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Grasshopper (orthoptera: Caelifera) And Plant Community Relationships On Indio Mountains Research Station, Hudspeth County, Texas

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GRASSHOPPER (ORTHOPTERA: CAELIFERA) AND PLANT COMMUNITY RELATIONSHIPS ON INDIO MOUNTAINS RESEARCH STATION, HUDSPETH COUNTY, TEXAS

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Dedication

I would like to dedicate this project and defense to my mother, Diana Caudillo.

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by

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Abstract

An ecogeographic analysis of a grasshopper survey was conducted at eight sites on Indio Mountains Research Station (IMRS) in the Chihuahuan Desert during September 2014 through December 2015. Five sites contained ephemeral water sources (earthen tanks), one had perennial water (spring system), and two were open desert. A total of 23 grasshopper species were identified, and six of those were new records for the property. The most species rich site was Echo Tank, with 14 grasshopper species. A UPGMA dendrogram showed Red Tank and Rattlesnake Tank, both wetland sites, to be the most similar (CBR = .84). A poisson model was applied to identify any relationships of temperature, precipitation, vegetation and seasonal patterns between the monsoon and dry season, and between years. The model of species count showed significance for three grasshopper species ($p<.03$), vegetation coverage among seven grasshopper species ($p<.009$), and seasonality patterns found in four species ($p<.02$). Information on variation and spatial pattern of grasshopper biodiversity on IMRS, will allow future studies to compare grasshopper diversity in response to grassland and shrubland ecosystems in an ever increasing arid environment.

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Introduction

Grasshoppers are insects in the order Orthoptera and suborder Caelifera (Rowell and Flook, 1998). Most belong to the family Acrididae which are often referred to as short-horned grasshoppers due to their short antenna (Capinera *et al*., 2004). Grasshoppers are found throughout North America and can occupy a wide range of habitats. The most ideal habitat for grasshoppers is open sunny environments where low growing vegetation is present (Capinera *et al.*, 2004). Grasshoppers are mainly herbivorous while a few can consume a variety of other insects, mushrooms, dead plant matter, and soil (Bright *et al.*, 1994). Some grasshopper species have been found to feed exclusively on either C_3 or C_4 grasses while others have been found to consume a mixture of the two types (Boutton, 1978).

In the Chihuahuan Desert region of New Mexico and Texas, the common grasshoppers found are *Bootettix argentatus, Cibolacris parviceps, Conozoa texana, Derotmema lacticinctum, Melanoplus ardius, Trimerotropis californica* and *Trimerotropis pallidipennis* (Richman *et al.*, 2009). These grasshoppers reside in a variety of habitats, the choice habitat resulting from diet restrictions of grasshoppers that tend to feed on specific plants in their preferred habitats (Richman *et al.*, 2009). In general, the greatest diversity and population densities of grasshoppers occupy semi-arid environments with warm semi-arid grasslands and shrublands (Otte, 1976).

Orthopterans can have a significant ecological impact on nutrient cycles and at times may be the dominant herbivores in a community (Capinera *et al*., 2004). Blumer and Diemer (1996) found that grasshoppers can accelerate ecosystem mineral cycling due to the reduction of standing dead material and also play an important role in the carbon-nitrogen balance by concentrating fecal nitrogen herbivore biomass. Although in some years when grasshopper populations reach destructive densities they may destroy a great deal of habitat and diminish plant production, but under certain conditions they can actually enhance plant production, although the mechanisms for this are still being investigated (Belovsky and Slade, 2002). Grasshoppers indirectly affect rates of mechanical and chemical digestion of plant material by other organisms by breaking down large

pieces of vegetation into smaller pieces that are then consumed, defecated, and further degraded by soil biota. Grasshopper feces (frass) have also been shown to increase solubility of chemical nutrients needed for plant growth (Capinera *et al.,* 2004). Additionally, grasshoppers play key roles in nutrient cycling by speeding up nitrogen cycling via changing the amount and decomposition rate of plant litter (Belovsky and Slade, 2000). Still, there are some conditions when grasshoppers may decrease nutrient cycling and plant abundance (Belovsky and Slade, 2000).

Environmental conditions dictate behavior of ectotherms. Most insects are ectotherms which rely on the environment to maintain a body temperature sufficient to carry out every day metabolic functions. Many positive correlations have been found between temperature and grasshopper density (Gage and Mukerji, 1977; Smith, 1954; Edwards, 1960; Pickford, 1966). There is evidence to show that insects are affected indirectly by precipitation patterns as well (Barton and Ives, 2014). Two studies in Saskatchewan found that grasshopper outbreaks were preceded by 2-4 years of below normal rainfall in May and June, or above-normal temperatures from July to September (Parker, 1933; Edwards, 1960). Negative relationships have also been found between precipitation and grasshopper densities (Skinner and Child, 2000). Temperature and precipitation have been shown to affect body-size in both male and female grasshoppers (Bidau and Marti, 2008).

The purpose of this study is to examine mechanisms, including habitat preference, that determine community assembly structure of grasshoppers occurring within Indio Mountains Research Station (IMRS). IMRS is located in southeastern Hudspeth County, Texas, north and east of the Rio Grande near the Culberson Country border, centered about 40 km southwest of Van Horn, Texas (Fig.1). IMRS is comprised of nearly 40,000 acres of Chihuahuan Desert landscape that is managed by the University of Texas at El Paso (UTEP). Elevation ranges from 900 m near the Rio Grande plain, to 1,600 m on Squaw Peak. There were previously 29 identified species of grasshoppers on IMRS property found in the families Acrididae, Romaleidae, and Tetrigidae (Worthington *et al.,* 2017).

A previous short-term study on IMRS did not show a significant difference in grasshopper diversity found at open desert sites compared to wetland sites, but this may have been due to bias resulting from insufficient data (Baqla, 2014). Previous works suggest that differences in plant communities and structure also play roles in grasshopper habitat preference, and that their selective feeding behavior can affect the relative abundance of different plant species in an area (Capinera *et al.,* 2004).

Using 8 study sites including both wetlands and grasslands, the objectives of this study were to: 1. determine grasshopper richness on IMRS; 2. estimate the true species richness of grasshoppers on IMRS and calculate Shannon's diversity index; 3. determine abundance patterns of grasshoppers found during both dry and monsoon seasons; 4. determine plant composition and similarity of plant richness between sites; 5. Predict abundance patterns of grasshoppers and vegetation cover and; 6. determine similarity of grasshopper richness between sites and reasons for these similarity patterns.

With respect to the objectives, it was hypothesized that 1. enough sampling would be conducted to observe all grasshopper species present on the property; 2. an estimate of true species richness would be similar to actual species surveyed. Further, Shannon's index would show wetland sites to have higher grasshopper diversity when compared to open desert sites.; 3. grasshopper abundance would decrease at all sites during the dry season (November through May) because of the positive effects of increased rainfall on plant richness, abundance, and productivity during the monsoon season (June through October); 4. plant composition structure will be most similar among the wetland sites and open desert sites while the permanent water source will contain more distinct vegetation; 5. higher richness in plant communities will correlate with higher grasshopper richness. Grass coverage will be the leading predictor for increased grasshopper

abundance; and 6. grasshopper species similarity will decrease from the permanent wetland site to ephemeral wetland sites, and then to open desert sites.

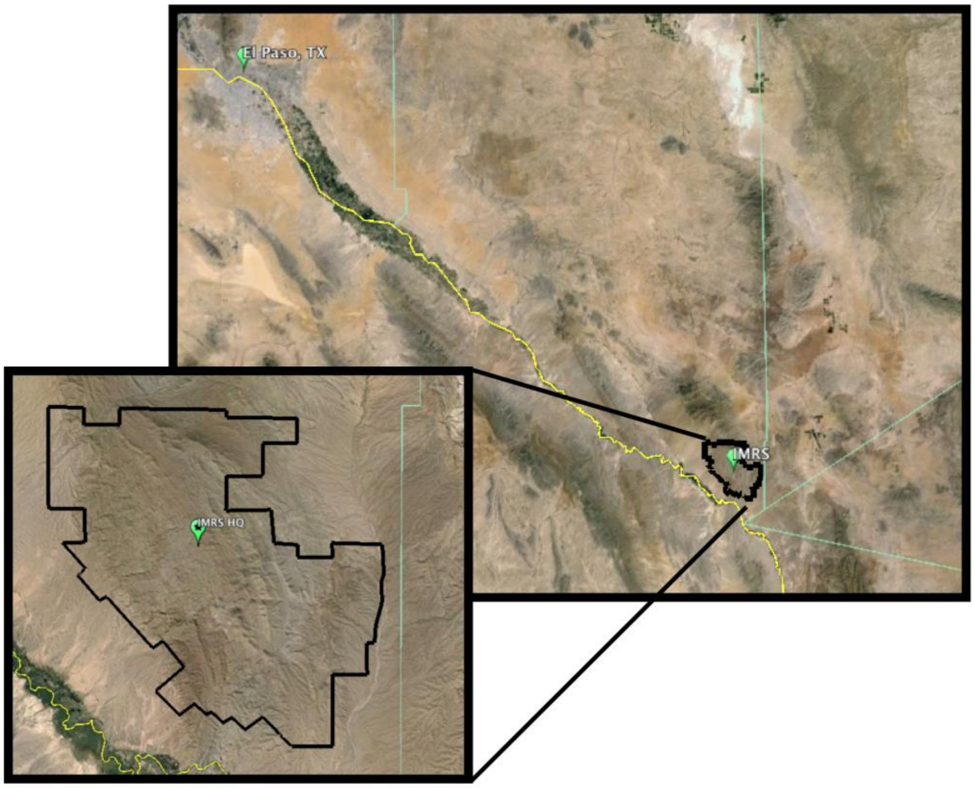

Figure 1 – Satellite image of Indio Mountains Research Station property. The green flag denotes IMRS headquarters.

Materials and Methods

Study Sites

The following eight sites were surveyed: Squaw Spring, Rattlesnake Tank, Mesquite Tank, Echo Tank, Red Tank, Lonely Tank, Woodpecker Well and Oak Arroyo (Fig. 2). Each site was chosen based on accessibility and coverage of different habitats on IMRS property.

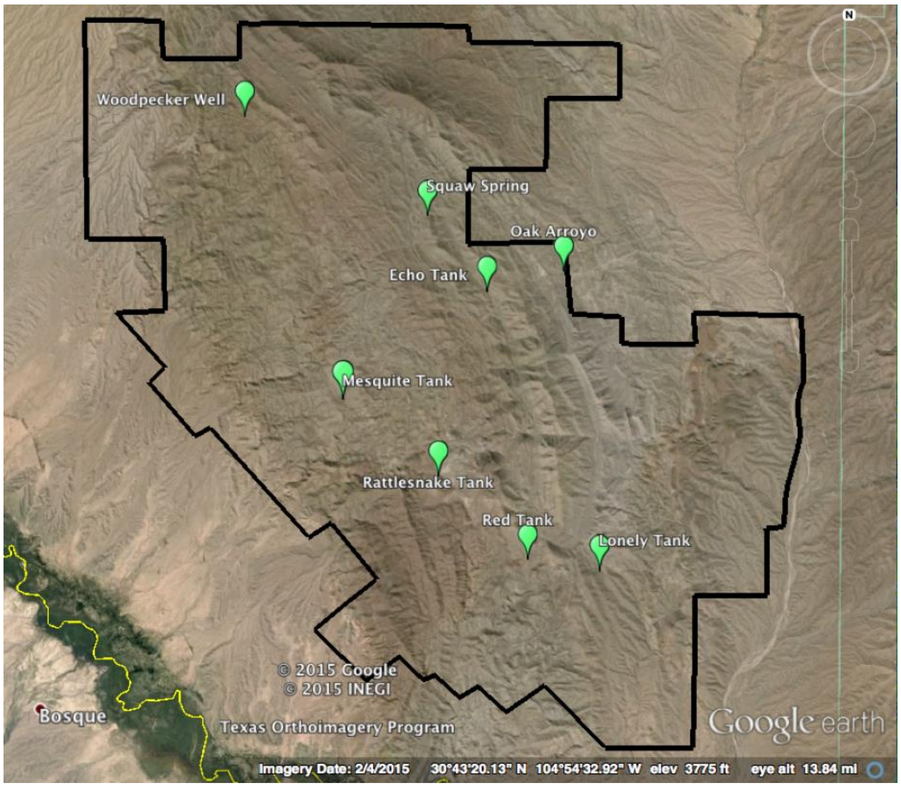

Figure 2 – Satellite image of IMRS property with 8 flags denoting survey sites for this study.

Squaw Spring

Squaw Spring (Fig. 3) is the only permanent water source on Indio Mountains Research Station. It is situated in Squaw Creek Canyon (30.796944° N, 105.010556° W; 1,263 m elev.) and located ca. 2.5 airline km N of IMRS Headquarters (Worthington *et al.*, 2017).

Figure 3 – Landscape of Squaw Spring.

Rattlesnake Tank

Rattlesnake Tank (Fig. 4) is at the head of a small east draining arroyo ca. 1 airline km ENE of the summit of Red Mountain and 0.235 km W of River Road (30.746389° N, 105.008333° W; 1,198 m elev.) (Worthington *et al.*, 2017).

Figure 4 – Landscape of Rattlesnake Tank.

Mesquite Tank

Mesquite Tank (Fig. 5) is near Bailey Evans Arroyo ca. 2.78 km WSW of IMRS Headquarters (30.7616° N, 105.03085° W; 1,167 m elev.) (Worthington *et al.*, 2017).

Figure 5 – Landscape of Mesquite Tank.

Echo Tank

Echo Tank (Fig. 6) lies in Echo Canyon directly below Echo Canyon Overlook (30.782303° N, 104.997864° W; 1,329 m elev.) (Worthington *et al.*, 2017).

Figure 6 – Landscape of Echo Tank.

Red Tank

Red Tank (Fig. 7) is a seasonally dry tank along River Road just W of Eagle Canyon (30.73000° N, 104.98333° W; 1,195 m elev.) (Worthington *et al.*, 2017).

Figure 7 – Landscape of Red Tank.

Lonely Tank

Lonely Tank (Fig. 8 and Fig. 9) is on Jeep Road heading east off River Road above where it crosses Eagle Canyon Arroyo on the way to south gate (30.72794° N, 104.97209° W; 1,190 m elev.) (Worthington *et al.*, 2017). It is the closest tank to the Rio Grande and adjacent to the southern edge of the property.

Figure 8 – Landscape of Lonely Tank.

Figure 9 – Landscape of Lonely Tank after a heavy rainfall event.

Woodpecker Well

Woodpecker Well (Fig. 10) is an open desert site on Main Road that is SW of Yucca Ridge (30.816667° N, 105.052778° W; 1,245 m elev.) (Worthington *et al.*, 2017).

Figure 10 – Landscape of Woodpecker Well.

Oak Arroyo

Oak Arroyo (Fig. 11) is an open desert site near a small arroyo lined by Sandpaper Oak (*Quercus pungens)* located near the IMRS east gate 30.78636° N, 104.98044° W; 1,327 m elev.) (Worthington *et al.*, 2017).

Figure 11 – Landscape of Oak Arroyo.

Data Collection

A standardized 30-minute sampling interval using sweep nets (Sutherland, 2006) was conducted at each site biweekly from August 2014 through December 2015. Due to transportation issues, data was not recorded for the months of December 2014 and January 2015, and data is missing for April and May 2015. Each survey encompassed a 50 x 50 m area (Otte, 1976). Time of day for each survey varied throughout the year to avoid bias of sampling the same time of day repeatedly at each site. Specimens were preserved in 70% ethyl alcohol for subsequent identification in the laboratory. Digital photographs were taken of pinned grasshoppers and compared to Capinera *et al.* (2004), Otte (1981, 1984), Orthoptera Species File (Eades *et al.,* 2015), Encyclopedia of Life (Parr *et al*., 2014), and Grasshoppers of the Western U.S. (Brust *et al*., 2014) for identification to species. Individuals were entered as count data.

A grid system was used to estimate cover of individual plant species and vegetation richness. Each site had flags marking a 50 x 50 m perimeter. The area was equally divided into five transects every ten meters. Each transect had 5 evenly spaced points at which a 1 m^2 quadrat was placed. Aerial percent coverage was recorded and all rooted vegetation was considered inside the quadrat. Plants that were unable to be identified in the field were pressed and later identified in the laboratory. Vegetation was identified to species whenever possible and classified by functional groups (grass, forb, shrub, non-cacti succulent, cacti, and bare ground). A few plants (some grasses) did not have fruits and were unable to be identified to species.

Precipitation and temperature data was collected from a Campbell Scientific UT10 weather station at IMRS Headquarters. The weather station stopped recording data October 28, 2015 due to technical difficulties. Proxy weather data was used from a nearby weather station (USC00419295) in Van Horn, TX.

Data Analysis

Species accumulation curves (SAC) and a rarefaction analysis for each site was used to determine if sampling efforts were sufficient enough to locate all grasshopper species. SAC revealed the cumulative number of species at each site as a function of sampling efforts (1 person 30-min). Using the following equation, Chao 1 (S_1) estimator calculated the estimated true number of grasshopper species diversity at each site:

$$S_1 = S_{obs}\frac{F_1^2}{2F_2}$$

S_{obs} is the number of species in the sample, F1 is the number of singletons and F2 is the number of doubletons (Chao, 1984; Colwell and Coddington, 1994). If a site that is being sampled continuously finds rare species, there are likely more species to be found. Shannon's Diversity index (H) was also calculated using the following equation:

$$\text{Shannon Index (H)} = -\sum_{i=1}^{s} p_i \ln p_i$$

S is the total number of species in the community. P_i is the proportion of *S* made up of the *i*th species A Zero-Inflated Poisson/Negative Binomial Models with mixed effects was applied to identify any relationships between grasshoppers and temperature, precipitation, vegetation and seasonal patterns between monsoon and dry season (Agresti, 2002). This model accounts for multiple correlations.

Vegetation was quantified as the sum percent cover within all 25 $1m^2$ quadrats at a single site. For analyses, shrubs, non-cacti succulents, and cacti were grouped as other. The Coefficient of Biogeographic Resemblance was calculated: $CBR=2C/N_1+N_2$, where C = the number of shared species, N_1 = the total number of species in first site and N_2 = the total number of species in the second site (Duellman, 1990; Lomolino *et al*., 2010). A dendrogram of similarity using Unweighted Pair Group Method with Arithmetic Mean (UPGMA; Sokal and Michener, 1958) was used to illustrate sister relationships between sites for both grasshopper and plant species.

To test if increased richness in plant community correlate with increased richness in grasshoppers, a Spearman's correlation test was run. All statistical analysis was done in the statistical software program R.

Results

This survey was conducted from September 2014 through December 2015 for an actual total survey time of 63.5 hr. A total of 23 grasshoppers from three families and seven subfamilies were identified to species while three were identified only to genus (*Trimerotropis sp.., Mermiria sp.,* and *Melanoplus sp.*). Six new species were added to Worthington *et al.* (2017) listing for a total of 35 species now known to occur on IMRS (*Syrbula montezuma, Shistocerca albolineata, Phoetaliotes nebrascensis, Melanoplus femmurrubrum, Melanoplus lakinus,* and *Melanoplus thomasi).* Only two species (*Schistocerca nitens* and *Trimerotropis pallidipennis*) and one genus *(Melanoplus sp.*) were found at all survey sites (Table 1). *Melanoplus femurrubrum* was the most frequently collected species (n = 1,146). There were six singleton records for *Acantherus piperatus, Clematodes larreae, Paratettix aztecus, Schistocerca albolineata, Syrbula montezuma,* and *Taeniopoda equs.*

Table 1 – Grasshopper species records for the eight survey sites used in this study. An X denotes that the grasshopper species was present. Species in bold are new account records for the property.

Family	Subfamily	Species	Survey Sites: Echo Tank	Mesquite Tank	Lonely Tank	Oak Arroyo	Rattlesnake Tank	Red Tank	Squaw Spring	Woodpecker Well
Acrididae	Copiocerinae	*Clematodes larreae*		X						
Acrididae	Cyrtacanthacridinae	***Schistocerca albolineata***								X
		Schistocerca nitens	X	X	X	X	X	X	X	X
Acrididae	Gomphocerinae	*Acantherus piperatus*			X					
		Acrolophitus maculipennis	X			X				
		Bootettix argentatus		X	X	X	X	X	X	X
		Cibolacris parviceps						X		X
		Mermiria spp.	X	X	X					
		Mermiria bivittata	X			X	X		X	
		Mermiria texana	X	X		X			X	
		Opeia obscura					X		X	X
		Syrbula montezuma				X				
Acrididae	Melanoplinae	*Melanoplus spp.*	X	X	X	X	X	X	X	X
		Melanoplus femurrubrum	X	X	X		X	X		X
		Melanoplus lakinus	X	X	X		X		X	
		Melanoplus thomasi	X	X			X	X		
		Phoetaliotes nebrascensis	X	X	X		X			
Acrididae	Oedipodinae	*Arphia pseudonietana*	X		X					
		Encoptolophus subgracilis			X		X	X	X	
		Trimerotropis spp.								X
		Trimerotropis pallidipennis	X	X	X	X	X	X	X	X
Romaleidae	Romaleinae	*Phrynotettix robusuts*	X			X			X	
		Taeniopoda equs							X	
Tetrigidae	Tetriginae	*Paratettix aztecus*			X					
		Paratettix mexicanus	X						X	
		Paratettix toltecus						X	X	

Sampling Effort

Species accumulation curves (SAC) were created to describe how the total number of species reported increased with increasing time spent sampling at each site (sampling events) and to determine if enough sampling was conducted to observe all grasshopper species on the property. (Figs. 12-19) Mesquite Tank was sampled the most with a total of 18 sampling events. Oak Arroyo was sampled 17 times while Echo Tank, Rattlesnake Tank and Squaw Spring were sampled 16 times. Lonely Tank and Red Tank were sampled a total of 15 times while Woodpecker Well was only sampled 14 times. The two open desert sites, Oak Arroyo, Woodpecker Well as well as the permanent spring, Squaw Spring, did not approach an asymptote. All five ephemeral wetland sites were sampled sufficiently.

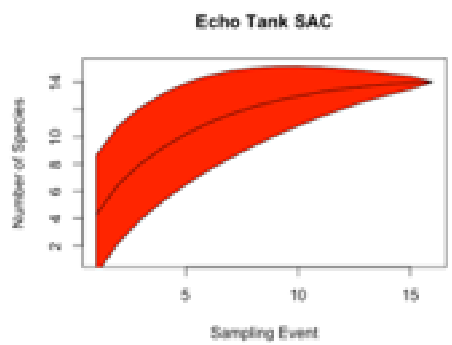

Figure 12 – Species accumulation curve for Echo Tank

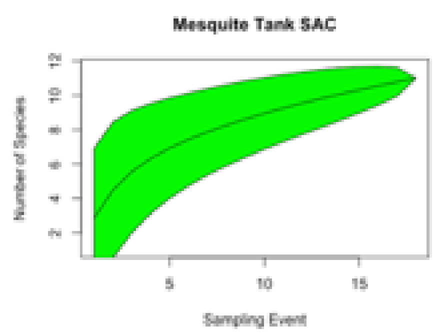

Figure 13 – Species accumulation curve for Mesquite Tank.

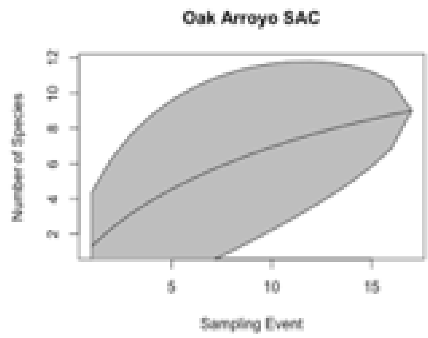

Figure 14 – Species accumulation curve for Oak Arroyo.

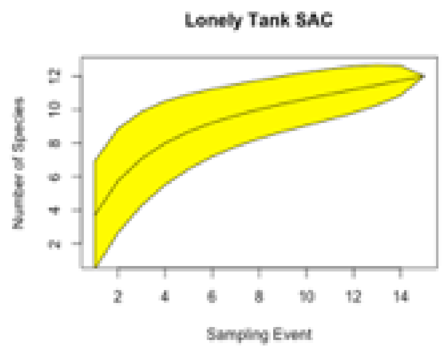

Figure 15 – Species accumulation curve for Lonely Tank.

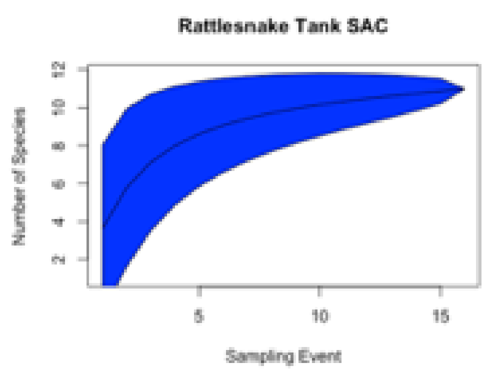

Figure 16 – Species accumulation curve for Rattlesnake Tank.

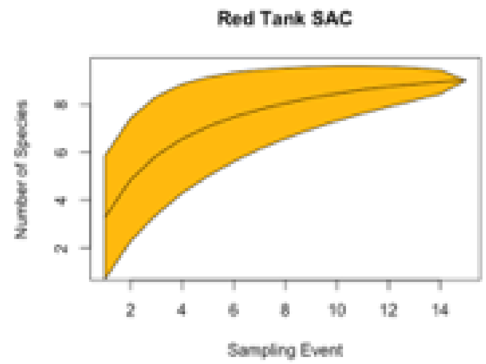

Figure 17 – Species accumulation curve for Red Tank.

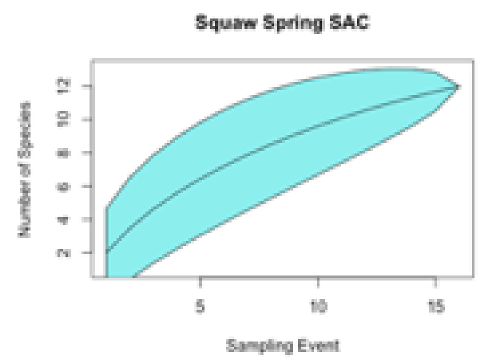

Figure 18 – Species accumulation curve for Squaw Spring.

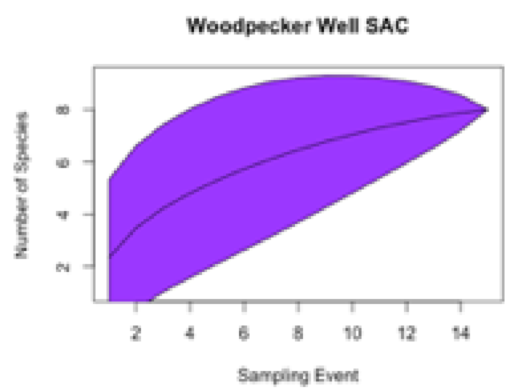

Figure 19 – Species accumulation curve for Woodpecker Well.

Grasshopper Richness and Abundance

Grasshopper richness was highest at Echo Tank with a total of 14 recorded and estimated number of species (Chao 1 = 14.5). 12 species were recorded at Lonely Tank and Squaw Spring with a Chao 1 estimated amount of 16 (Chao 1 = 16.5) and 18 (Chao 1 = 18.25) possible species, respectively. 11 species were recorded at Mesquite Tank with a Chao 1 estimated amount of 17 possible species. 10 species were recorded at Rattlesnake Tank with a Chao 1 estimated amount of 12 possible species. Oak Arroyo, Red Tank and Woodpecker Well all had a total of 9 species recorded with a Chao 1 estimated amount of 11, 9 and 9 possible species, respectively. Sampling effort was sufficient at Echo Tank, Red Tank and Woodpecker Well to collect all species present. Shannon's diversity index values ranged from 0.285 to 1.036 indicating that every species in the sample is nearly the same (Table 2).

Table 2 – Total number of sampling event, actual and estimated grasshopper species richness and Shannon's Diversity index per site.

Survey Site	Sampling Events	Actual Number of Species	Chao 1 Estimated Number of Species	Shannon's Diversity Index (H)
Echo Tank	16	14	14.5	0.823
Lonely Tank	15	12	16.5	1.036
Mesquite Tank	18	11	17	0.609
Oak Arroyo	17	9	11	0.285
Rattlesnake Tank	16	10	12	0.859
Red Tank	15	9	9	0.845
Squaw Spring	16	12	18.25	0.611
Woodpecker Well	14	9	9	0.478

Seasonal Abundance Patterns

Of the 23 grasshopper species sampled throughout this survey, only 10 were sampled enough to apply a Poisson distribution of species count model; *Melanoplus* sp., *Bootettix argentatus, Schistocera nitens, Trimerotropis pallidipennis, Melanoplus thomasi, Mermiria*

bivittata, Encoptolophus subgracilis, Melanoplus femurrubrum, Melanoplus lakinus, and *Phoetaliotes nebrascensis.* Analysis for *M.* bivittata and *P. nebrasencis* were inconclusive. Poisson models predict a likely outcome from sampled trials. Excluding monsoon and dry season estimates, all models were randomized at month level. If errors occurred, models were changed to random model by sites. *Bootettix argentatus, M. thomasi,* and *E. subgracilis* all had positive Poisson estimates and significant p-values for grasshopper count and temperature (p = .00025; p = .0301; and p = .03574). As temperature increased, the number of individuals of these three species of grasshoppers also increased. *Melanoplus thomasi, M. bivittata* and *M. lakinus* all had positive Poisson estimates and significant p-values for grasshopper count and precipitation (p = .0293; p = .00833; and p = .00011). As precipitation increased, the number of individuals of these three species of grasshoppers also increased. Seasonal patterns were observed for *Melanoplus sp., M. thomasi, E. subgracilis,* and *M. femurrubrum. Melanoplus sp.* and *M. femurrubrum* were found more during the monsoon season months of June through October (p = .00680 and p = .02415). Both *M. thomasi* and *E. subgracilis* were found more often during the dry season months of November through May (p = .0099 and p = .00016). Refer to Tables 3-10 for Poisson Model estimates and p-values.

Table 3 – Poisson model estimates for *Melanoplus sp.* Significant values are in bold.

Variable	Estimate	P-value
Year	-1.4545	**0.00011**
Water	0.1903	0.69204
Temperature	-0.0243	0.50096
Precipitation	-139.9726	0.75432
Grass	0.0803	**5.7 e^{-06}**
Forbs	0.0254	0.27900
Other	0.0133	0.49459
Monsoon Season	2.5122	**0.00680**

Table 4 – Poisson model estimates for *Melanoplus lakinus.* Significant values are in bold.

Variable	Estimate	P-value
Year	-0.1945	0.72758
Water	-1.2857	**4.7e-05**
Temperature	-0.0543	0.27377
Precipitation	2128.6714	**0.00011**
Grass	0.1311	**8.1e-06**
Forbs	0.0585	**0.04921**
Other	0.0757	**0.00108**
Monsoon Season	-0.5373	0.56820

Table 5 – Poisson model estimates for *Melanoplus thomasi.* Significant values are in bold.

Variable	Estimate	P-value
Year		
Water	-5.8566	0.1006
Temperature	0.2116	**0.0301**
Precipitation	8754.4926	**0.0293**
Grass	0.2951	**0.0096**
Forbs	-0.0779	0.3073
Other	3.2263	0.0611
Monsoon Season	-8.6369	**0.0099**

Table 6 – Poisson model estimates for *Melanoplus femurrubrum.* Significant values are in bold.

Variable	Estimate	P-value
Year	-3.4970	**0.00025**
Water	-1.1915	**0.03118**
Temperature	-0.0482	0.44357
Precipitation	610.4779	0.13383
Grass	0.0129	0.51805
Forbs	0.0697	**0.04668**
Bare Ground	-0.0197	0.33225
Monsoon Season	3.6045	**0.02415**

Table 7 – Poisson model estimates for *Schistocerca nitens.* Significant values are in bold.

Variable	Estimate	P-value
Year	-2.8507	**1.1 e^{-06}**
Water	-0.6790	0.05417
Temperature	0.0383	0.45475
Precipitation	241.1544	0.71395
Grass	0.0836	**0.00019**
Forbs	0.0270	0.39489
Other	0.0335	0.19990
Monsoon Season	1.7229	0.19236

Table 8 – Poisson model estimates for *Trimerotropis pallidipennis*. Significant values are in bold.

Variable	Estimate	P-value
Year	4.5 e^{-03}	0.99562
Water	9.04 e^{-01}	**0.04690**
Temperature	5.95 e^{-02}	0.15252
Precipitation	-1.67 e^{+02}	0.69569
Grass	-3.94 e^{-02}	**0.00576**
Forbs	-1.13 e^{-01}	**0.00086**
Other	-7.31 e^{-02}	**8.5 e^{-06}**
Monsoon Season	7.49 e^{-01}	0.50575

Table 9 – Poisson model estimates for *Encoptolophus subgracilis*. Significant values are in bold.

Variable	Estimate	P-value
Year		
Water	-7.74 e^{-01}	0.21298
Temperature	1.58 e^{-01}	**0.03574**
Precipitation	1.99 e^{+03}	**0.00833**
Grass	-1.27 e^{+01}	0.99832
Forbs	8.61 e^{+00}	0.99835
Other	-2.00 e^{+01}	0.99833
Monsoon Season	-5.80 e^{+00}	**0.00016**

Table 10 - Poisson model estimates for *Bootettix argentatus.* Significant values are in bold.

Variable	Estimate	P-value
Year	0.4624	0.37143
Water	0.1865	0.33774
Temperature	0.0687	**0.00025**
Precipitation	116.5109	0.60229
Grass	-0.0804	**7.6 e^{-11}**
Forbs	-0.0347	**0.01177**
Other	-0.0924	**2.7 e^{-13}**
Monsoon Season	0.2100	0.68490

Plant Composition and Structure

Five cacti species, 22 grass species (nine unidentified), 24 forb species (12 unidentified), seven shrub species (six unidentified), and six non-cacti succulent species were found. A total of 47 identified plant species from 22 families were sampled (Table 11). Oak Arroyo had the highest species richness (25) followed in order by Squaw Spring (23), Lonely Tank (17), Red Tank (14), Mesquite Tank (13), Echo Tank (12), with Rattlesnake Tank and Woodpecker Well each having only 10 species. Squaw Spring had the most diverse families sampled (12) followed in order by Oak Arroyo (10), Echo Tank (8), with Lonely Tank and Mesquite Tank each having seven, Red Tank and Rattlesnake Tank each having six, and Woodpecker Well five species. Grasses dominated ground coverage at Echo Tank (43%), Lonely Tank (44%), and Mesquite Tank (41%). Although the most diverse in number of species sampled, Oak Arroyo was dominated by bare ground (44%). Bare ground also dominated Red Tank (41%) and Woodpecker Well (63%). Rattlesnake Tank was dominated by forbs plants (34%) followed closely by grass coverage (33%). Cacti were only found at Squaw Spring (1%) and Woodpecker Well (9%). Other non-cacti succulents were found at Oak Arroyo (8%). Refer to Figure 20 for total percentage coverage.

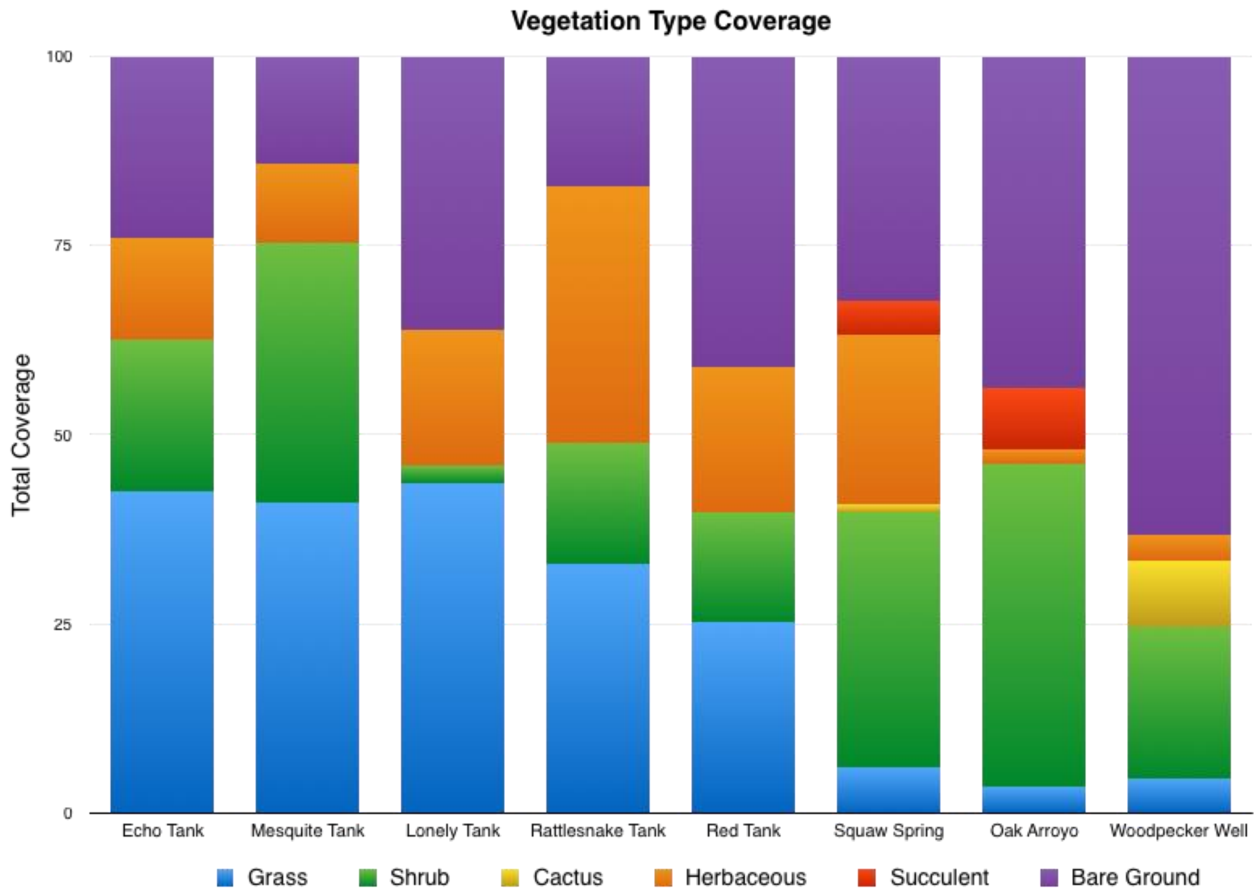

Figure 20 – Stacked bar graph of vegetation functional sum percentage at each survey site.

Table 11 – Sum percent of plant species cover records for the eight survey sties used in this study. Exotic plant species are indicated by (*).

			Percent Occurrence at Survey Sites							
			Echo Tank	Lonely Tank	Mesquite Tank	Oak Arroyo	Rattlesnake Tank	Red Tank	Squaw Spring	Woodpecker Well
Functional Type	**Family**	**Species**								
Bare Ground	N/A	N/A	24.00	36.00	7.00	44.00	17.00	31.00	32.00	63.00
Cactus	Cactaceae	*Corphantha dasyacantha*							0.04	
Cactus	Cactaceae	*Cylindropuntia leptocaulis*							0.20	
Cactus	Cactaceae	*Echinocereus coccineus*							0.60	
Cactus	Cactaceae	*Opuntia spp.*							0.20	8.52
Cactus	Cactaceae	*Cylindropuntia imbricata*								0.36
Grass	Poaceae	*Bouteloua barbata*						2.68		
Grass	Poaceae	*Bouteloua curtipendula*			0.88					
Grass	Poaceae	*Bouteloua gracilis*							0.40	2.40
Grass	Poaceae	*Chloris virgata* *	2.04	0.40	0.92			0.12		
Grass	Poaceae	*Cynodon dactylon* *		0.20				3.80		
Grass	Poaceae	*Dasyochloa pulchella*				0.32				1.60
Grass	Poaceae	*Digitaria californica*					0.08		0.60	
Grass	Poaceae	*Echinochloa colona* *		34.60				16.08		
Grass	Poaceae	*Echinochloa crus-galli* *	37.08		36.44					
Grass	Poaceae	*Eragrostis cilianensis* *						0.20		
Grass	Poaceae	**Grass 1**							2.32	
Grass	Poaceae	**Grass 2**				1.40				
Grass	Poaceae	**Grass 3**							0.68	
Grass	Poaceae	**Grass 4**		0.20						
Grass	Poaceae	**Grass 5**				0.12				
Grass	Poaceae	**Grass 6**				1.28				
Grass	Poaceae	**Grass 7**						1.00		
Grass	Poaceae	**Grass 8**						1.32		0.56
Grass	Poaceae	**Grass 9**				0.04				
Grass	Poaceae	*Polpogon viridis* *		7.48						
Grass	Poaceae	*Setaria leucopila*	3.44	0.68	2.72		32.92		2.12	
Grass	Poaceae	*Sporobolus contractus*				0.40				
Herbaceous	Asteraceae	*Viguiera stenoloba*				1.40				
Herbaceous	Asteraceae	*Baccharis salicifolia*							9.12	
Herbaceous	Asteraceae	*Bahia absinthifolia*	0.96							
Herbaceous	Asteraceae	*Chrysactina mexicana*		0.12						
Herbaceous	Asteraceae	*Parthenium incanum*		1.00	4.80					
Herbaceous	Asteraceae	**Species 10**							0.40	
Herbaceous	Asteraceae	**Species 16**					2.16			
Herbaceous	Asteraceae	*Verbesina enceloides*	0.48	0.40						
Herbaceous	Asteraceae	*Xanthium strumarium*		2.92	2.64		25.08	11.20		
Herbaceous	Asteraceae	**Species 17**								2.24
Herbaceous	Asteraceae	**Species 3**								1.08
Herbaceous	Cyperaceae	*Eleocharis spp.*						4.00		
Herbaceous	Euphorbiaceae	*Croton pottsii*		0.56						
Herbaceous	Gentianaceae	*Eustoma exaltatum*							0.72	
Herbaceous	Malvaceae	*Sphaeralcea angustifolia*	3.60	0.48	0.32		4.80			
Herbaceous	Solanaceae	*Solanum elaeagnifolium*	8.36	3.20	2.72	0.20	1.88	1.84	0.24	

Functional Type	Family	Species	Echo Tank	Lonely Tank	Mesquite Tank	Oak Arroyo	Rattlesnake Tank	Red Tank	Squaw Spring	Woodpecker Well
Herbaceous		**Species 15**						2.08		
Herbaceous		**Species 18**						0.08		
Herbaceous		**Species 4**							10.40	
Herbaceous		**Species 5**		2.48						
Herbaceous		**Species 6**							1.60	
Herbaceous		**Species 7**		6.80						
Herbaceous		**Species 8**				0.24				
Herbaceous		**Species 9**								0.12
Shrub	Berberidaceae	*Berberis trifoliata*				0.80			1.00	
Shrub	Boraginaceae	*Tiquilia greggii*	0.80			1.12				
Shrub	Chenopodiaceae	*Atriplex canescens*					6.68		7.32	
Shrub	Fabaceae	*Acacia constricta*			2.80	15.40	0.60			
Shrub	Fabaceae	*Acacia greggii*	10.24		17.40	8.40	4.00		12.76	1.56
Shrub	Fabaceae	*Prosopis glandulosa*	2.80	0.72	7.60		4.68	8.52	6.88	
Shrub	Fagaceae	*Querus pungens*				4.00				
Shrub	Oleaceae	*Forestiera angustifolia*	3.20		0.48	0.72				
Shrub	Rhamnaceae	*Ziziphus obtusifolia*							3.12	
Shrub	Scrophulariaceae	**Species 1**				2.44				
Shrub	Scrophulariaceae	**Species 2**				2.60				
Shrub	Verbenaceae	*Aloysia wrightii*	2.92	1.60						
Shrub	Zygophyllaceae	*Larrea tridentata*			1.88			5.96	2.60	18.40
Shrub		**Species 11**				0.24				
Shrub		**Species 12**				0.80				
Shrub		**Species 13**				1.20				
Shrub		**Species 14**				2.80				
Succulent	Agavaceae	*Agave lechugilla*							0.40	
Succulent	Ephedraceae	*Ephedra aspera*				1.00				
Succulent	Koeberliniaceae	*Koeberlinia spinosa*				1.52				
Succulent	Nolinaceae	*Dasylirion leiophyllum*				3.52				
Succulent	Nolinaceae	*Nolina erumpens*				2.00				
Succulent	Typhaceae	*Typha domingensis*							4.00	

Sites were compared pair-wise using the Coefficient of Biogeographic Resemblance (Duellman, 1990). This coefficient was used to compare sites based on the number of species shared (Table 12). The CBR values were used to create a UPGMA dendrogram which shows sister relationships between the survey sites (Fig. 21). The highest similarity was between Echo Tank and Mesquite Tank (.64) followed by Lonely Tank, Rattlesnake Tank, Squaw Spring, Red Tank, Oak Arroyo and Woodpecker Well.

Table 12 – Plant species similarity matrix showing the number of total species per site (bold), shared species between sites, and the Coefficient of Biogeographic Resemblance between sites (in yellow).

Veg Matrix

	Echo Tank	Lonely Tank	Mesquite Tank	Oak Arroyo	Rattlesnake Tank	Red Tank	Squaw Spring	Woodpecker Well
Echo Tank	**12**	7	8	4	5	3	4	1
Lonely Tank	0.48	**17**	7	1	5	6	4	0
Mesquite Tank	0.64	0.47	**13**	4	7	4	6	2
Oak Arroyo	0.22	0.05	0.21	**25**	3	1	3	2
Rattlesnake Tank	0.45	0.37	0.61	0.17	**10**	3	7	1
Red Tank	0.23	0.39	0.30	0.05	0.25	**14**	3	1
Squaw Spring	0.23	0.20	0.33	0.13	0.42	0.02	**23**	4
Woodpecker Well	0.09	0.00	0.17	0.11	0.10	0.08	0.24	**10**

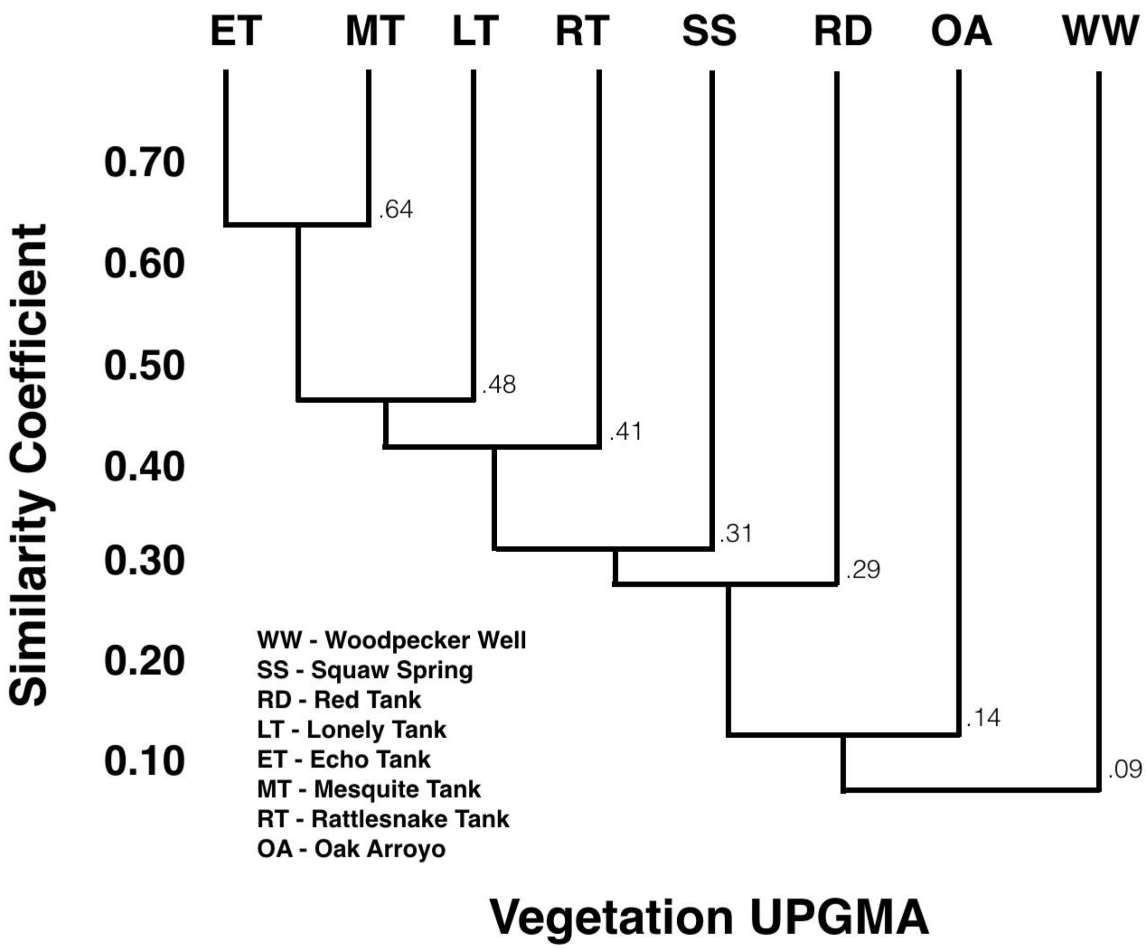

Figure 21 – UPGMA dendrogram showing pair-wise similarity of plant species between all sites.

Grasshopper and Vegetation Species Patterns

To test if increased richness of the plant community correlated with increased richness in grasshoppers, a Spearman's correlation test was run. There was no evidence for any correlation between grasshopper richness and plant richness (r = 0.037).

Of the 23 grasshopper species sampled throughout this survey, only 10 were sampled enough to apply a Poisson distribution of species count model; *Melanoplus sp., Bootettix argentatus, Schistocera nitens, Trimerotropis pallidipennis, Melanoplus thomasi, Mermiria bivittat, Encoptolophus subgracilis, Melanoplus femurrubrum, Melanoplus lakinus*, and

Phoetaliotes nebrascensis. All models were randomized at month level. If errors occurred, models were changed to random model by sites. *Melanoplus sp., B. argentatus, S. nitens, T. pallidpipennis, M. thomasi,* and *M. lakinus* all displayed significant Poisson estimates for grass coverage and grasshopper count ($p = 5.7e^{-06}$; $p = 7.6e^{-11}$; $p = .00019$, $p = .00576$; $p = .0096$; and $p = 8.1e^{-06}$). As grass coverage increased, the number of individuals of *Melanoplus sp., S. nitens, M. thomasi,* and *M. lakinus* also increased while *B. argentatus,* and *T. pallidipennis* decreased. *B. argentatus, T. pallidipennis, M. femurrubrum* and *M. lakinus* all displayed significant Poisson estimates for forb vegetation coverage and grasshopper count. ($p = .01177$; $p = .00086$; $p = .04668$; and $p = .04921$). As forbs vegetation coverage increased, the number of individuals of *M. femurrubrum* and *M. lakinus* increased while *B. argentatus* and *T. pallidipennis* decreased. Shrubs, cacti and other non-cacti succulents were analyzed together (Functional Group: Other). *Bootettix argentatus,* T. *pallidipennis* and *M. lakinus* all displayed significant Poisson estimates for the vegetation functional group 'Other' and grasshopper count ($p = 2.7e^{-13}$; $p = 8.5e^{-06}$; and $p = .00108$). As the coverage for shrubs, cacti and other non-cacti succulents increased, the number of individuals of *M. lakinus* also increased while *B. argentatus* and *T. pallidipennis* decreased. Refer to Tables 3-10 for all Poisson Model estimates and p-values.

Comparison of Survey Sites – Grasshoppers

Sites were compared pair-wise using the Coefficient of Biogeographic Resemblance (Duellman, 1990). This coefficient was used to compare sites based on the number of species shared (Table 13). Only *Schistocerca nitens* and *Trimerotropis pallidipennis* were found at all eight sites. *Bootettix argentatus* was found at all sites except Echo Tank. The CBR values were used to create a UPGMA dendrogram which shows sister relationships between the survey sites (Fig. 22). The highest similarity was between Red Tank and Rattlesnake Tank followed by Mesquite Tank, Lonely Tank, and Echo Tank. Woodpecker Well and Squaw Spring clustered together (.53) followed by Oak Arroyo.

Table 13 – Grasshopper species similarity matrix showing the number of total species per site (bold), shared species between sites, and the Coefficient of Biogeographic Resemblance between sites (in yellow).

Grasshopper Matrix

	Echo Tank	Lonely Tank	Mesquite Tank	Oak Arroyo	Rattlesnake Tank	Red Tank	Squaw Spring	Woodpecker Well
Echo Tank	**14**	8	9	7	8	5	8	4
Lonely Tank	0.62	**12**	8	4	8	6	5	5
Mesquite Tank	0.72	0.70	**11**	5	8	6	6	5
Oak Arroyo	0.61	0.38	0.50	**9**	5	4	5	4
Rattlesnake Tank	0.67	0.73	0.76	0.53	**10**	8	7	6
Red Tank	0.43	0.57	0.60	0.44	0.84	**9**	5	6
Squaw Spring	0.62	0.42	0.52	0.48	0.64	0.48	**12**	5
Woodpecker Well	0.35	0.48	0.50	0.44	0.63	0.67	0.48	**9**

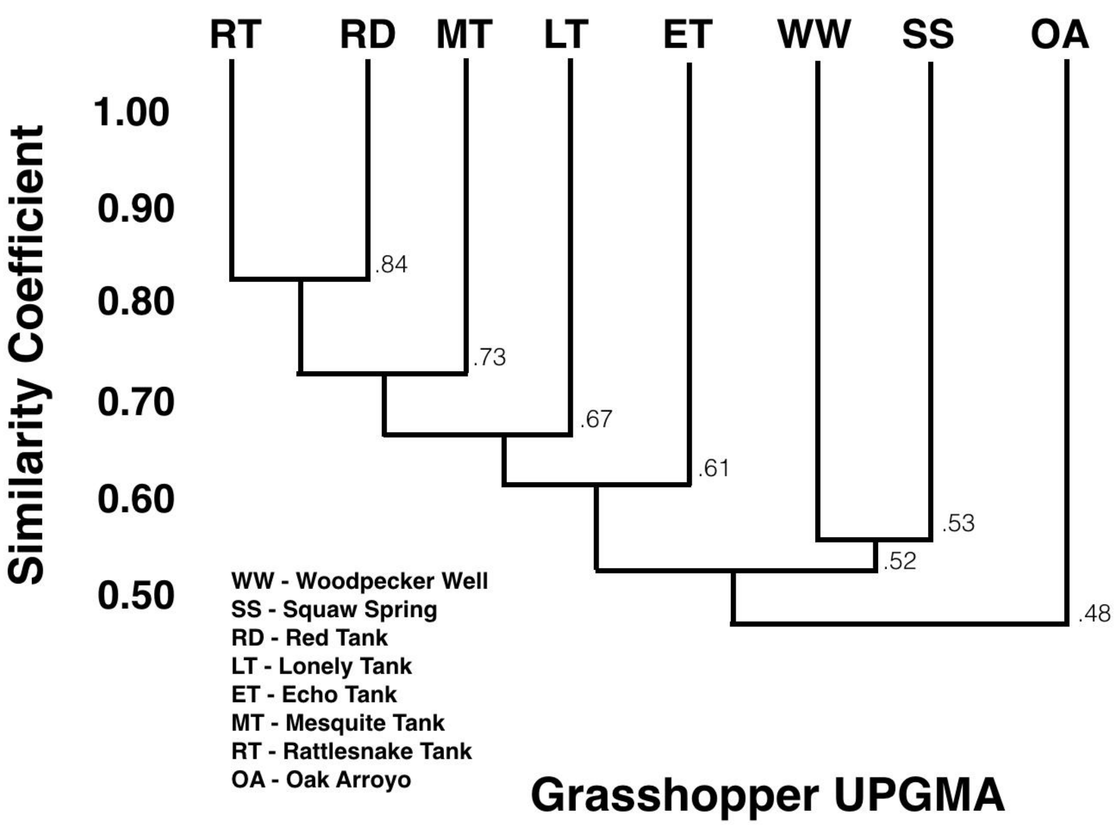

Figure 22 - UPGMA dendrogram showing pair-wise similarity of grasshopper species between all sites.

Discussion

Sampling Effort

Each survey site was sampled an average of 15 times (range = 14 - 18). More sampling efforts need to be conducted to observe all grasshopper species present on the property in open desert sites. Referring to the species accumulation curves, the three sites that did not approach an asymptote were Oak Arroyo, Woodpecker Well and Squaw Spring. Squaw Spring, a riparian zone, had more distinct vegetation and different topography when compared to all other sites. Stein *et al.* (2014) have shown strong associations with species richness, vegetation and topographic heterogeneity. Habitat heterogeneity has been shown to drive species richness for birds, bats, and other vertebrate species (Lorenzón *et al.*, 2016; Luo et al., 2012; Lopez-Gonzalez *et al*, 2015). There is even evidence for this pattern in marine environments (Sanciangco *et al*., 2013). Habitat heterogeneity has also been shown to drive richness and geographic distribution of stream invertebrates (Astorga, *et al.,* 2014). These factors could influence grasshopper richness at Squaw Spring as well as Oak Arroyo because there are more niches to occupy. Woodpecker Well, although not topographically heterogeneous, contained a lot of bare ground and was dominated by Creosote Bush. The sampling method (sweep net) may not have been the best method to obtain grasshoppers from shrubs. A second sample method of utilizing a beat sheet may result in collecting more rare or reclusive species.

Grasshopper Richness and Abundance

Although species accumulation curves indicated that not all species were found at Woodpecker Well, Oak Arroyo and Squaw Spring, Chao 1 estimates were very similar to the actual number of species sampled. The inconsistency of predicted number of species may be attributed to nature of the Chao 1 estimator which uses the number of rare species sampled as a way of calculating how likely it is to discover new species (Chao, 1984; Colwell and Coddington, 1994). Shannon's Diversity Index values ranged from 0.285 to 1.035. Average ranges are 1.5 - 3.5 for most ecological studies (Magurran, 2004). The low grasshopper index values may indicate that

there are overlaps between some of the eight communities with very little diversity. Lonely Tank had the largest value (H = 1.036) followed by Rattlesnake Tank and Red Tank (H = 0.859, H = 0.845). Lonely Tank is also the site closest to the Rio Grande and furthest south on the edge of IMRS. Red Tank and Rattlesnake Tank are the next two closest sites to Lonely Tank. More sampling of other areas might show an increasing diversity gradient towards the Rio Grande. Oak Arroyo had the lowest index of .285 and although it was the most grasshopper rich site, several species were rare and some were found only once scoring evenness less than other sites. As predicted, both open desert sites were the least diverse compared to all other wetland sites. Forbs and grasses have shallow root systems which compete for water. The lack of a somewhat more stable supply of water at these open desert sites compared to tanks, inhibit forb and grass growth which these grasshoppers tend to utilize the most.

Seasonal Abundance Patterns

Seasonal richness of *M. femurrubrum* and *Melanoplus sp.* decreased during the dry season. *Melanoplus femurrubrum* tend to favor habitats that include tall vegetation of grasslands and low moist weedy areas (Cantrall, 1943; Shotwell, 1938). *Melanoplus thomasi* and *E. subgracilis* had the inverse relationship and were found less during the monsoon season. Positive precipitation correlations were also found among *M. thomasi, M. bivittata* and *M. lakinus.* Although no significant relationship was found between precipitation and *M. femurrubrum,* a decrease of *M. femurrubrum* abundance during the dry season is supported with known natural history of this grasshopper. Positive temperature correlations were found among *B. argentatus, M. thomasi,* and *E. subgracilis.* As expected, no grasshoppers were found to have a negative correlation with increasing temperature or precipitation. It is important to note that *Melanoplus* sp. could be any of the other three species in the genus found on IMRS; small nymphs have very similar morphology to immature *Phoetailotes nebrascensis*, another melanopline grasshopper.

Plant Composition and Structure

The presence of grass was the leading factor in number of grasshopper individuals for six out of the eight species tested. Grass was the numerically dominant vegetation type growing within Echo Tank, Lonely Tank, and Mesquite Tank. Interestingly, Oak Arroyo had the highest plant richness with most shrub species form the family Laminaceae. Squaw Spring had the second highest plant richness (23) which may be explained by the permanent water availability. A perennial water source can The UPGMA dendrogram grouped all wetland sites together with the two open desert sites as outliers. Red Tank paired with Woodpecker Well and Oak Arroyo since they shared the more creosote than any other tank. Echo Tank and Mesquite Tank were the most similar sharing more plant species than any other sites. Although not the shortest distance from other tanks (3.9 km), these two share the same arroyo system. Woodpecker Well had the least plant richness (10 species) and was dominated by *Larrea tridentata* (Zygophyllaceae). Both open desert sites had the lowest and highest plant richness (OA and WW). Oak Arroyo and Woodpecker Well have a 58-m elevational difference (WW = 1262 m; OA = 1320 m) which could explain the two extremes. All other sites ranged between 1186-1270 m.

Grasshopper and Vegetation Species Patterns

There was no correlation between increased plant richness and grasshopper richness throughout suggesting there are not many grasshopper specialists. Vegetation cover seemed to play an important role in grasshopper abundance. As grass coverage increased, *Melanoplus sp.*, *S. nitens, M. thomasi,* and *M. lakinus* populations increased as well. *Trimerotropis pallidipennis* and *B. argentatus* both decreased as grass coverage increased. *Trimerotropis pallidipennis* is generally found in a desert habitat with shrubs, grasses and plenty of bare ground to thermoregulate and rest (Barnes, 1960). It is important to note that *Bootettix argentatus* commonly known as the Creosote Bush grasshopper resides exclusively on *Larrea tridentata* (Creosote Bush) which can outcompete grasses with the ability to access the water table whereas grasses are only able to access surface

water (Gibbens and Lenz, 2001). *Bootettix argentatus* was found at all tanks except for Echo Tank where *Larrea tridentata* was not recorded as well.

As forbs coverage increased, *M. femurrubrum* and *M. lakinus* also increased in numbers, while abundance of *B. argentatus* and *T. pallidipennis* decreased. As shrubs, cacti and other non-cacti succulent cover increased, number of individuals of *M. lakinus* also increased, while *B. argentatus* and *T. pallidipennis* numbers decreased. These estimates are further supported by habitat preferences of *B. argentatus* and *T. pallidipennis*. Craig *et al*. (1999) found that band winged grasshoppers (such as *T. pallidipennis*) were associated with more open ground, in short grass vegetation, while melanoplinae grasshoppers were more often in mixed grass areas with a high percentage of forb to graminoid cover. This is the case found at Rattlesnake Tank where most *Melanoplus* species occur.

Comparison of Survey Sites – Grasshoppers

The most common grasshoppers found across all sites were *S. nitens, T. pallidipennis* and *B. argentatus. Schistocera nitens* and *T. pallidipennis* are strong flyers and can travel long distances which could account for their ubiquitous presence on the property (Otte, 1984; Dirsh, 1974). Similar to the vegetation UPGMA dendrogram, all ephemeral wetland sites were clustered together compared to the two open desert sites and perennial water source. Unlike the vegetation UPGMA dendrogram, Rattlesnake Tank and Red Tank were most similar. Rattlesnake Tank and Red Tank are 2.7 km apart while Mesquite Tank is 2.7 km from Rattlesnake Tank and further from Red Tank (ca. 5.4 km). Although both grasshopper and vegetation UPGMA dendrograms were not congruent, it shows that similarity between the tanks are based on diversity of grass species and non-specialist grasshoppers. Trends were similar when sites were grouped together in a hierarchical manner (wetlands to open desert sites).

Future Directions

A follow-up study should incorporate quantifying plant nutritional value throughout the season. Boutton (1978) observed grasshoppers, other mandibulate insects, and haustellate insects

occupying C_3 grasses more often than C_4 grasses. Plant nutritional value was quantified and it was found that C_3 grasses always had a significantly higher protein content compared to C_4 grasses hosting grasshoppers. It would be interesting to investigate the relationships between grass protein and grasshopper densities. Seasonal change in plant protein, if any, may be able to predict possible outbreaks.

Investigating competition between nymph-overwintering adult grasshoppers and later-developing nymphal grasshoppers could reveal high competition especially at high densities. From personal observation, there were a few heavy rainfall events in the summer of 2015 that caused at least two generations of grasshoppers to hatch. This surge of new grasshoppers was obvious at Rattlesnake Tank. Branson (2011) has already conducted a study investigating competition between nymph-overwintering adult grasshoppers and later-developing nymphal grasshoppers, but only found weak interactions even at high densities. The study took place in Montana grasslands, with a relatively homogeneous topography, which overwhelmingly different compared to heterogeneous landscapes of the Chihuahuan Desert scrub in which IMRS is located. If weak competition was to be found it would be interesting to investigate what the true limiting resource of grasshoppers at IMRS would be.

Throughout this study, several grasshoppers were observed to have red mites on hindwings and occasionally on hind legs. Mite load varied from 2^{nd}-5^{th} instar and adults. From personal observation, it was also noted that mites were more prevalent in Tanks that were holding water at the moment of capture. A previous study on IMRS compared the ectoparasite load on a parthenogenic whiptail lizard and a gonochoristic whiptail lizard and found evidence to both support and reject the red queen hypothesis (Lukefahr, 2013). Proposed by Van Valen (1973), the Red Queen Hypothesis refers to organisms co-evoloving with other organisms to survive. The mites on the lizards take blood meals and eat dead skin but what are the mites gaining from the grasshoppers? It would be beneficial to test if these mites are the same species or not and investigate if they are using grasshoppers as an intermediate invertebrate host for nutrition or simply as a dispersal mechanism.

Grasshopper biodiversity is a product of the long-term evolution of grassland ecosystems (Zhong-Wei *et al*., 2006). This study adds to the overall general knowledge of grasshoppers and the biodiversity of this group of insects in an arid ecosystem. A pressing issue many scientists across many disciplines are concerned with today is global climate change. Grasshoppers respond to global climate change which not only include weather changes but land use changes and other human caused disturbances. These responses of grasshopper biodiversity to global climate change are representations of the response of grassland ecosystems to such change (Zhong-Wei *et al*., 2006). By investigating the variation and spatial pattern of grasshopper biodiversity on IMRS, future studies will be able to compare this response to grassland and shrubland ecosystems in an ever increasing arid environment.

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Vita

Sara Ebrahim Baqla graduated 8th in her class from Ysleta High School in El Paso, Texas in 2009. She was accepted into The University of Texas at El Paso (UTEP) and started her bachelor's in the Fall of 2009. She first pursued a degree in Commercial Music but like most college students she began to explore other interests and changed her major three times before realizing her true calling: Ecology. As an undergraduate, she had the opportunity to take part in the Students Mentoring to Achieve Retention Triads in Science (SMARTS) program. This program allowed her to learn about the natural world in the Chihuahuan Desert environment which led to her fascination of arthropods, specifically insects. She completed her bachelor's degree in Ecology and Evolutionary Biology in the Spring of 2014, and she immediately continued to pursue her Master's Degree from UTEP the following fall semester.

Sara has presented at four conferences hosted by the Southwestern Association of Naturalists (SWAN) and one hosted by the Campus Office of Undergraduate Research Initiatives (COURI) Symposium.

Sara will continue her outdoor adventures in California where she will be working in the Trinity Alps Wilderness. Her duties will include trail maintenance and the implementation of conservation methods to protect the natural flora and fauna of the area. She hopes that education will be the answer to the world's biodiversity crisis.

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