself quickly, it will have to invade primarily from the edges toward the center, a much slower project. Wind erosion will continue to remove salinity at a relatively high rate.

If the first path is followed, salinity will eventually stop decreasing as the wind will no longer be able to excavate soil from the thick *A. polycarpa* cover. The remaining salinity will continue to exclude *L. tridentata*, making this kind of a field stable over the 100 year time scale. The time scale was estimated by assuming that wind is the chief remover of salinity, that the saline soil region extends to ~ 1 m depth, and that about 50 cm of soil can be excavated in 50 years (Ray, 1995). If the second path is followed, salinity will continue to drop until *L. tridentata* can successfully compete. This system is not stable over the 100 year time scale, and should be reclaimed as normal desert eventually.

In both cases, the salt transported downwind will accumulate about large *L. tridentata*, causing salt stress and allowing other species to invade. This produces the type of mixed population seen east of field 11.

One possible problem with this model is that it does not account for variability in precipitation, which might keep the invasion process of *A. polycarpa* from being continuous as the model assumes. It could be that occasional droughts happen that cause fields which had fallen well into the model on one path or the other to look more similar to one another.

The model predicts more downwind disturbance in fields that do not get quickly invaded by *A. polycarpa*. However, fields 6 and 7 (fast reclamation fields) exhibit more blown wind in remote sensing for longer than field 11 (a slow reclamation field) (Ray, 1995). This should be checked in the field.

Proposals for Further Research

Since soil samples where collected from the centers of transect pixels, their locations were essentially random with respect to plant positions and land form. It is thus unknown how salinity varies with respect to distance from plants or if sand deposited from upwind fields contain more salt than neighboring soil. Conducting small scale (covering ~100 m^2 of ground surface per analysis) salinity surveys, noting the positions of plants and wind-deposited mounds of soil, should provide considerable insight into shrub/salinity and deposition/salinity relationships. Moreover, if a consistent method for collecting samples so as to measure salinity in locations significant to the shrub populations could be developed as a result of this experiment, later surveys could be conducted more efficiently. This type of small scale study should be considered a high priority in any future investigations of the Manix Basin degradation process.

After such a study has been carried out, a much larger survey of perennial communities and soil salinity could be conducted that covers most of the Basin, including the land approaching the playa to the north of the region examined in this paper. This would not necessarily need to be done by transect; it could be done by distributing sites as in the classification survey conducted for this project as long as the site location was recorded by GPS. The purpose of such a large scale survey would be to test the classification scheme proposed here, and to extend the examination of shrub/salinity relationships to the entire Basin.

Finally, more field transects could be performed to confirm elevated salt levels on other fields. Ideally, such transects would contain enough points (placed in ways informed by the small-scale survey) to confirm or deny regions of higher salinity downwind of abandoned fields.

Conclusions

A preliminary investigation into the degradation process in the Manix Basin was performed. Two viable methods of shrub surveying were employed, and a protocol for estimating soil salinity in this region was developed. Several important hypotheses suggesting processes at work in the Basin were formulated for further testing.

A preliminary characterization of the shrub communities in the Manix Basin was developed, and a suggestive correlation between soil salinity and shrub communities was found. Elevated salinity has been documented on an abandoned field. Finally, a tentative model that synthesizes these hypotheses, incorporating wind erosion, salinization, and ecology and involving biotic control of salinity, has been proposed to explain the patterns of degradation observed.

These hypotheses and the model need to be tested. Small scale salinity analyses should be performed to examine the distribution of salt around plants and wind deposited mounds. Salinity data needs to be taken throughout the Basin to see if the correlation with plant communities holds. Downwind areas of different fields should be compared to look for the distinction between fast and slow reclamation fields proposed earlier. The model proposed here can be used to generate other hypotheses to conduct productive experiments.

In conclusion, the time scale of the problem should be noted. The only conventional method for correcting saline soils is by flushing with fresh water and removing the drainage. Even in areas with abundant water supplies, this is a costly and labor intensive project. In arid regions, such as the one studied, this is next to impossible. Natural processes such as erosion will have to remove the salt. The tentative model proposed here suggests that the fields which will recover will do so on the 100 year time scale, but that some fields simply won’t recover. Already 18 years have passed without a restoration of field 11. Thus, the observations made during this project suggest that the interaction between wind erosion, salinization, and ecology occurring in the Manix Basin may result not only in large areas of degraded soil, but in an extremely long period of restoration, if restoration occurs at all.

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Appendix A- KCl Standard Curve

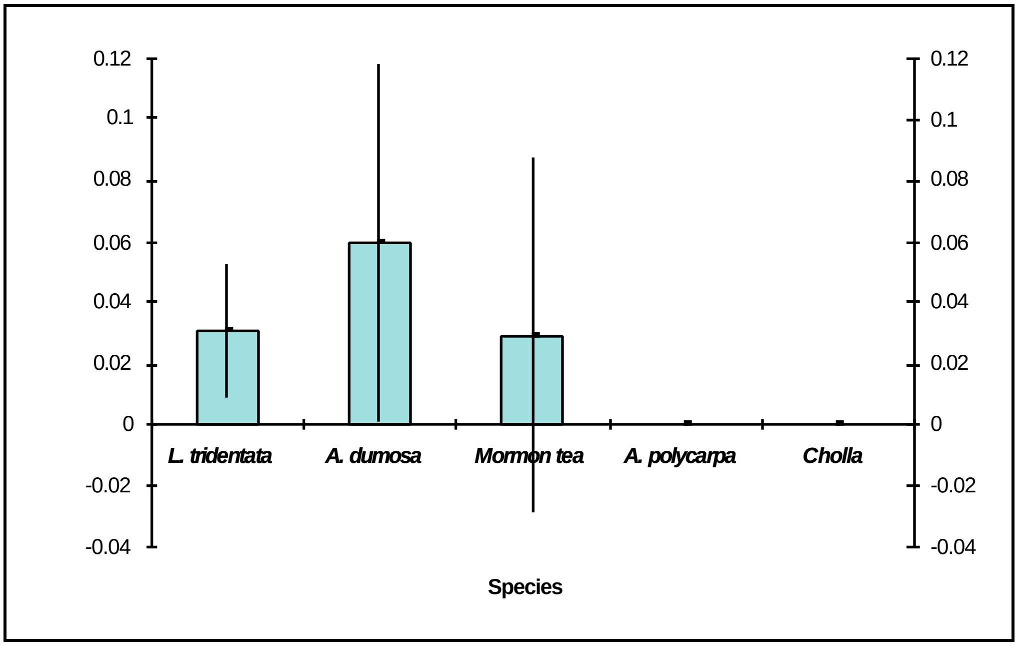
Concentration (mM)	Conductance (µS cm^{-1})
1000	101 500
100	11 580
10	1 272
5	656
1	135.2

Appendix B - Average Plant Communities from Eight Site Clusters

This section contains fractional coverage (including bare ground) data for the eight site clusters used to characterize the perennial plant communities in the Manix Basin. Each graph shows the mean fraction of area covered by each species together with error bars illustrating the associated sample deviation. The location included was the location of the first site in the group.

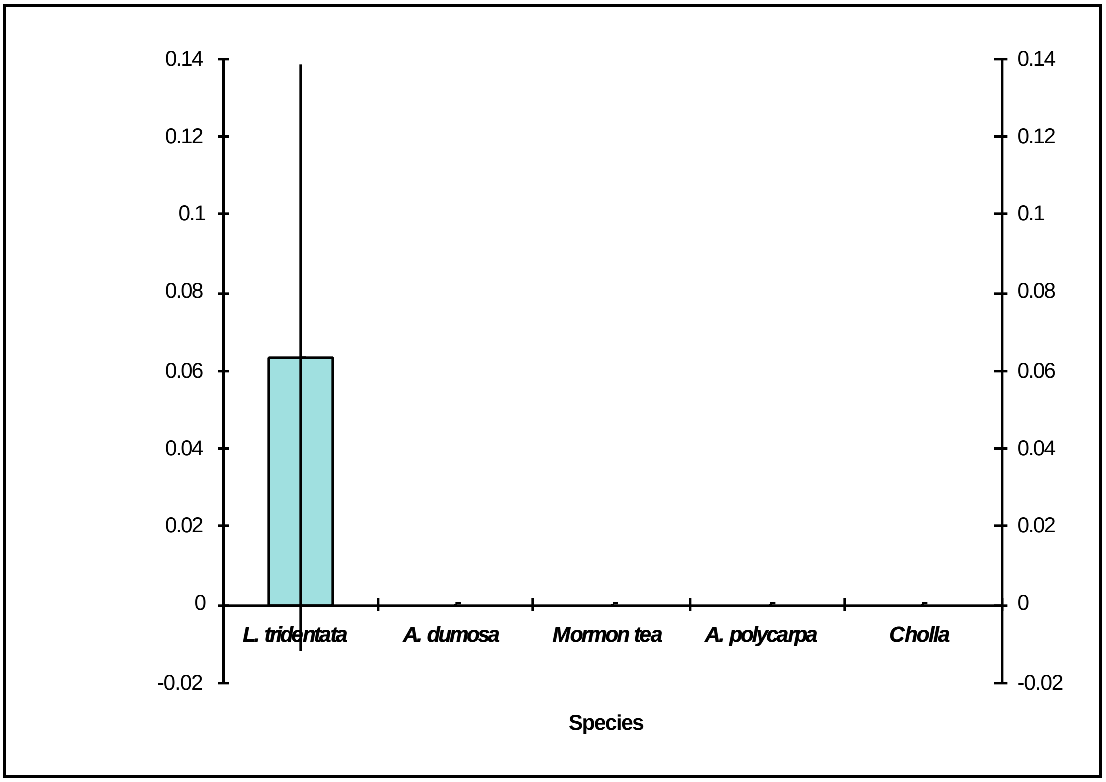
Group 1. Lightly armored, small-medium pebbles, stable surface, slowly rolling. Southern-most group.

34° 56’ 36.5” N 116° 41’ 53.0” W



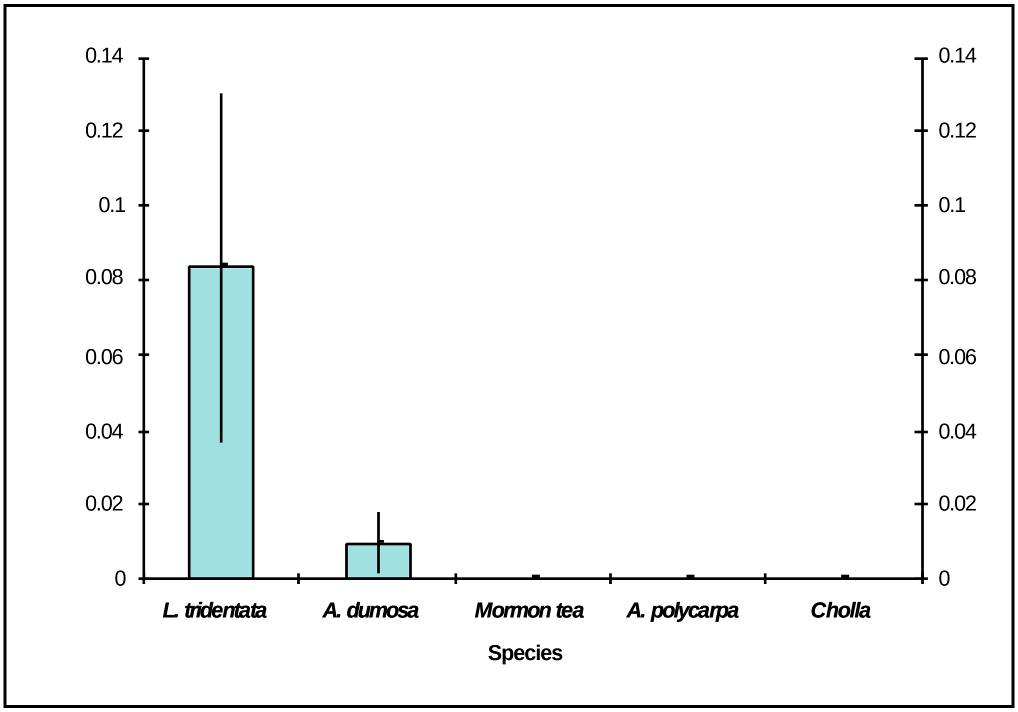
Group 2. Small pebbles, level surface, light wind rippling. Inside an old flood-irrigation field.

34° 56’ 51.1” N 116° 41’ 56.7” W



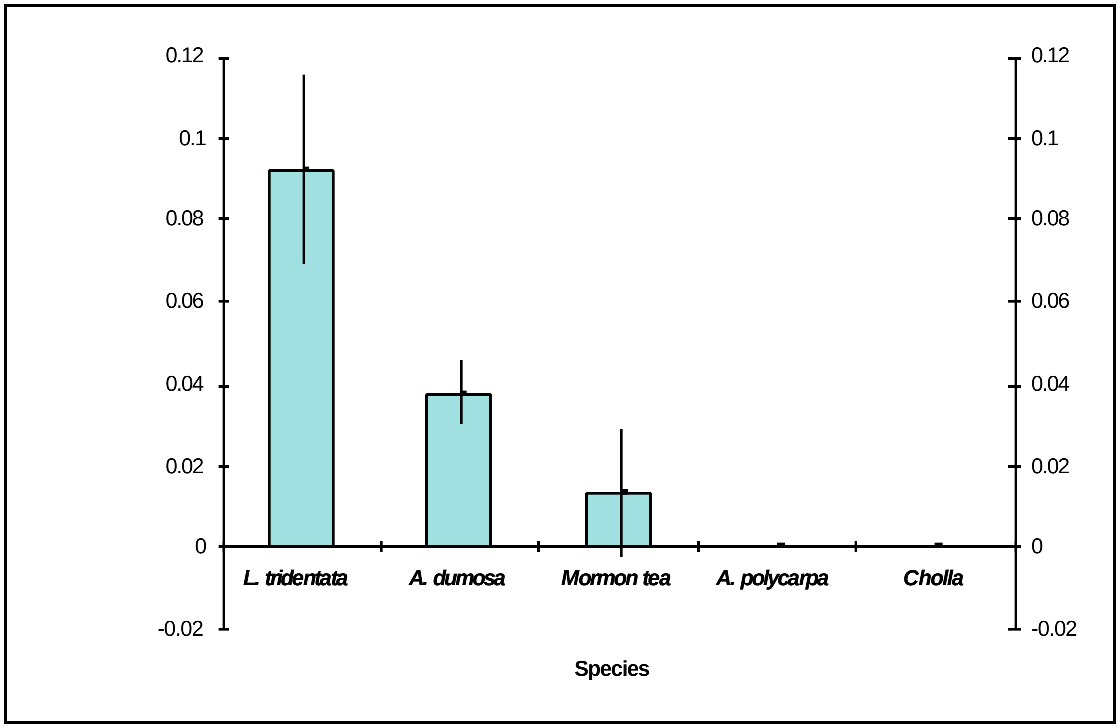
Group 3. Well sorted small pebbles, very slowly rolling surface, yellow grass present. Directly north of an old flood-irrigation field.

34° 57’ 11.0” N 116° 41’ 54.5” W



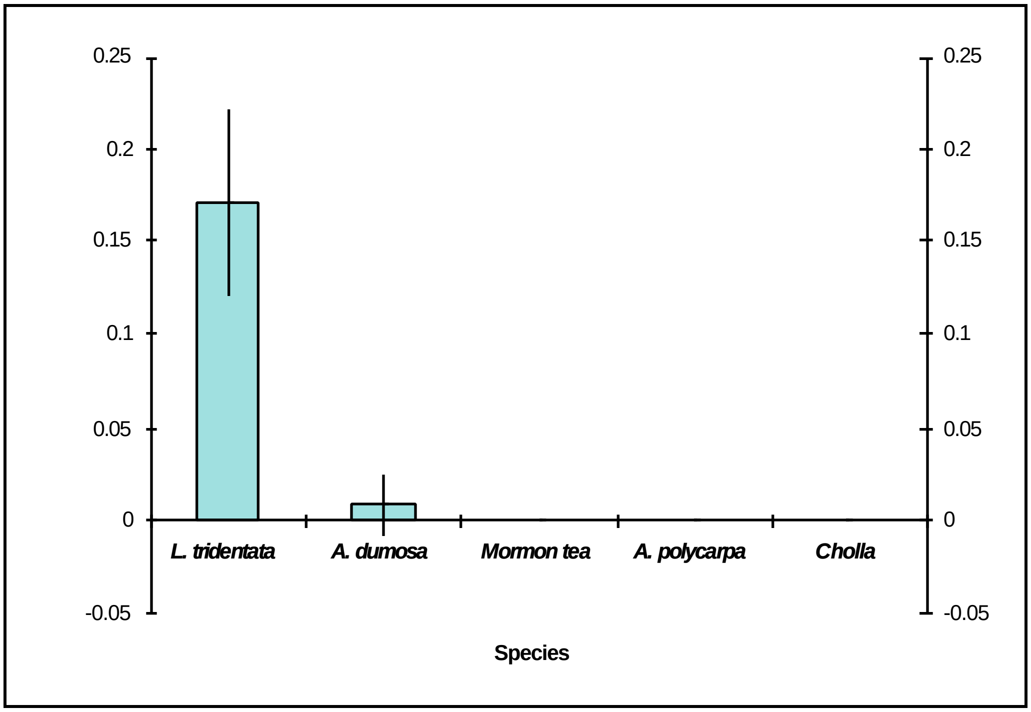
Group 4. Poorly sorted pebbles, small rocks, level surface. East of Group 3.

34° 57’ 10.8” N 116° 41’ 51.2” W



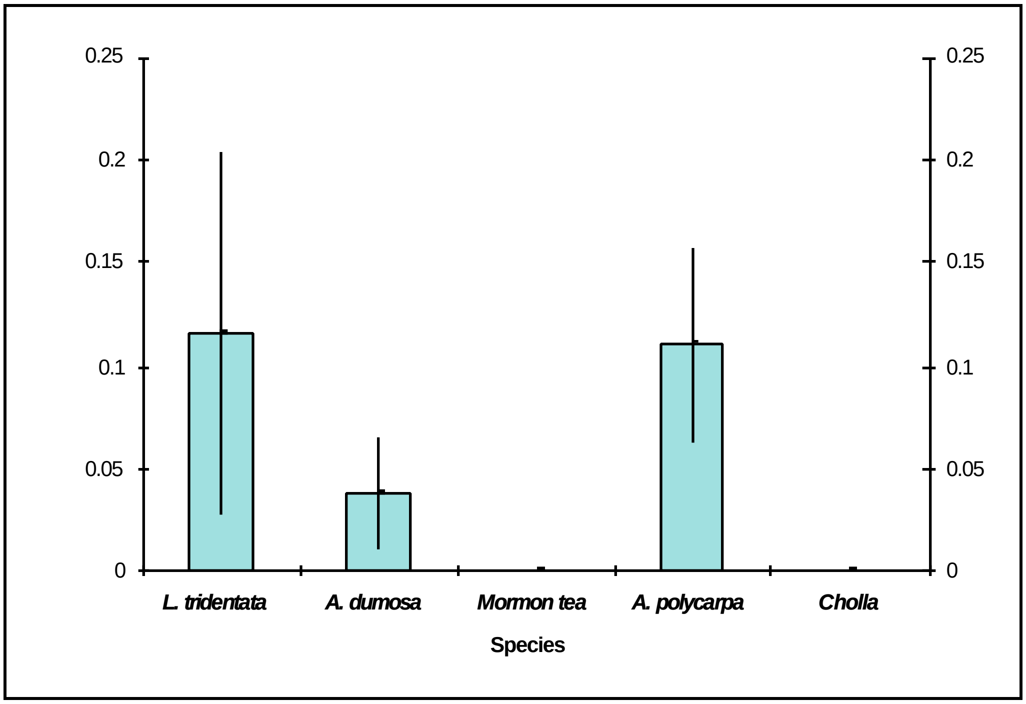
Group 5. Deflation with long sand mounds behind large plants, fine pebbles, yellow grass. East of entrance road.

34° 57' 12.1" N 116° 41' 45.2" W



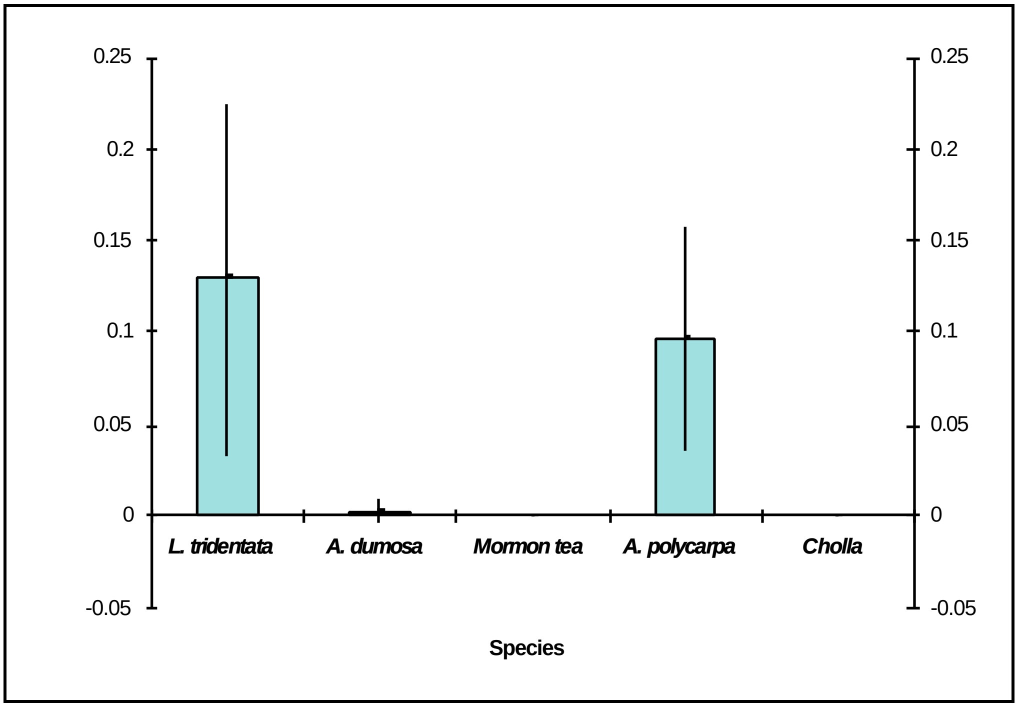
Group 6. Well sorted small pebbles, sandy mounds around large plants, rolling surface. Northwest of all fields.

34° 59' 37.5" N 116° 43' 31.2" W



Group 7. Unsorted pebbles, sandy mounds around large plants. East of field 11.

34° 58’ 34.6” N 116° 42’ 19.3” W



Group 8. Some fine pebbles, compacted soil, level surface. Inside of field 3.

34° 58’ 7.9” N 116° 42’ 1.4” W