

The Saguaro Cactus in a Sky Island Ecotone



Final Report

August 2011

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Acknowledgements

This project was made possible by funding from the National Park Service's George Melendez Wright Climate Change Fellowship Program and the Desert Southwest Cooperative Ecosystem Studies Unit. Thank you to all Saguaro National Park staff for their assistance with this project: Tiffany Alvarez, Dan Bell, Lynne Dehner, Emma Fajardo, Kelly Flickinger, Rob Hastings, Anna Iwaki, Drew Jackson, Kim Kwasny, Lauren Kingston, Kara O'Brien, Johnny Ortiz, Nic Perkins, Rafael Rojas, and Alexis Sanchez. Also, special thanks to the many volunteers who assisted with field surveys: Matt Christensen, Albi von Dach, Alicia Knust, Tony Schall, Bianca Torres, and Erin Zylstra.

Abstract

Climate change predictions indicate that the southwestern United States is moving towards conditions of increasing minimum temperatures and decreased frequency of freeze events. Freezing temperatures have been shown to cause mortality in the saguaro cactus, and the frequency of saguaro-killing freezes has a greater return interval at higher elevations. As freeze events become less frequent and their severity decreases, we expect that the geographical and elevational range of the saguaro may change. To establish a baseline for examining these changes more closely at Saguaro National Park's Rincon Mountain District, we established 120, 0.25 hectare (0.62 acre) plots in 2011 in the saguaros' upper elevation range between 3,500 feet (1,067 meters) and 5,500 feet (1,676 meters). In addition to providing baseline statistics that can be used to identify changes in the future, we explain about half of the variation in saguaro presence at this elevation range. These results provide insight into the how the saguaro may respond to changing climatic conditions.

Introduction

The saguaro cactus (*Carnegiea gigantea*) occurs in the Sonoran Desert, primarily in Sonora in Mexico and Arizona in the United States (Figure 1). Saguaros reach the northeastern edge of their range in Saguaro National Park's Rincon Mountain District (RMD) in southern Arizona, where they are heuristically thought to be bounded at around 5,000 feet (1,524 m) in elevation (Steenbergh and Lowe, 1977). The species is known to be intolerant of prolonged freezing temperatures (Steenbergh and Lowe, 1977), and cannot survive at elevations in which extended freezes occur. In addition, as a desert species, saguaros have not evolved with fire and can be easily killed by fires, which appear to be increasing in the desert southwest (Esque et al., 2003).

According to the Intergovernmental Panel on Climate Change (IPCC, 2007), climate change is already being observed globally, with warmer minimum temperatures predicted for the southwestern United States (Weiss and Overpeck, 2005). In "sky island" mountain ranges such as the Rincons, biomes established along an elevational gradient may be expected to shift upward in coming years along with changing climate conditions (Figure 2). Because some studies in Arizona have indicated that species are moving upslope regionally in response to these changes (Crimmins et al., 2009), it seems possible that saguaros may also be moving upslope in the park, or may in the future. At the same time, warmer conditions may also encourage the proliferation of grasses that are fire-tolerant, including non-native perennial grasses such as buffelgrass, which may limit the distribution of saguaros at higher elevations (Falk ref).

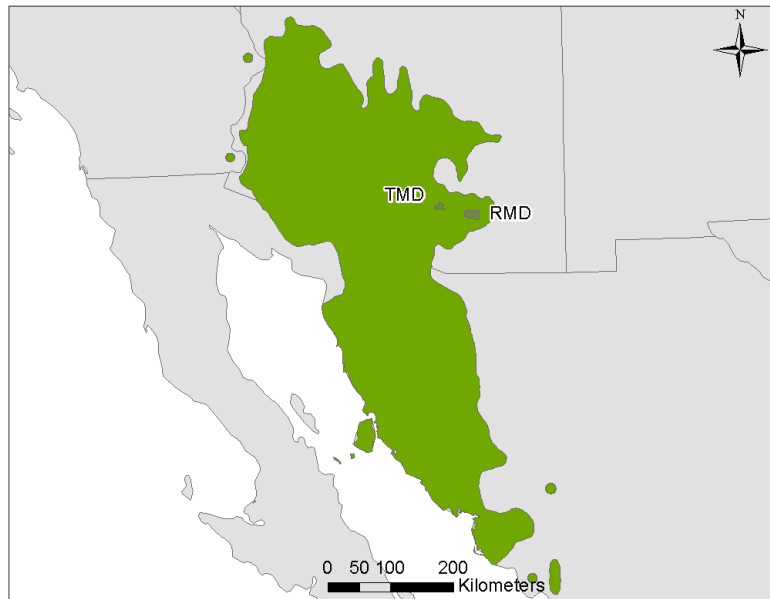


Figure 1. Range of the saguaro (*Carnegiea gigantea*). The locations of Tucson Mountain District and Rincon Mountain District of Saguaro National Park are indicated.

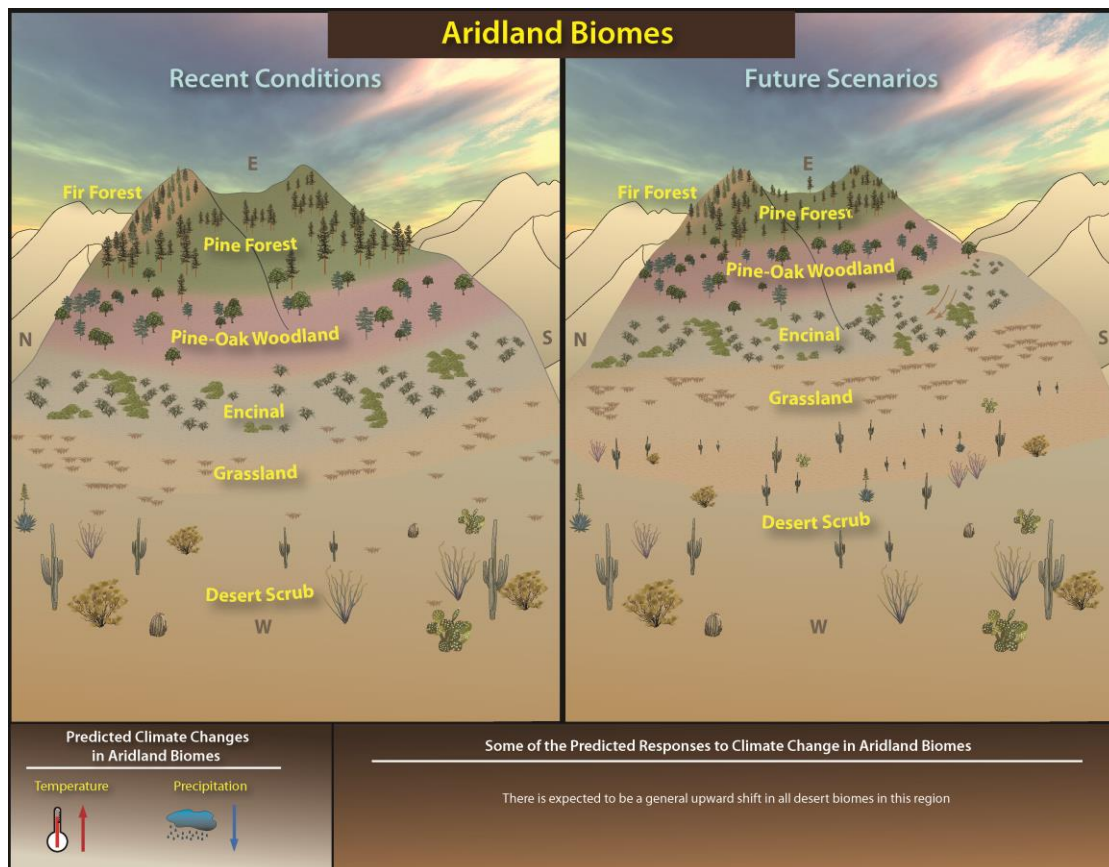


Figure 2. Conceptual model depicting recent conditions and possible effects of climate change on aridland biomes. Figure by Robert Bennetts, National Park Service.

Historically, saguaro studies in Saguaro National Park have predominantly been conducted at lower elevations where the species is most abundant. In 1990, park employees established 45 random plots in prime saguaro habitat identified in historic vegetation maps (O'Brien et al., 2011). Surveys on these plots have come to be known as the Saguaro Census plots, with saguaros measured every ten years. This long-term monitoring project has provided key insights into the structure and population shifts of the saguaro at Saguaro National Park. The plots comprising the Saguaro Census, however, do not extend to the upper elevation limits of the saguaro range in the Rincon Mountains.

The purpose of this study was to expand the scope of the 2010 Saguaro Census by examining saguaros at higher elevations in Saguaro National Park, in the ecotone area between desert and grasslands. Our objectives were to 1) establish plots that would allow us to determine the current distribution and density of saguaros in the RMD and create a baseline for observing future changes in these parameters; 2) develop a model for predicting the relative influence of three factors known to influence saguaro distribution (solar radiation, elevation, and fire history); and 3) use saguaro demographics to test the hypothesis that the distribution of saguaros is already changing, with younger saguaro occurring at high elevations.

Methods

Defining the ecotone

Using one-foot resolution aerial imagery in a GIS, we identified locations of saguaros by searching for their shadows in the images. The unmistakable locations (Figure 3) of 71 saguaro shadows were recorded at high elevations in the GIS. On north-facing slopes mature saguaro shadows were observed to disappear from the landscape at an upper elevation of 3,500 ft (1,067 m). On south-facing slopes, saguaro shadows were detected at nearly 5,500 ft (1,676 m). Based on this information, we decided to use an elevation range from 3,500 to 5,500 for our study area.



Figure 3. Saguaros in the ecotone identified from aerial imagery by their shadows. Saguaro shadows are circled in the image.

Plot selection

After identifying the elevation range of the ecotone, we selected plot stratifications based on three predictor variables: burn history, solar insolation, and elevation (Figure 4). We compiled data for these variables in a GIS to enable plot selection.

Three major burns below 5,500 ft have occurred in the park's recent history: the Chiva Fire in 1989, the Mother's Day Fire in 1994 and the Box Canyon Fire in 1999. Combined, these three fires burned 8,533 acres within the study area. Additionally, 14 other fires have occurred in the study area since 1943. We utilized fire history data as a binary variable indicating whether the plot was burned or unburned as indicated by park fire records going back to 1943.

To evaluate the role of aspect in determining suitable saguaro habitat, we calculated the solar insolation received across the park using the solar insolation toolset in ArcGIS. Solar insolation values had a stronger correlation than aspect with the identified saguaro shadow locations. We classified solar insolation into three groups: low (312,148 to 142,915 WH/m²), medium (142,916 to 246,964 WH/m²), and high (246,965 to 351,014 WH/m²) based on the watt hours per meter squared received at each location.

Finally, we utilized a digital elevation model to identify elevation values across the park. We categorized elevation by four, 500 ft (152 m) increments: 3,500 ft to 4,000 ft; 4,001 ft to 4,500 ft; 4,501 ft to 5,000 ft; and 5,001 ft to 5,500 ft.

After assembling these three datasets, we created a gridded tessellation of 50 m (164 ft) by 50 m (164 ft) cells in the study area. This procedure created 37,499 total possible plots that fell within the study area, to which we next assigned a stratification number. We then generated 120 random points (Figure 5) using the Generate Random Points tool in the open source Hawth's Analysis Tools for ArcGIS (Beyer, 2004), with five points being allocated to each of the 24 strata. Finally, we selected the plots that overlapped with the 120 randomly generated points for sampling. The elevations of these plots compared to the Saguaro Census plots are shown in Figure 6.

After identifying the 120 plots to sample, we developed a survey methodology based on that used in an associated project called the Saguaro Census. We measured all saguaros under approximately four meters using a folding ruler, and estimated the height of saguaros exceeding four meters using a clinometer. We counted all saguaro arms and holes created by birds. We began field work for this project in July 2010 and finished in July 2011.

Statistical analysis

At the conclusion of the field work, we classified each plot with a binary variable indicating the presence (1) or absence (0) of saguaros. We used this variable (*SAGUARO*) as the outcome variable in a logistic regression model. The general equation for a logistic regression model is:

$$g(x) = \beta_0 + \beta_1x_1 + \beta_2x_2 + \beta_px_p$$

Three independent variables were utilized to predict saguaro presence in this model. These variables were *elev* (continuous variable ranging between 3,500 feet to 5,500 feet indicating the

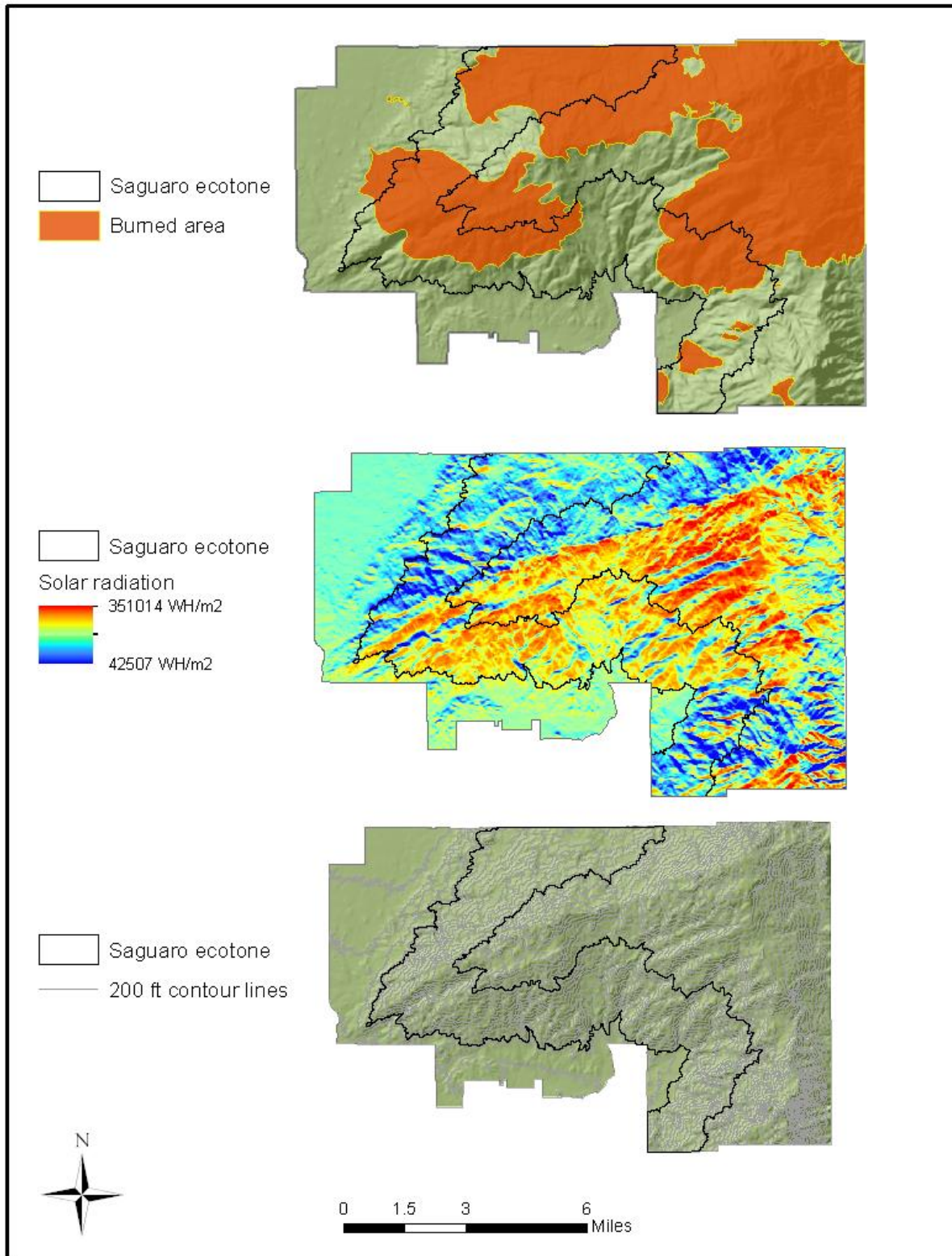


Figure 4. Historic fire locations (top), solar insolation (middle), and elevation gradient (bottom) at the Rincon Mountain District of Saguaro National Park.

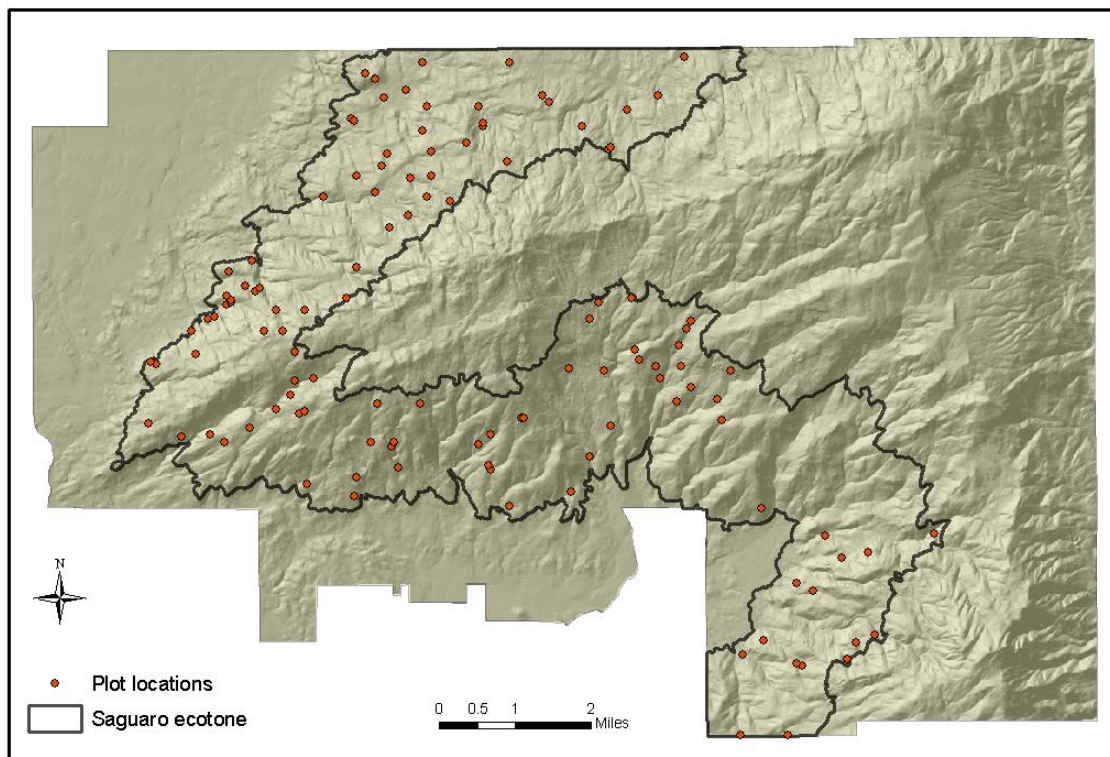


Figure 5. Locations for 120 plots established for the study of the upper elevation ecotone of saguaros at the Rincon Mountain District of Saguaro National Park.

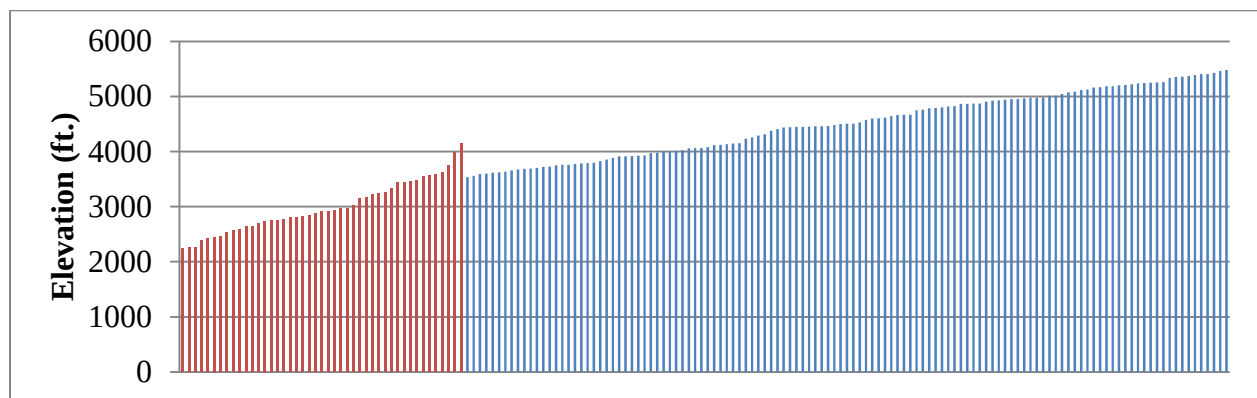


Figure 6. Elevation of historic saguaro plots (red; n=45) and newly established ecotone plots (blue; n=120) at the Rincon Mountain District of Saguaro National Park.

Survey methodology

plot elevation), *burn* (binary variable indicating whether there was a fire occurring since 1943 on the plot), and *solar* (continuous variable ranging between 38,866 and 351,014 WH/m² to indicate total solar insolation on the plot). Solar radiation (*solar*) is modeled in increments of 1000 WH/m².

The full model evaluated was:

$$g(\text{SAGUARO}) = \beta_0 + \beta_1 \text{elev} + \beta_2 \text{burn} + \beta_3 \text{solar}$$

Following the evaluation of the full model, we utilized likelihood ratio tests to determine whether each variable significantly contributed to the predictive capability of the model. Additionally, we calculated predicted probabilities for encountering saguaros on a plot with a change in elevation or solar insolation.

Geospatial analysis

Using the Raster Calculator tool in ArcMap, we applied the coefficients calculated in the logistic regression model to the geospatial data for fire history, elevation, and solar insolation in the GIS to calculate the probability that a saguaro was present on any given 50 m x 50 m space in the park.

The probability equation is:

$$\text{Probability} = \frac{1}{(1 + e^{-1 * (\beta_0 + \beta_1 \text{elev} + \beta_2 \text{burn} + \beta_3 \text{solar})})}$$

This procedure gave us a probability value for each 50 m x 50 m cell of the study area when the elevation, solar insolation and fire history is known. From this surface we extracted only those points which had at least a one percent or five percent probability of having a saguaro present. After determining the boundary of the saguaro range at these thresholds, we used the inverse distance weighting interpolation method in ArcGIS to create a saguaro density surface within both the one percent and five percent boundary. We created this surface from all 120 plots in this study as well as 71 other plots on which saguaros were surveyed in 2010 and 2011.

Results

Descriptive statistics for the three predictor variables are provided in Table 2, with the results from the logistic regression model shown in Table 3. Odds ratios are provided in percentages in Table 3 to aid in the interpretation of results. Table 3 indicates that while holding the other variables at their mean, increasing elevation by one meter decreases the odds of a saguaro being present by 1.13%; exposing an area to fire decreases the odds of a saguaro being present by 82.21%, and increasing solar radiation by 1000 WH/m² increases the odds of a saguaro being present by 2.19%.

Table 1. Descriptive statistics for saguaro plots in the ecotone (n=120).

Variable	Mean	Std. Dev.	Min.	Max.
<i>elev</i>	1375.61	175.09	1079	1671
<i>burn</i>	0.53	0.50	0	1
<i>solar</i>	194.18	60.52	68	294

Table 2. Logistic regression results for saguaro presence on plots located in the upper elevation ecotone for saguaros at the Rincon Mountain District of Saguaro National Park.

Variable	β	Odds ratio (%)
<i>elev</i> ***	-0.0113 (0 .0022)	-1.13
<i>burn</i> **	-1.7267 (0.5839)	-82.21
<i>solar</i> ***	0.0217 (0.0056)	2.19

Note: Std. Err. in parentheses;
*p<0.05, **p<0.01, ***p<0.001

Predicted probabilities can also be used to interpret logistic regression data. Figure 7 indicates the degree to which the probability of encountering a saguaro changes when burn history and solar insolation are held at the mean and only elevation changes. At 3,500 ft (1,067 m) there is an 87% probability of saguaros being present, which drops to 50% at 4,085 ft (1,245 m) and finally drops below 1% at 5,433 ft (1,656 m).

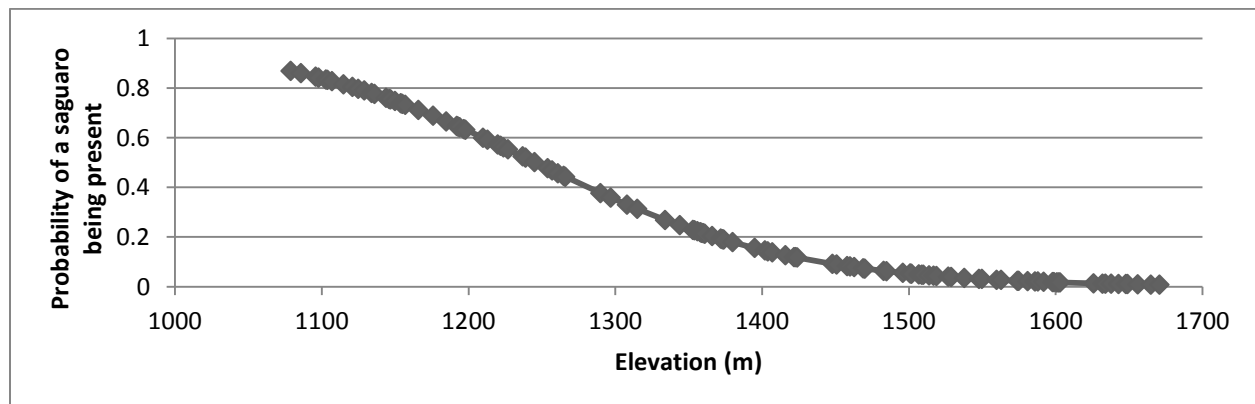


Figure 7. Predicted probability of a saguaro being present at the Rincon Mountain District at Saguaro National Park as elevation changes.

We also used the predicted probabilities to create cartographic products. Figure 8 displays the probability of a saguaro being present across the RMD using the three independent variables.

Probabilities outside the defined ecotone (3,500 to 5,500 feet) should be interpreted with caution as data for the model was only collected within this elevation range.

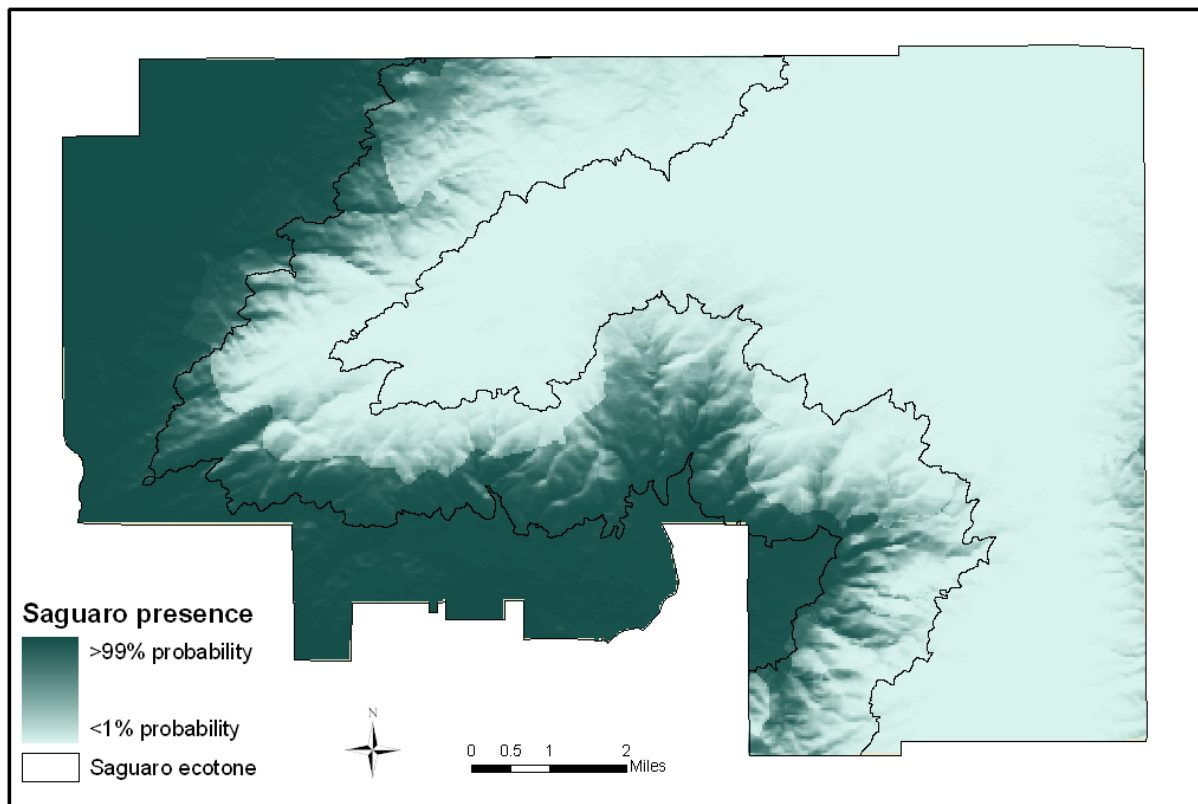


Figure 8. Probability surface for saguaro presence in the upper elevation ecotone at the Rincon Mountain District of Saguaro National Park.

Saguaro Density

Figure 8 indicates the probability that a saguaro is present at a location, but does not supply information about the predicted number of saguaros at that location. Population density surfaces are provided in Figures 9 and 10 for the area with at least a one percent probability and five percent probability of having a saguaro present. These figures display the number of predicted saguaros ranging from 477 saguaros per hectare to zero saguaros per hectare.

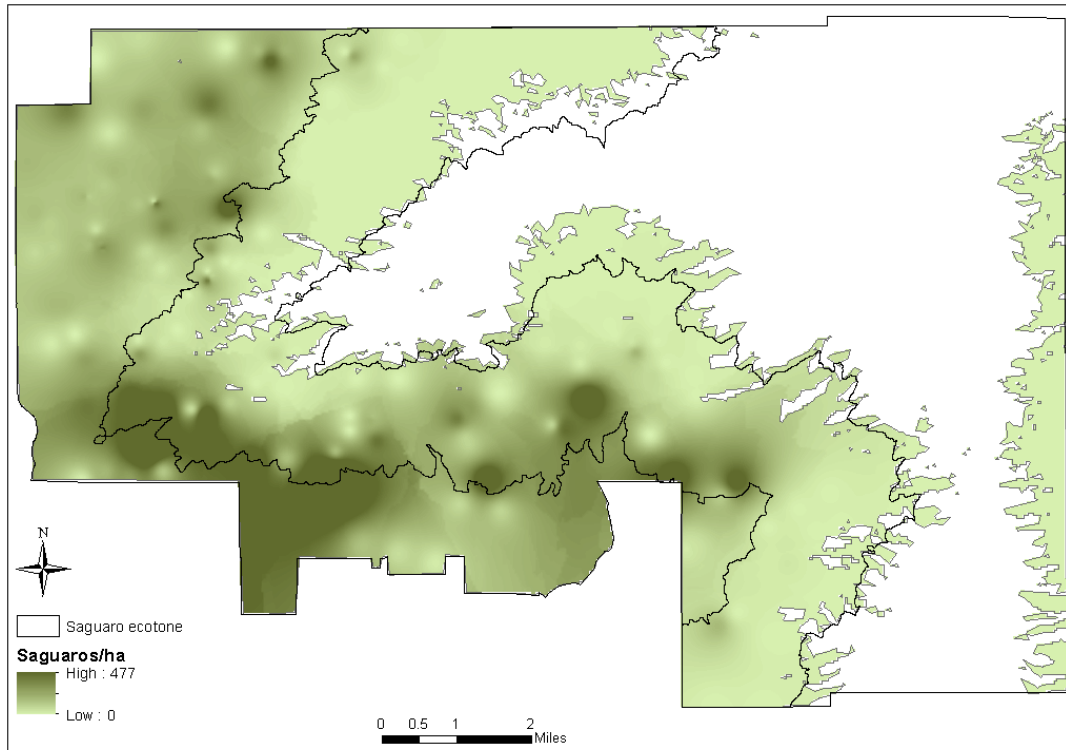


Figure 9. Saguaros per hectare at the Rincon Mountain District of Saguardo National Park. Saguardo density is indicated where the probability of a saguardo being present is at least 1%.

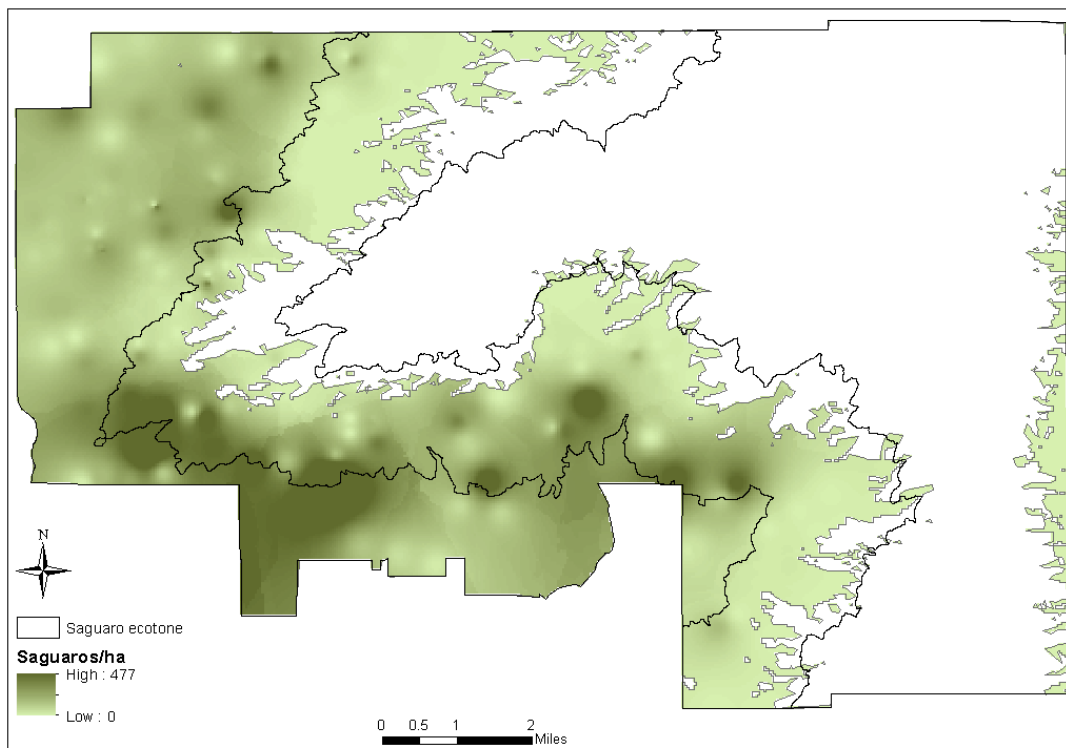


Figure 10. Saguaros per hectare at the Rincon Mountain District of Saguardo National Park. Saguardo density is indicated where the probability of a saguardo being present is at least 5%.

Finally, we examined the population structure observed along the elevation gradient (Figure 11). There appears to be a slight trend for younger saguaros at higher elevations in the RMD, but the trend is not statistically significant.

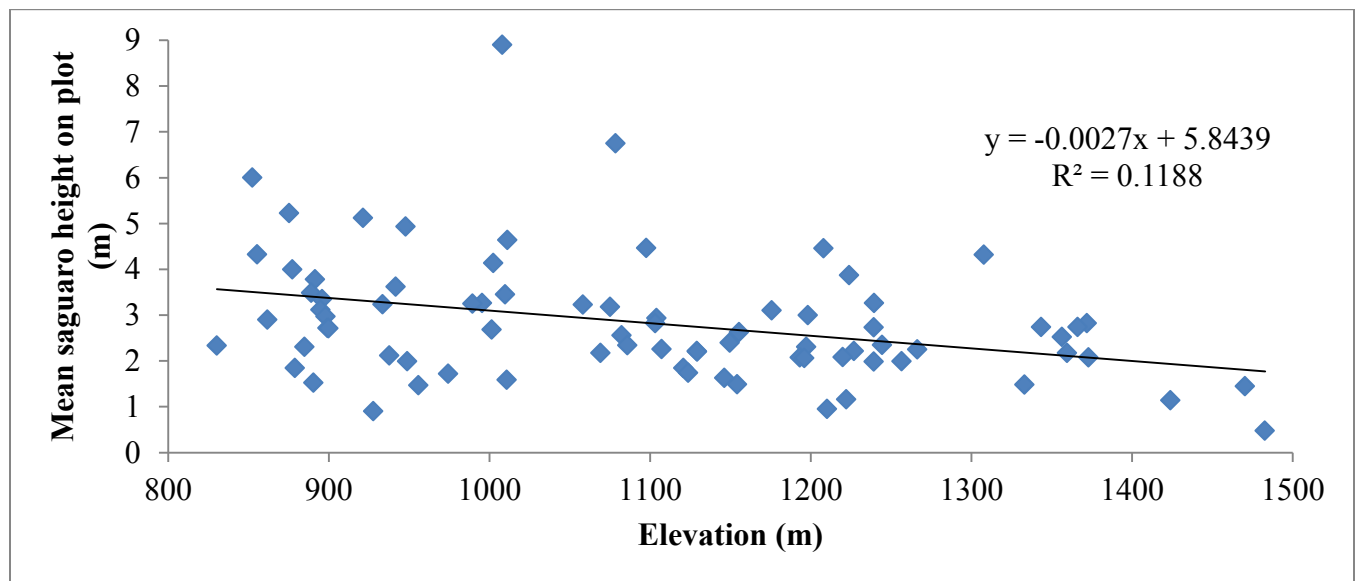


Figure 11. Mean plant height by elevation from saguaros across an elevation gradient at the Rincon Mountain District of Saguaro National Park.

Discussion

In this study we examine three causal factors determining saguaro presence: fire history, solar insolation, and elevation. The statistical results indicate that of these three, fire has the largest potential for affecting saguaros in its upper elevation range at Saguaro National Park. Exposing an area to fire decreases the odds of saguaro presence by 82%. Saguaro success in this ecotone elevation band will be influenced by interactions with other vegetation types. Buffelgrass (*Pennisetum ciliare*), an invasive African grass species, is also freeze-intolerant and is bounded at about the same elevation. Currently, 18 (15%) of the plots have buffelgrass present. Its competitive success in the Sonoran Desert will be favored by the changing climatic conditions being predicted (Stevens and Falk, 2009), promoting a fire regime that saguaros are not adapted to withstand (GAO, 2007; Saunders et al., 2009). Even with the coarse binary variable indicating whether a fire had occurred going back to 1943, we show that the effect of fire is felt by the saguaro population for many years after a fire occurs.

The effects of elevation and solar insolation are less pronounced than fire. Every one meter increase in elevation decreases the odds of a saguaro being present by one percent, while holding the other predictor variables at their mean. Additionally, increasing solar insolation at a site by 1000 WH/m², while holding the other predictor variables at their mean increases the odds of a saguaro being present by two percent.

As Figure 11 indicates, saguaros at upper elevations tend to be shorter than at lower elevations. The correlation between saguaros and height (Steenbergh and Lowe, 1977) also indicates that

higher elevation saguaro populations tend to be younger. These population structure differences provide insight into the return interval of saguaro-killing freeze events.

In February 2011, midway through the field work for this project we directly observed a frost with sufficient severity to damage and kill many saguaros. Tucson received two days of cold temperatures that were among the coldest low and coldest high temperatures in a record extending back to 1895 (NOAA, 2011). Wind chill temperatures in the mountains were recorded at 20 to 30 degrees below zero. This event served as a vivid reminder that while freeze events may be trending towards decreased frequency, they still occur with catastrophic effects to the saguaro population. In the days, weeks, and months following this freeze, we observed numerous saguaros which suffered damage or mortality. However, as Steenbergh and Lowe (1977) documented, the lethal blow delivered from a single freeze event can take nine years to manifest itself through complete plant mortality.



Figure 2. Saguaro damaged by cold temperatures in February 2011 at the Rincon Mountain District of Saguaro National Park.

While the February 2011 freeze event had a devastating effect on many saguaros at high elevations, the timing of our study offers a serendipitous opportunity to reexamine these plots in the near future to gain further insight into the role of freeze events on limiting saguaro populations in the ecotone.

Conclusions

Our objective in establishing these plots was to create a baseline dataset for examining future change in saguaros across the elevational gradient of the saguaro ecotone. Climate change is predicted to alter the functioning of ecosystems through multiple mechanisms. Modifications of temperature and precipitation will no doubt impact the saguaro population. However, as indicated by this study, indirect factors like fire can also present a serious threat to the well-being of this population. The influx of fire-prone exotic grass in saguaro habitat poses a serious threat that could have lasting impacts on the saguaro population for decades to come. Our hope is that this study will provide baseline data useful for understanding how this iconic species responds to these changes in the future.

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Appendix A: Plot Strata

Stratum	Elevation	Solar Radiation	Burn History
1	3500-4000	low	no burn
2	3500-4000	med	no burn
3	3500-4000	high	no burn
4	3500-4000	low	burn
5	3500-4000	med	burn
6	3500-4000	high	burn
7	4000-4500	low	no burn
8	4000-4500	med	no burn
9	4000-4500	high	no burn
10	4000-4500	low	burn
11	4000-4500	med	burn
12	4000-4500	high	burn
13	4500-5000	low	no burn
14	4500-5000	med	no burn
15	4500-5000	high	no burn
16	4500-5000	low	burn
17	4500-5000	med	burn
18	4500-5000	high	burn
19	5000-5500	low	no burn
20	5000-5500	med	no burn
21	5000-5500	high	no burn
22	5000-5500	low	burn
23	5000-5500	med	burn
24	5000-5500	high	burn

Appendix B. Plot coordinates (coordinate system: UTM; datum: NAD 83).

strata	plot#	NE_E	NE_N	NW_E	NW_N	SE_E	SE_N	SW_E	SW_N
1	122	527190	3559983	527140	3559983	527190	3559933	527140	3559933
1	204	539740	3553783	539690	3553783	539740	3553733	539690	3553733
1	207	540190	3554083	540140	3554083	540190	3554033	540140	3554033
1	325	527340	3559933	527290	3559933	527340	3559883	527290	3559883
1	360	531790	3566083	531740	3566083	531790	3566033	531740	3566033
2	121	527140	3558683	527090	3558683	527140	3558633	527090	3558633
2	146	530490	3557383	530440	3557383	530490	3557333	530440	3557333
2	152	531490	3557133	531440	3557133	531490	3557083	531440	3557083
2	180	536090	3557233	536040	3557233	536090	3557183	536040	3557183
2	206	540140	3556883	540090	3556883	540140	3556833	540090	3556833
3	149	530840	3563483	530790	3563483	530840	3563433	530790	3563433
3	160	532440	3557733	532390	3557733	532440	3557683	532390	3557683
3	176	534790	3556933	534740	3556933	534790	3556883	534740	3556883
3	310	536540	3557983	536490	3557983	536540	3557933	536490	3557933
3	314	527890	3558383	527840	3558383	527890	3558333	527840	3558333
4	130	528540	3560933	528490	3560933	528540	3560883	528490	3560883
4	329	528090	3560633	528040	3560633	528090	3560583	528040	3560583
4	333	528440	3560883	528390	3560883	528440	3560833	528390	3560833
4	341	529240	3561583	529190	3561583	529240	3561533	529190	3561533
4	344	529390	3562133	529340	3562133	529390	3562083	529340	3562083
5	133	528790	3561383	528740	3561383	528790	3561333	528740	3561333
5	153	531490	3565083	531440	3565083	531490	3565033	531440	3565033
5	164	532940	3566333	532890	3566333	532940	3566283	532890	3566283
5	354	531490	3565133	531440	3565133	531490	3565083	531440	3565083
5	358	532640	3565733	532590	3565733	532640	3565683	532590	3565683
6	335	528840	3561183	528790	3561183	528840	3561133	528790	3561133
6	336	528940	3561233	528890	3561233	528940	3561183	528890	3561183
6	337	528940	3561283	528890	3561283	528940	3561233	528890	3561233
6	342	528890	3561883	528840	3561883	528890	3561833	528840	3561833
6	359	531990	3565983	531940	3565983	531990	3565933	531940	3565933
7	203	539690	3552083	539640	3552083	539690	3552033	539640	3552033
7	304	540940	3555283	540890	3555283	540940	3555233	540890	3555233
7	305	541890	3555833	541840	3555833	541890	3555783	541840	3555783
7	307	541540	3556283	541490	3556283	541540	3556233	541490	3556233
7	315	528490	3558433	528440	3558433	528490	3558383	528440	3558383
8	132	528740	3558283	528690	3558283	528740	3558233	528690	3558233
8	173	534340	3557783	534290	3557783	534340	3557733	534290	3557733
8	174	534390	3557683	534340	3557683	534390	3557633	534340	3557633
8	185	536790	3559783	536740	3559783	536790	3559733	536740	3559733
8	186	536940	3558633	536890	3558633	536940	3558583	536890	3558583
9	191	537990	3559633	537940	3559633	537990	3559583	537940	3559583

9	193	538340	3559133	538290	3559133	538340	3559083	538290	3559083
9	210	541240	3555133	541190	3555133	541240	3555083	541190	3555083
9	309	531590	3557533	531540	3557533	531590	3557483	531540	3557483
9	312	534190	3558233	534140	3558233	534190	3558183	534140	3558183
10	165	533040	3565383	532990	3565383	533040	3565333	532990	3565333
10	326	528190	3560133	528140	3560133	528190	3560083	528140	3560083
10	339	529440	3561483	529390	3561483	529440	3561433	529390	3561433
10	340	529540	3561533	529490	3561533	529540	3561483	529490	3561483
10	352	532990	3564883	532940	3564883	532990	3564833	532940	3564833
11	154	531540	3563933	531490	3563933	531540	3563883	531490	3563883
11	156	531840	3558283	531790	3558283	531840	3558233	531790	3558233
11	157	532090	3564133	532040	3564133	532090	3564083	532040	3564083
11	159	532190	3564383	532140	3564383	532190	3564333	532140	3564333
11	169	534140	3565383	534090	3565383	534140	3565333	534090	3565333
12	311	532340	3558183	532290	3558183	532340	3558133	532290	3558133
12	313	532390	3558283	532340	3558283	532390	3558233	532340	3558233
12	316	534440	3558433	534390	3558433	534440	3558383	534390	3558383
12	317	529340	3558583	529290	3558583	529340	3558533	529290	3558533
12	348	531990	3563583	531940	3563583	531990	3563533	531940	3563533
13	300	541040	3553533	540990	3553533	541040	3553483	540990	3553483
13	301	540940	3553583	540890	3553583	540940	3553533	540890	3553533
13	306	542440	3555933	542390	3555933	542440	3555883	542390	3555883
13	345	532290	3562833	532240	3562833	532290	3562783	532240	3562783
13	346	532690	3563083	532640	3563083	532690	3563033	532640	3563033
14	162	532690	3563883	532640	3563883	532690	3563833	532640	3563833
14	194	538440	3559883	538390	3559883	538440	3559833	538390	3559833
14	208	540690	3552083	540640	3552083	540690	3552033	540640	3552033
14	323	536090	3559833	536040	3559833	536090	3559783	536040	3559783
14	349	533190	3563933	533140	3563933	533190	3563883	533140	3563883
15	197	538640	3559433	538590	3559433	538640	3559383	538590	3559383
15	200	539190	3559183	539140	3559183	539190	3559133	539140	3559133
15	318	539340	3558733	539290	3558733	539340	3558683	539290	3558683
15	324	537940	3559883	537890	3559883	537940	3559833	537890	3559833
15	328	538440	3560333	538390	3560333	538440	3560283	538390	3560283
16	137	529840	3558983	529790	3558983	529840	3558933	529790	3558933
16	138	529840	3561083	529790	3561083	529840	3561033	529790	3561033
16	188	537290	3565333	537240	3565333	537290	3565283	537240	3565283
16	195	538490	3566433	538440	3566433	538490	3566383	538440	3566383
16	356	535540	3565633	535490	3565633	535540	3565583	535490	3565583
17	140	530140	3559283	530090	3559283	530140	3559233	530090	3559233
17	144	530340	3558883	530290	3558883	530340	3558833	530290	3558833
17	171	534240	3564983	534190	3564983	534240	3564933	534190	3564933
17	172	534240	3565033	534190	3565033	534240	3564983	534190	3564983

17	177	534790	3566333	534740	3566333	534790	3566283	534740	3566283
18	142	530240	3559583	530190	3559583	530240	3559533	530190	3559533
18	145	530440	3558933	530390	3558933	530440	3558883	530390	3558883
18	148	530640	3559633	530590	3559633	530640	3559583	530590	3559583
18	320	535140	3558783	535090	3558783	535140	3558733	535090	3558733
18	350	533190	3564433	533140	3564433	533190	3564383	533140	3564383
19	302	542190	3554033	542140	3554033	542190	3553983	542140	3553983
19	303	542590	3554183	542540	3554183	542590	3554133	542540	3554133
19	308	543840	3556333	543790	3556333	543840	3556283	543790	3556283
19	327	537490	3560233	537440	3560233	537490	3560183	537440	3560183
19	347	533090	3563483	533040	3563483	533090	3563433	533040	3563433
20	166	533040	3565383	532990	3565383	533040	3565333	532990	3565333
20	196	538540	3560683	538490	3560683	538540	3560633	538490	3560633
20	211	541940	3553683	541890	3553683	541940	3553633	541890	3553633
20	338	537440	3561333	537390	3561333	537440	3561283	537390	3561283
20	343	531590	3561983	531540	3561983	531590	3561933	531540	3561933
21	182	536490	3560883	536440	3560883	536490	3560833	536440	3560833
21	183	536690	3561233	536640	3561233	536690	3561183	536640	3561183
21	189	537540	3560033	537490	3560033	537540	3559983	537490	3559983
21	202	539490	3559783	539440	3559783	539490	3559733	539440	3559733
21	332	529640	3560633	529590	3560633	529640	3560583	529590	3560583
22	330	530040	3560633	529990	3560633	530040	3560583	529990	3560583
22	331	538690	3560833	538640	3560833	538690	3560783	538640	3560783
22	334	530490	3561083	530440	3561083	530490	3561033	530440	3561033
22	351	536940	3564483	536890	3564483	536940	3564433	536890	3564433
22	353	536390	3564983	536340	3564983	536390	3564933	536340	3564933
23	151	531340	3561333	531290	3561333	531340	3561283	531290	3561283
23	175	534740	3564233	534690	3564233	534740	3564183	534690	3564183
23	179	535640	3565483	535590	3565483	535640	3565433	535590	3565433
23	187	536940	3564533	536890	3564533	536940	3564483	536890	3564483
23	357	537990	3565633	537940	3565633	537990	3565583	537940	3565583
24	143	530240	3560183	530190	3560183	530240	3560133	530190	3560133
24	168	533890	3564633	533840	3564633	533890	3564583	533840	3564583
24	319	535090	3558783	535040	3558783	535090	3558733	535040	3558733
24	321	532040	3559083	531990	3559083	532040	3559033	531990	3559033
24	322	532940	3559083	532890	3559083	532940	3559033	532890	3559033

Appendix C. Number of saguaros on each plot

Plot	No. of Saguaros	Plot	No. of Saguaros	Plot	No. of Saguaros
121	38	185‡	1	320	0
122	3	186‡	55	321‡	0
130	4	187	0	322	0
132	47	188	0	323	1
133‡	0	189	0	324	2
137	0	191	13	325	0
138	0	193	5	326	0
140	0	194	0	327	0
142	5	195*	0	328	0
143	0	196	0	329‡	1
144	0	197	0	330	0
145	0	200	0	331	0
146	11	202	0	332	0
148‡	0	203	0	333	0
149	0	204	12	334	0
151	0	206	39	335‡	29
152	46	207	0	336	9
153	0	208	0	337‡	5
154	0	210	2	338	0
156	0	211	0	339	0
157	0	300	0	340	0
159	0	301	0	341	0
160‡	30	302	0	342‡	18
162	0	303	0	343	0
164	0	304	1	344	4
165	0	305	0	345	0
166	0	306	0	346	0
168	0	307	0	347	0
169	0	308	0	348‡	0
171	0	309	11	349	0
172	0	310	32	350	0
173	6	311‡	14	351*	0
174‡	6	312	27	352	0
175*	0	313‡	10	353*	0
176‡	48	314‡	51	354	0
177	0	315	4	355	5
179	0	316‡	19	356*	0
180	22	317	0	357*	0
182	0	318	0	358	0
183	0	319	0	359‡	16
				360	0

* Indicates plots that were not directly observed. In this area near the Douglas Spring Trail, saguaros were only observed at much lower elevations; ‡ indicates plots with buffelgrass present.

Appendix D. Measures of fit for logistic regression model predicting presence of saguaros in the upper elevation ecotone.

Fit Statistic	Value
Pseudo R ²	0.449
McFadden's R ²	0.449
McFadden's Adjusted R ²	0.396
ML (Cox-Snell) R ²	0.429
Cragg-Uhler(Nagelkerke) R ²	0.602
McKelvey & Zavoina's R ²	0.658
Count R ²	0.825
Adjusted Count R ²	0.447
Efron's R ²	0.507

Appendix E: Notes for Future Researchers

Future researchers may find the numbering scheme used in this project to be confusing. After conducting the 2010 Saguaro Census, we sought to fill in some of the geographic holes in plot coverage at the RMD to enable the creation of better saguaro density maps. With only 25 Saguaro Census plots located at the RMD, there were many areas of the park for which we had very little saguaro demographic data. Plots with the 100 or 200 prefix were randomly selected below 5,000 feet to provide this information. After initiating surveys of these plots, we became interested in more closely examining saguaros in the upper elevation ecotone. We then modified the project to look more closely at saguaros between 3,500 and 5,500 feet. We created a research plan that could incorporate the 50 m x 50 m plots that had already been surveyed into this analysis of the saguaro ecotone. Plots with a 300 prefix are ecotone plots. Plots with a 100 or 200 prefix were originally designated to fill in the geographic holes, but some of these were also utilized in the ecotone study if they met the criteria the ecotone stratification scheme.

Future iterations of this project should consider collecting data about dominant perennial vegetation in the saguaro ecotone plots. Due to our budget and time constraints we were not able to collect this data in 2011. Additionally, future surveyors should consider mapping individual saguaros.