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HABITAT USE AND HOME RANGE OF *PHRYNOSOMA BLAINVILLII* IN THE SAN JOAQUIN DESERT OF CALIFORNIA

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Abstract.**—The Blainville's Horned Lizard (*Phrynosoma blainvillii*) is a California Species of Special Concern for which little ecological data exists that could be used to manage the species. In 2009, we recorded habitat characteristics at Atwell Island, and in 2010, we followed 20 radio-tagged lizards at this location and Semitropic Ridge, both in the San Joaquin Desert of California, USA. The presence of alkali flats and sandy soil correlated with a high abundance of horned lizards, and at Atwell Island, lizards had a distinct preference for Sandridge loamy fine sand. When above ground and active, we found *P. blainvillii* at either site on areas of bare ground most often. At the Semitropic site, we found lizards under shrubs and bare ground most often, whereas at the Atwell site, we found lizards often in sparse vegetation and more often on bare ground. Lizards at both sites used medium-dense and dense areas of vegetation much less than expected based on equal use. We had enough data to calculate home range size for 10 lizards, five at each site. Home range sizes determined by the 100% Minimum Convex Polygon estimator ranged from 0.58 ha to 13.93 ha. The average home range size for lizards at the Semitropic Ridge Preserve site was 7.28 (± 2.74 SE) ha and at the Atwell Island site was 2.68 (± 0.69 SE) ha, which were not significantly different than estimates made using the Fixed-K Local convex hull (LoCoH) estimator.**

Key Words.—conservation; fixed-k LoCoH; management; minimum convex polygon; telemetry

INTRODUCTION

Blainville's Horned Lizard (*Phrynosoma blainvillii*; Fig. 1), formerly Coast Horned Lizard (*P. coronatum* or *P.c. frontale*), is endemic to California and the northwestern tip of Baja California, Mexico (Stebbins 2003; Leaché et. al 2009). Populations of *P. blainvillii* have undergone declines in many areas of their range and are listed as a California Species of Special Concern (California Department of Fish and Game. 2011. Available from http://www.dfg.gov./biogeodata/cnddb/pdfs/SPAnimals.pdf_[Accessed 2 July 2015]). The decline in *P. blainvillii* populations has been attributed to habitat degradation and loss, pesticide use, and collection for the pet trade (Goldberg 1983; Jennings 1987; Jennings and Hayes 1994; Fisher et al. 2002; Stebbins 2003). In some areas, exotic ant species eliminate the native harvester ant species (*Pogonomyrmex* and *Messor* spp.), the preferred prey of horned lizards (Fisher et al. 2002; Suarez and Case 2002; Sherbrooke 2003; Stebbins 2003).

Phrynosoma blainvillii is one of the least-studied species of the horned lizard genus (Smith 1946; Milne and Milne 1950; Jennings and Hayes 1994), and most of those studies occurred in the southern part of their range in southern California (Goldberg 1983; Hager and Brattstrom 1997; Suarez et al. 1998; Fisher et al. 2002; Montanucci 2004). There has been only one behavioral (Tollestrup 1981) and one ecological (Gerson 2011) study in the San Joaquin Valley. For a species that is experiencing population declines and is under-studied, understanding why they are found in particular locales and quantifying how much land they need to survive in these locales are critical aspects in developing management and conservation plans.

To gain a better understanding of why *P. blainvillii* is found in particular locales in the San Joaquin Desert (Germano et al. 2011), we studied microhabitat

FIGURE 1. Adult Blainville's Horned Lizard (*Phrynosoma blainvillii*) from the San Joaquin Desert of California, USA. (Photographed by Susan Hult).

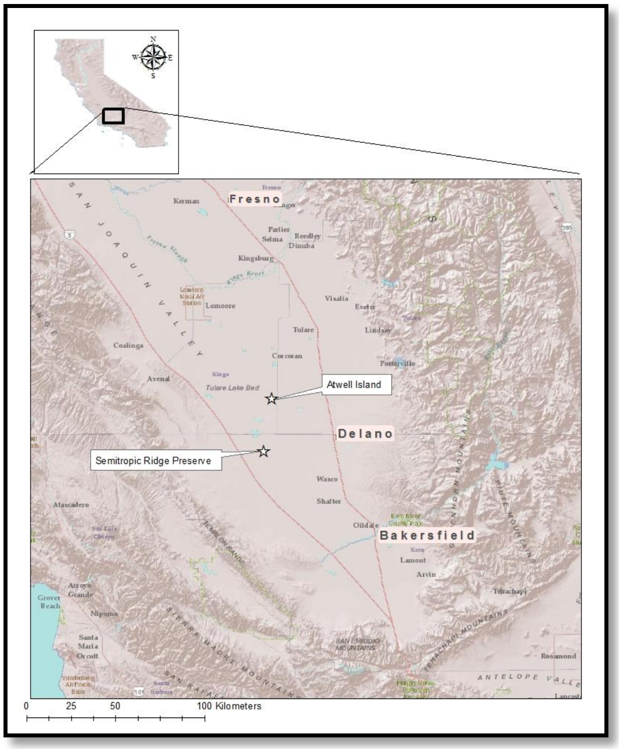

FIGURE 2. Map of the Atwell Island and Semitropic study sites of Blainville's Horned Lizards (*Phrynosoma blainvillii*) in the San Joaquin Desert of California, USA. (Map created by Susan Hult).

characteristics of lizards we found during walking surveys and from locations of radio-tagged lizards. To help determine how much land may be optimal for horned lizard survival, we estimated home range size for 10 telemetered lizards. The factors that shape home range ecology and habitat use of *P. blainvillii* in the San Joaquin Desert can serve as baseline information that can be incorporated into the decision-making processes for the conservation of habitat, and ultimately, conservation of this state-protected species. In a companion paper (Hult and Germano 2015), we present data on the population structure, activity, and thermal preferences of *P. blainvillii* in the San Joaquin Desert.

MATERIALS AND METHODS

Study sites.—We studied horned lizards at two sites in the San Joaquin Desert (Germano et al. 2011): Atwell Island on Bureau of Land Management (BLM) land near Alpaugh, in southeastern Kings County, and at the Semitropic Ridge Preserve managed by the Center for Natural Lands Management, located 24 km northwest of Wasco, Kern County, California, USA (Fig. 2). At the Atwell Island site, we sampled two areas, both of which straddled the old shoreline and the sand ridge of the former Tulare Lake; thus both areas contain soils typical of lacustrine deposits as well as loose sandy soils. At Location 1 (pasture), we surveyed for lizards in a fenced 156 ha parcel that had been seasonally grazed by cattle for many years. Within the pasture, there were five soil series and their associated habitat series (Appendix). Westcamp loam, Westcamp silt loam, and Excelsior fine sandy loam comprised approximately 47% of the total area (Soil Survey Staff, Natural Resources Conservation Service, U.S. Department of Agriculture. 2009. Web Soil Survey. Available from http://websoilsurvey.nrcs.usda.gov. [Accessed 10 September 2009]; Fig. 3). These soils support the Seepweed Series habitat (Sawyer and Keeler-Wolf 1995; U.S. Department of Interior, unpubl. report).

The dominant shrubs in this area were Bush Seepweed (*Suaeda moquinii*) and Alkali Heath (*Frankenia salina*), whereas Saltgrass (*Distichlis spicata*) and non-native annual grasses (*Bromus* spp.) were the dominant grassland species present. Spikeweed (*Centromadia pungens*) and Goldfields (*Lasthenia californica* and *L. minor*) were other dominant plant species (Appendix). The Sandridge loamy fine sand and Posochanet silt loam, which comprised approximately 53% of the total area (Fig. 3), supports the California Annual Grassland habitat series (Sawyer and Keeler-Wolf 1995). A mixture of non-native and native annual grasses typically dominates this habitat series (Sawyer and Keeler-Wolf 1995). However, cattle grazing occurred throughout the pasture and the dominant vegetative structure were the shrubs Goldenbush (*Isocoma acradenia*) with a few Valley Saltbush (*Atriplex polycarpa*), and the forbs Fiddleneck (*Amsinkia menziesii*), Broadleaf Filaree (*Erodium botrys*), and Spikeweed (*Centromadia pungens*). Non-native annual grasses (e.g., *Bromus* spp.) were present, but were generally grazed or trampled down (Appendix).

Throughout the first location, the pasture, there were many large open spaces with little or no vegetative structure due to cattle grazing. The natural senescence of herbaceous vegetation occurred at the pasture as the season became hotter and drier, and there were an abundance of soil mounds created mostly by Heermann's Kangaroo Rats (*Dipodomys heermanni*). Sympatric lizards in the pasture included California Whiptail (*Aspidoscelis tigris munda*) and Western Side-blotched Lizard (*Uta stansburiana elegans*). The overall topography was mostly level at an elevation range of 61–66 m above sea level. The land surrounding the pasture was formerly cultivated fields that were fallow or had undergone habitat restoration treatments in the years preceding our study. Unlike the immediately surrounding areas, the pasture had not undergone cultivation or significant substrate disturbance such as canal or road development, deep disk plowing, or laser leveling. Based on visual estimates and aerial imagery, we characterized the overall microhabitat of the pasture

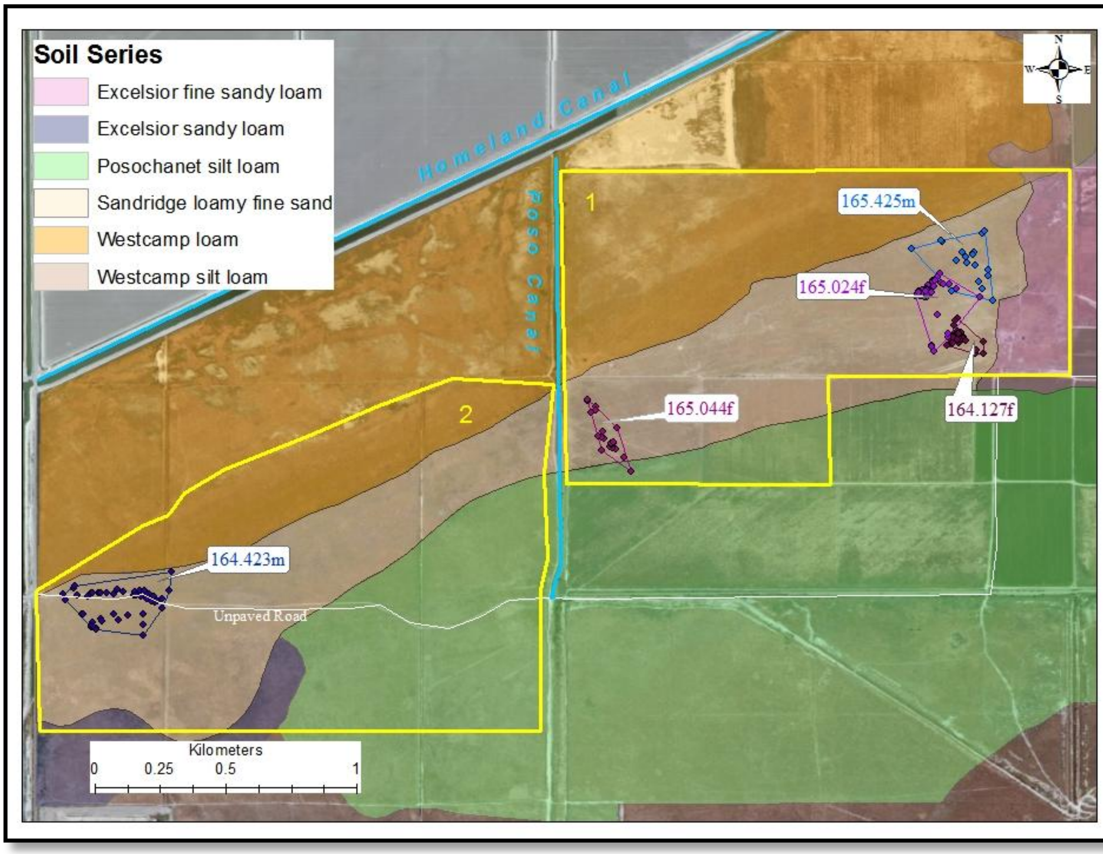

FIGURE 3. Home range as determined by the 100% Minimum Convex Polygon (MCP) method of five Blainville's Horned Lizards (*Phrynosoma blainvillii*) at two locations on the Atwell Island site, Kings County, California, USA, in 2010. Each lizard's home range is labeled with their identification number followed by f for female and m for male. The yellow outlines delineate the boundary of the two study locations at the Atwell site. The colored polygons represent the different soil series and show the affinity of lizards for the Sandridge series (middle swath of soil). Soil series map from the Natural Resources Conservation Service Soil Survey Staff, U.S. Department of Agriculture.

as 30% dense vegetation, 25% bare ground, 20% shrubs, 15% sparse vegetation, and 10% medium dense vegetation.

The second location (Location 2) at the Atwell Island site was a 120 ha area adjacent to and southwest of the pasture, but separated by an unlined irrigation (Poso) canal (Fig 3). This area was not fenced in and we delineated the boundary based on soil type, vegetative communities, roads, and reports of historical sightings of horned lizard from locals. This location had been cultivated with grain crops until the late 1980s and had been fallow since that time. Despite the agricultural activity, Location 2 also had never undergone laser leveling or deep disk plowing (U.S. Department of Interior, unpubl. report). There was never a grazing regime at this location with the exception of an occasional sheep trespass. The soil types and associated vegetative communities were similar to the pasture (Appendix; Fig. 3). However, because of the decades of inactivity, all of the soil series and associated vegetative communities in Location 2 were dominated by dense areas of non-native annual grasses (*Bromus* spp.) with fewer scattered patches of shrubs and forbs. An unpaved and rarely used road bisected Location 2 and this was the main source of open space and bare ground. Aside from the road, a few rodent burrows scattered throughout the location provided areas of bare ground and sparse herbaceous vegetation. There were narrow trails formed by Desert Cottontails (*Sylvilagus audubonii*), Black-tailed Jackrabbits (*Lepus californicus*), and Heermann's Kangaroo Rats in the dense grass. The Western Side-blotched Lizard and the California Whiptail were the only other lizard species we observed at this location. Based on visual estimates and aerial imagery, the overall habitat in this location was 80% dense grassland, 10% bare ground, 5% shrubs, 5% medium dense herbaceous vegetation, and < 1% sparse herbaceous vegetation.

The study location at the Semitropic Ridge Preserve was approximately 400 ha. The Semitropic Ridge Preserve comprises one of largest natural remnants of native habitat in the San Joaquin Valley. The topography was nearly level with an elevation range of 72–73 m above sea level. Our study site was dominated by Valley Saltbush Scrub habitat, with Spiny Saltbush (*Atriplex*

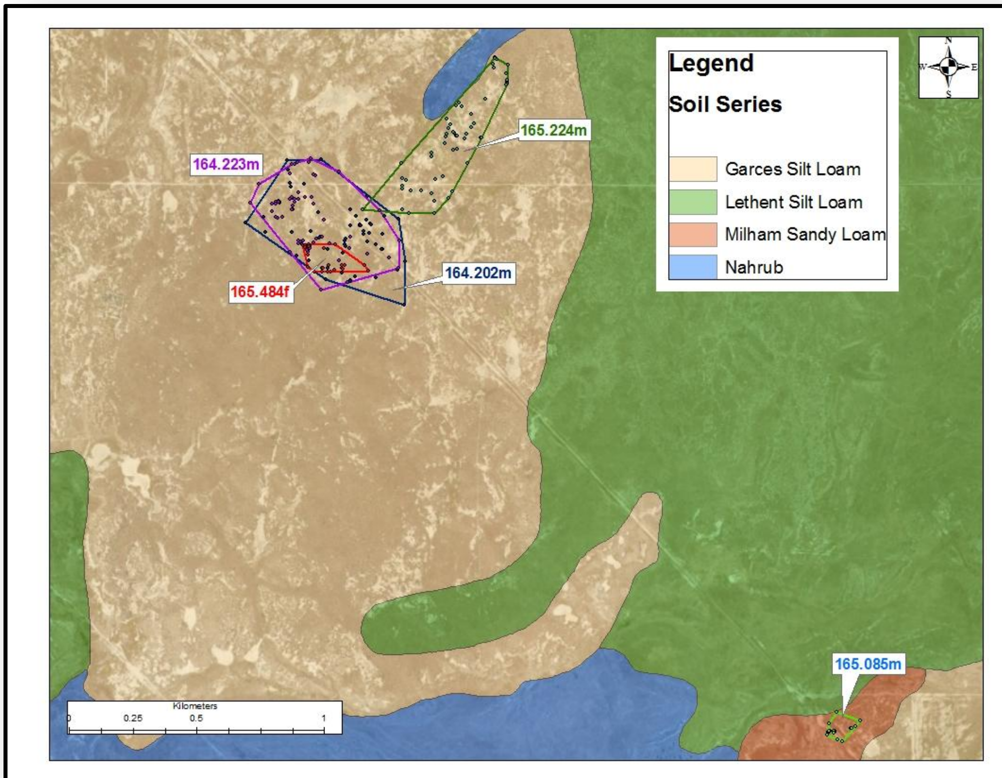

FIGURE 4. Home range of five Blainville's Horned Lizards (*Phrynosoma blainvillii*) at the Semitropic Ridge Preserve site in Kern County, California, USA, in 2010 as determined by the 100% Minimum Convex Polygon (MCP) method. Each lizard home range is labeled with their identification number followed by f for female and m for male. The colored polygons represent the different soil series and show the affinity of lizards for the Garces Silt Loam series. Soil series map from the Natural Resources Conservation Service Soil Survey Staff, United States Department of Agriculture.

spinifera) the dominant shrub, and Red Brome (*Bromus madritensis rubens*), Spikeweed (*Centromadia pungens*), Goldfields (*Lasthenia californica*), and Fiddleneck (*Amsinkia menziesii*) the dominant herbaceous plants (Appendix). There were large patches of open areas in the form of alkali playas and scalds characterized by bare ground with patches of white, crusty soil intermingled throughout the study area. Soils at this site were predominantly Garces silt loam (40% of the area), Lethent silt loam (40%), and Nahrub (20%; Soil Survey Staff, Natural Resources Conservation Service, U.S. Department of Agriculture. 2009. *op. cit*.; Fig. 4). We visually characterized the overall microhabitat as 50% sparse vegetation, 20% shrubs, 15% bare ground, 10% dense vegetation, and 5% medium dense vegetation.

Field data collection.—We conducted our research over the spring, summer, and fall for two years beginning 20 April 2009 and ending 15 November 2010. In the first season, we focused our search times from 0800–1500 to coincide with peak lizard activity (Heath 1965; Pianka and Parker 1975; Hager and Brattstrom 1997). In the second season, 2010, we increased our search times to include more afternoon and evening encounters to determine additional periods of lizard activity beyond peak periods. We located lizards using meandering transects and chance encounters 5–6 d a week. Meandering transects were accomplished by walking linear pathways within the entire boundary of both locations using various landmarks arbitrarily chosen as end points, such as a utility pole or fence posts. We made searches during all weather conditions except for rainfall, which made the dirt roads leading to our study site impassible. In our first season, 2009, we did not encounter enough lizards at the Semitropic Ridge location to collect habitat information.

We conducted the radio telemetry research from 16 March to 7 September 2010 concurrently at the Atwell Island site and the Semitropic site (See Home range analysis below), and had more success in 2010 locating lizards at the Semitropic site. We located lizards to be radio-tagged using meandering transects and chance encounters. Most searches occurred between 0800 and 1200 to coincide with peak activity, although some

TABLE 1. Identification, sex, date of capture, date of last relocation, number of days followed, total number of observations, and the reason (outcome) of the termination of study for each lizard for 14 radio tagged Blainville's Horned Lizard (*Phrynosoma blainvillii*) at the Atwell Island and Semitropic Ridge Preserve sites in 2010 in the San Joaquin Valley, California.

Lizard ID	Sex	Capture date	Date of first relocation	Date of last relocation	Days Followed	Total No. observations	Outcome
Atwell							
A165.044f	F	8-Apr-10	10-Apr-10	1-Jun-10	52	20	Transmitter found on ground
A164.144f	F	13-Apr-10	15-Apr-10	23-May-10	38	11	Transmitter found on ground
A164.127f	F	17-Apr-10	23-Apr-10	17-Jun-10	55	30	Lost signal
A164.486f	F	2-May-10	5-May-10	10-May-10	5	3	Deceased
A164.423m	M	27-May-10	29-May-10	18-Aug-10	81	62	Shed transmitter
A165.024f	F	7-Jun-10	8-Jun-10	7-Sep-10	91	64	Shed transmitter
A164.425m	M	10-Jun-10	11-Jun-10	2-Jul-10	22	19	Lost signal
Semitropic							
S165.224m	M	7-Apr-10	10-Apr-10	12-Aug-10	124	60	Lost signal
S164.223m	M	9-Apr-10	13-Apr-10	22-Jul-10	100	62	Shed transmitter
S164.202m	M	16-Apr-10	30-Apr-10	9-Aug-10	102	69	Lost signal
S164.243f	F	23-Apr-10	30-Apr-10	9-May-10	9	5	Transmitter found on ground
S165.484f	F	23-Apr-10	30-Apr-10	16-Jun-10	47	22	Deceased
S165.085m	M	4-May-10	9-May-10	13-Jul-10	58	45	Shed transmitter
S164.063f	F	20-May-10	25-May-10	17-Jun-10	23	6	Deceased

searches occurred in the afternoon. When captured, we recorded date, time of day, and capture location using Global Positioning System (GPS, datum = WGS 1984) obtained using a Magellan MobileMapper CX GPS Unit (Magellan, Santa Clara, California, USA). We also recorded standard morphometric data: snout-vent length (SVL) to the nearest 1 mm and mass to 1 g using a spring scale. We determined the sex of each lizard based on the presence of enlarged post-anal scales in males (Tinkham 1951; Powell and Russell 1985; Sherbrooke 2003).

We fitted lizards ≥ 25 g with radio-transmitters (SOPR-2070; 2.2–2.7 g; battery life 19 weeks; Wildlife Materials, Inc., Murphysboro, Illinois, USA) using a mesh harness glued to the lizard to help secure the transmitter to the lizard (Warner et al. 2006). During the course of the study, however, we discovered that arms of the mesh harness would often come loose and detach from lizards despite several attempts of re-gluing them back on in the field. Therefore, in the later part of the study, we ceased using the mesh harness and simply attached the transmitter to lizards directly using only non-toxic silicone glue. We spread a few drops of glue to the top of the transmitter and sprinkled sand over it to avoid disrupting the camouflage design of *P. blainvillii*. When attaching the transmitter, we kept lizards in a small enclosure until the silicone glue was dry, and then released them at their exact capture location. We trimmed the antenna so it projected only 5 cm beyond the length of each lizard to reduce the chance that it might interfere with movement as lizards navigated in shrubs and rodent burrows. The mass of the transmitter package (2.5 g) ranged from 6–10% of the lizard's mass at the time of capture. Although the transmitter weights were greater than the 5% typically recommended, we did not see a difference in movement of lizards to those without transmitters, so we believed that the transmitter did not affect movement or survival.

We radio-tracked lizards using an R-1000 Telemetry Receiver (Communications Specialists, Inc., Orange, California, USA) and a three element folding Yagi-Uda antenna (Model # F165-3FB AF Antronics, Inc. Urbana, Illinois, USA). The reception range of this equipment, with the snipped transmitter antennae, ranged from approximately 320 m when lizards were underground to approximately 800 m when lizards were above ground. The topography at the Atwell and Semitropic sites is nearly flat and there are no obstacles such as large trees or hills, thus range detection was optimal. We tracked lizards 5–7 d a week, keeping a consistent sampling scheme of at least a 6-h time lapse between observations to reduce dependency among observations. For each observation, we recorded the date, time of day, climatic conditions, and ground temperature. We tracked all lizards until one of the following occurred: (1) the transmitter was found on the ground detached from the lizard in an undetermined manner; (2) lizards sloughed their skin along with the transmitter; (3) the transmitter signal was abruptly undetectable and an extensive search of an approximately 1.5 km radius around the study area for 3 d proved unsuccessful; or (4) lizards were found dead (Table 1).

Habitat assessment.—In 2009, at the time of a lizard encounter during walking surveys, we noted the soil type as simply loose or compact as well as its color. We more accurately defined the soil type by recording the GPS coordinates of every lizard location into the

ArcMap function of ArcGIS v. 9.3.1 software (Environmental Systems Research Institute, Inc., Redlands, California, USA). We used a US Department of Agriculture soil series map (Soil Survey Staff, Natural Resources Conservation Service, U.S. Department of Agriculture. 2010. *op. cit.*) as a base layer. Data were ground-truthed by other BLM employees during vegetation surveys in the pastures. This enabled us to record the soil series for each location. The soil series map had delineated boundaries that enabled us to calculate the area that each soil series covered within the boundaries of our two study locations. Unlike the soil series, we did not have a habitat series layer in ArcGIS that would have allowed us to calculate the area of each habitat series within the two locations. However, our field knowledge of the location sites as well as aerial photographs revealed that the habitat series associated with a particular soil series virtually matched the boundaries of the soil series. Because we found a high degree of correlation between soil series and habitat series, we focused the rest of our spatial analysis on soil series.

To determine if *P. blainvillii* at the two Atwell sites was found on a particular soil series differently than equal use, we used a Chi-square goodness of fit test. To see if *P. blainvillii* used a particular soil type and associated habitat series differently than random use, we compared the same field data to a set of 100 randomly located coordinates within the pasture. To generate 100 random coordinates, we used Hawth's Analysis Tools for ArcGIS v. 3.27. We then uploaded the coordinates into a Magellan GPS unit, which we used to navigate to each point. At each random point, we mimicked the data collection methodology that we employed when we encountered a lizard and recorded the same data. We analyzed our random and field data using a contingency table test. We ran a separate analysis on the 155 observations from our seven telemetered (2010) lizards using a contingency table and compared it to our 2009 data.

In 2010, at both the Atwell Island and Semitropic sites, we recorded the microhabitat characteristics within a 1-m circular area at each location of a radio-tagged lizard. We used the capture location as the center point of the circular area. We measured the distance to the nearest shrub and/or to the nearest patch of herbaceous vegetation, which was either a conglomerate of grass and forbs or one or the other. We also took a photograph of the location. The vegetative cover was visually estimated at the time of each lizard observation or by examining the photographs of the encounter area after the field study. We only scored lizards who were above ground and categorized the microhabitat features of the precise location where each lizard was encountered as (1) Bare Ground: including cow pies (dried domestic bovine manure), sandy patches with no herbaceous vegetation or sandy patches with very few stems and trampled grass; the vegetation in this category was considered not to impede lizard locomotion; (2) Shrub: lizards were seeking cover under a shrub; in some cases there was some herbaceous vegetation mixed in the shrubs; (3) Sparse: herbaceous vegetation provided 1–20% of cover; (4) Medium Dense: herbaceous vegetation provided 20–50% cover; or (5) Dense: herbaceous vegetation provided 50–100% cover. If lizards occupied a habitat feature more often than predicted by its availability, we considered the feature Selected; if lizards occupied a habitat feature less often than predicted by its availability, we considered the feature Avoided.

We compared microhabitat use within a site using sequential Chi-square. We also compared the use of microhabitats by males and females, irrespective of site, using a Contingency Table, followed by sequential Chi-square. Because detectability of lizards might be an issue in determining habitat use using visual surveys, we compared the data from the 2009 non-telemetered lizards at Atwell to the data from our 2010 telemetered lizards at Atwell using the same statistical tests. We did not include the data gathered in 2009 from the non-telemetered lizards at Atwell in analysis when we performed habitat use comparison analyses between Atwell and Semitropic. We used Minitab 16 statistical software (Minitab Inc., State College, Pennsylvania, USA) to run Contingency Tables, one-way ANOVAs and two-sample t-tests. For all tests, $\alpha = 0.05$

Home range analysis.—In the 2010 season, we fitted 14 *P. blainvillii* with transmitters; five females and two males at the Atwell site and four males and three females at the Semitropic site (Table 1). We entered the geographic coordinates for all lizards into the ArcMap function of ArcGIS v. 9.2 software (Esri, Redlands, California, USA). The number of observations recorded for the seven lizards at the Atwell site ranged from three to 64 and for the Semitropic site from five to 69 (Table 1). Of the 14 lizards fitted with transmitters, 10 (five at each site) had ≥ 19 observations, for which we calculated home ranges.

We calculated home ranges using two estimators: the minimum convex polygon (MCP) method (Mohr and Stumpf 1966) using the Hawth's Analysis Tools for ArcGIS v. 3.27 (Beyer, H.L. 2004. Hawth's Analysis Tools for ArcGIS. Available from http://www. http://www.spatialecology.com/htools/. [Accessed 19 September 2010]) and the local nearest-neighbor convex-hull (LoCoH; also known as k-NNCH; Getz and Wilmers 2004; Getz et al. 2007) using the Fixed-K LoCoH algorithm on the LoCoH web application (available from http://locoh.cnr.berkeley.edu/. [Accessed 10 July 2010]). LoCoH requires the user to choose a value for *k*, which is the number of nearest neighbors

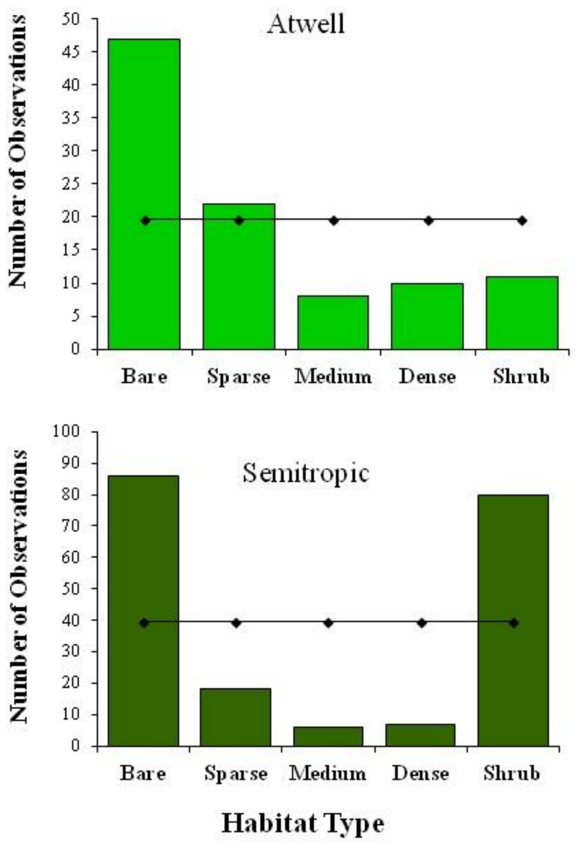

FIGURE 5. Number of sightings of radio-tracked Blainville's Horned Lizards (*Phrynosoma blainvillii*) when above ground in five habitats at the Atwell and Semitropic sites in the San Joaquin Desert of California,USA, in 2010. The habitat types are bare ground, sparse vegetation, medium-dense vegetation, dense vegetation, and shrub.

LoCoH will use to construct a convex hull. We followed the procedure described at the web site to determine the best k value for each lizard (Table 2). Our data had locational points very near or on top of each other that the LoCoH program may perceive as a duplicate point, so to ensure that all data points were considered in the analysis, we chose to displace duplicate points by one unit in a random direction.

The MCP method is sensitive to outlying points, and including them in the area when the outliers should not be included can result in overestimates of true home ranges. These outliers can be the result of the exploratory movement of an animal rather than a movement necessary for survival and reproduction, or, prior to the use of GPS technology to obtain points, triangulation errors. Outliers are generally removed without biological basis, thus contributing researcher bias into the results and as a result might not provide a repeatable home-range estimate among different researchers (Samuel and Fuller 1996). To reduce bias in excluding outliers, many researchers choose to use the polygon that surrounds 95% of the total area and report it as the 95% MCP. When we examined our data, only three of the 10 lizards had any points that could be considered outliers, and in each case, it was only one point. Therefore, we chose to eliminate the one point for each lizard and report the subsequent 100% MCP for all home range estimates.

To determine if home range sizes differed between the Atwell and Semitropic sites, we used a two-sample *t*-test with unequal variances on log-transformed data. We used a one-way ANOVA test to determine if the method used to estimate home range sizes (Fixed-K LoCoH and MCP) calculated significantly different home range sizes. We did not test for sex differences by site in home range size because we did not have enough locations for all females to determine an accurate home range. To determine if the use of microhabitats by *P. blainvillii* was the same between Atwell and Semitropic sites, we used a Contingency Table analysis. For all tests, $\alpha = 0.05$

RESULTS

Habitat use.—At the Atwell Island site, we found *P. blainvillii* significantly more often than expected on the Sandridge loamy fine sand soil series and its accompanying vegetative community than any other soil series based on equal use ($\chi^2 = 471.34$, df = 3, $P = 0.001$). The same held true when we compared lizard data to random point data ($\chi^2 = 121.7$, df = 3, $P = 0.001$). Although the Sandridge series comprised approximately 50% of the total soil series in each of the two locations, 98.2% of our lizard observations occurred there. Lizards that had transmitters on in 2010 corroborated our findings from the data we collected in 2009 from non-telemetered lizards in that they preferred the Sandridge soil series and associated habitat and avoided the Westcamp, Posochanet, and Excelsior soil series and their associated habitats ($\chi^2 = 603.92$, df = 3, $P = 0.001$; Fig. 3).

Phrynosoma blainvillii that were radio-tagged differed significantly in their use of microhabitats between the Atwell and Semitropic sites ($\chi^2 = 35.78$, df = 4, $P < 0.001$). At the Atwell site, lizards did not use microhabitats equally ($\chi^2 = 53.94$, df = 4, $P < 0.001$); we found them significantly more often in areas of bare ground and sparse vegetation than in areas with medium or dense herbaceous vegetation or under shrubs ($\chi^2 = 53.70$, df = 2, $P < 0.001$; Fig. 5). We found horned lizards equally as often in areas of medium or dense herbaceous vegetation or under shrubs ($\chi^2 = 0.491$, df = 2, $P = 0.782$), and observations differed significantly between areas of bare ground and sparse vegetation ($\chi^2 = 8.35$, df = 1, $P = 0.004$). These data mirrored the findings from the 2009 non-telemetered lizard data from

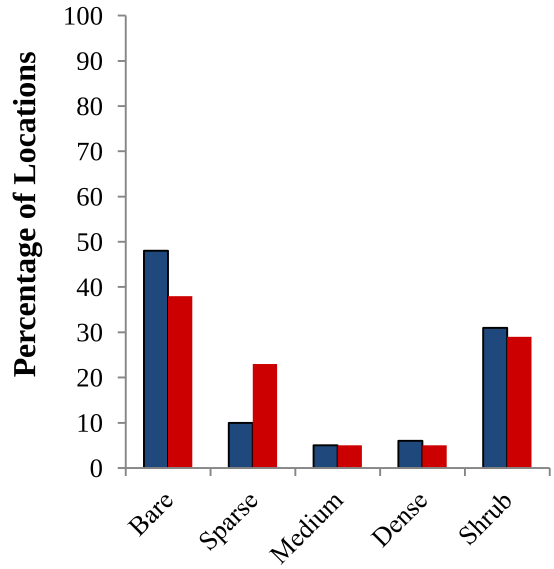

FIGURE 6. Frequency of sightings of male (blue) and female (red) radio-tracked Blainville's Horned Lizards (*Phrynosoma blainvillii*) when above ground in five habitats at Atwell and Semitropic study sites in 2010 in the San Joaquin Desert of California, USA.

TABLE 2. Sex, number of observations used in analysis (n), and home range estimates (including the k-value for the LoCoH analysis) of 10 Blainville's Horned Lizard (*Phrynosoma blainvillii*) based on Fixed-K Local Convex Hull (LoCoH) at the 100% isopleth level and the 100% minimum convex polygon (MCP) at the Atwell Island and Semitropic Ridge Preserve sites in 2010 in the San Joaquin Desert of California.

			Fixed-K LoCoH		MCP
Lizard ID	Sex	n	k-value	Size (ha)	Size (ha)
Atwell					
164.127f	F	30	10	0.59	0.87
165.044f	F	20	13	1.21	1.24
165.024f	F	64	15	2.96	3.09
165.425m	M	19	10	3.91	3.95
164.423m	M	62	15	3.99	4.24
Total Mean		-	-	2.53	2.68
SE				0.69	0.69
Semitropic					
165.085m	M	45	10	0.55	0.58
165.484f	F	22	8	1.27	1.30
165.224m	M	60	12	7.46	8.39
164.223m	M	62	17	11.84	12.18
164.202m	M	69	14	13.41	13.93
Total Mean		-	-	6.91	7.28
SE				2.64	2.74

the Atwell sites. The data from 2009 showed lizards did not use microhabitats equally (χ^2 = 212.50, df = 4, P < 0.001). We found them significantly more often in areas of bare ground and sparse vegetation than in areas with medium or dense herbaceous vegetation or under shrubs (χ^2 = 63.09, df = 2, P < 0.001), and they were found equally as often in areas of medium or dense herbaceous vegetation or under shrubs (χ^2 = 2.86, df = 2, P = 0.240). Lizards we encountered in 2009 during meandering surveys also differed significantly between areas of bare ground and sparse vegetation (χ^2 = 17.07, df = 1, P < 0.001).

Lizards at the Semitropic site that were radio-tagged also did not use microhabitats equally (χ^2 = 163.53, df = 4, P < 0.001). We found them significantly more often in areas of bare ground and under shrubs than in areas with either sparse, medium, or dense herbaceous vegetation (χ^2 = 512.04, df = 2, P < 0.001; Fig. 5). We found lizards equally as often in areas of bare ground and under shrubs (χ^2 = 0.151, df = 2, P = 0.658), and equally as often in medium and dense herbaceous vegetation (χ^2 < 0.001, df = 2, P = 1.00). Irrespective of site, males and females used microhabitats similarly (χ^2 = 8.20, df = 2, P = 0.084; Fig. 6). Regardless of sex or site, *P. blainvillii* differed in their overall use of microhabitats (χ^2 = 180.51, df = 4, P < 0.001), with medium and dense cover used equally as often (χ^2 = 0.129, df = 2, P = 0.719), but with bare ground, under shrubs, and sparse vegetation differing significantly in their use (χ^2 = 7.50-49.82, df = 2, P = 0.006 to < 0.001). Overall, we found horned lizards most often in microhabitats that consisted of bare ground, then under shrubs, then in sparse vegetation, and least often in medium and dense herbaceous vegetation.

Home range.—Five of the six male *P. blainvillii* had larger 100% MCP home ranges than females at both sites, but the difference was not significant (U = 4, P > 0.05). Home range size based on LoCoH was slightly smaller than 100% MCP for all lizards, and the difference was significant ($F_{1,18}$ = 0.010, P = 0.905). The mean (± SE) home range size based on the 100% MCP method of the five lizards at the Atwell site was 2.68 (± 0.69) ha and of the five lizards at the Semitropic site was 7.28 (± 2.74) ha (Table 2). The mean home range using the LoCoH method was 2.53 (± 0.69) ha at the Atwell site and 6.91 (± 2.64) ha at the Semitropic site (Table 2). Although the mean home range size at the Semitropic site was almost three times larger than the mean size at the Atwell site, the differences were not significant either for MCP estimates (t = -1.63, P = 0.179) or LoCoH (t = -1.60, P = 0.184). Regardless of the site, the average home range size of all lizards (n = 10) based on the 100% MCP method was 4.98 ha (± 1.54) and was 4.71 ha (± 1.48) for LoCoH.

DISCUSSION

Habitat use.—When above ground and active, *P. blainvillii* at our sites selected proportionately more areas of bare ground and sparse herbaceous vegetation and avoided areas of dense vegetation, particularly of non-native grasses. These findings are consistent with what has been reported for *P. blainvillii* in southern California (Hager and Brattstrom 1997) and in the northern San Joaquin Valley (Gerson 2011), as well as in other species of horned lizards (Whiting et al. 1993; Fair and Henke 1997; Montgomery and Mackessy 2003). Considering the dorso-ventrally flattened body shape and short legs of horned lizards, dense vegetation likely impedes movement. In a study on a closely related species, the Desert Horned Lizard (*P. platyrhinos*), Newbold (2005) found a significant negative association between Cheatgrass cover and lizard mobility as well as lizard abundance. Harvester ants (*Pogonomyrmex* and *Messor* spp.), the main prey of horned lizards, are granivores and forage on grass seeds in areas of sparse vegetation (Whiting et al. 1993), where the sit-and-wait foraging strategy of horned lizards would be more compatible with open spaces than with dense vegetation.

Most of the early observations of habitat use by *P. blainvillii* had been obtained by chance encounters or systematic searches (Smith 1946; Tollestrup 1981; Hager and Brattstrom 1997; Gerson 2011). Because of their cryptic nature and tendency to remain motionless when approached, this can bias results because *P. blainvillii* are generally seen only when they are out in the open and have decided to flee, thus catching the eye of the observer. Concerns have been raised about the accuracy of reporting open areas and sparse herbaceous vegetation as being the preferred microhabitat of horned lizards due to observer bias and increased detectability in this type of habitat (Fair and Henke 1999; Burrow et al. 2001). However, our study reduced this bias by using radio-tagged animals that allows locating lizards regardless of detectability, thus providing a more accurate picture as to how they use habitat.

At the Atwell sites, we found lizards almost exclusively in Sandridge loamy fine sand. Of all the soil types at the Atwell study sites, Sandridge soil is somewhat excessively well drained whereas Westcamp loam, Posochanet silt loam, and Excelsior fine sandy loam are moderately well to somewhat poorly drained (Soil Survey Staff, Natural Resources Conservation Service, US Department of Agriculture. 2010. *op. cit*.). The higher permeability and drainage of Sandridge soils allows rainwater to percolate down through the soil, which would allow sufficient moisture for egg development as well as prevent excessive moisture build-up. These same soil and habitat characteristics are most likely beneficial to harvester ants, an important food for horned lizards (Heath 1965; Pianka and Parker 1975; Montanucci 1989; Suarez and Case 2002; Barrows and Allen 2009). Harvester ants need soils that are easy to excavate and are able to maintain the structural integrity, proper temperature, and humidity of their nests (Johnson 2000), as well as soils that support vegetation that is important as food sources and refugia (Whiting et al. 1993; Johnson 2000). Although we did not systematically record ant abundances, we observed high numbers of harvester ants on Sandridge soil but very few harvester ants in the other soils. Because Sandridge soil is moderately coarse, it likely also provides a substrate that is easy for horned lizards to burrow themselves into for thermoregulation, predator avoidance, and excavate nests for egg deposition.

Because we had data from only one season (2010) at the Semitropic Ridge location, we were unable to make solid inferences concerning soil preference. However, the data we do have suggests that *P. blainvillii* had an affinity for the Garces silt loam and avoided the Lethent silt loam and Nahrub soils. The Garces soil has a higher drainage class (well drained) than the Lethent and Nahrub soils (Soil Survey Staff, Natural Resources Conservation Service, U.S. Department of Agriculture. 2010. *op. cit*.). Milham Sandy Loam, where one lizard was found, had more than twice the percentage of sand content of the other soils, thus it has the most rapid permeability as well as being well-drained (Soil Survey Staff, Natural Resources Conservation Service, U.S. Department of Agriculture. 2010. *op. cit*.). We observed more shrubs and harvester ants in the area with Garces and Milham soil and fewer shrubs, more dense grass, and fewer ants with the Lethent and Nahrub soils. Without further study in this particular area, we can only infer that perhaps soil permeability, stability, and the associated habitat may be important factors as to the clear preference of *P. blainvillii* at the Atwell and Semitropic sites. Our inferences are supported by the finding of Gerson (2011) in the northern end of the San Joaquin Valley in which *P. blainvillii* seemed to favor soils with a sandy loam and loam content and avoiding areas with clay soil components, which have lower permeability and drainage classes than sandier soils.

***Home range of* P. blainvillii**.—The mean home range size (4.98 ha) of *P. blainvillii* in the San Joaquin Desert is substantially larger than the mean adult home range of 0.094 ha calculated by Hager (1992) for *P. blainvillii* in San Bernardino and Riverside counties in southern California. It should be noted that the home range estimates by Hager were derived from four non-telemetered adult lizards (three males, one female) using the focused animal technique. Home ranges were calculated using the minimum convex polygon method with rather low numbers (14–25) of locations. In a radio-telemetry study on *P. blainvillii* in southern California, lizards had a mean home range of about 10 ha (Fisher et al. 2002). This value is twice as large as our mean home range estimate; however, the estimator used and the number of lizards and sightings are not specified, so it is difficult to assess the robustness of the data. Therefore, with the data that is currently available, it is not possible to estimate the area of land that is optimal for *P. blainvillii* conservation across its range. The size of home ranges of *P. blainvillii* at our two sites in the San Joaquin Desert varied considerably (0.58–13.93 ha). Two correlates that can affect home range size are yearly and seasonal shifts (Rose 1982). For example, Hager (1992) reported a ten-fold home range size difference in one lizard between years, whereas Fair and Henke (1999) found that *P. cornutum* had a substantial decrease in home range size from the summer to the fall. In addition to yearly and seasonal shifts, other factors that affect home range size in lizards include climatic changes, habitat productivity, lizard density, predator abundance, lizard sex, and social factors such as behavioral changes during the breeding season (Rose 1982; Christian and Waldschmidt 1984). Our radio telemetry study occurred over one year from spring until fall and thus may not have detected yearly shifts in home range. Therefore, given these factors and our small sample size (five lizards at each site), it is difficult to define an optimal amount of land that would be suitable for *P. blainvillii* in the San Joaquin Valley, and our results should be considered tentative and only baseline information.

Of course, there are other correlates that make home range optimal for any animal other than just size. These factors include prey availability, mates, and microhabitat components critical for predator avoidance, thermoregulation, and shelter (Burt 1943; Rose 1982; Munger 1984; White and Garrot 1990). For example, we found that bare ground is a microhabitat feature that is favored by these lizards, and sparse vegetation and shrub cover are used more often than expected by chance. Therefore, land containing these microhabitat components have conservation value for lizard populations and should be maintained. We recommend further long-term telemetry studies on *P. blainvillii* in the San Joaquin Valley to enhance our data, especially over changing seasons and climate. This information becomes more important to land managers who are interested in the conservation of *P. blainvillii* as the pressures of human habitation, especially in the form of habitat loss, continues in the San Joaquin Valley.

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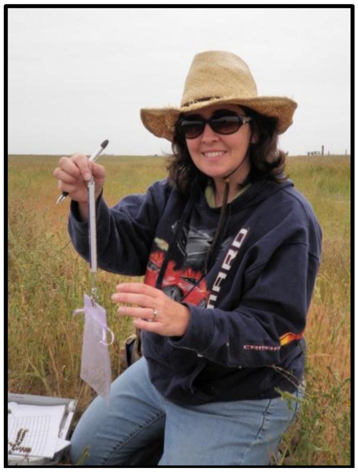

SUSAN HULT studied the ecology and demography of Blainville's Horned Lizard (*Phrynosoma blainvillii*) in the San Joaquin Valley of California for her M.S. degree in Biology, which she completed in June 2014 at California State University, Bakersfield. She received her B.S. in Fisheries, Wildlife, and Conservation Biology from the University of Minnesota, Twin Cities. She has worked for the Bureau of Land Management in California's San Joaquin Valley at the Atwell Island Restoration Project, and in northeast Montana working on habitat analysis of Greater Sage Grouse (*Centrocercus urophasianus*), Black-tailed Prairie Dogs (*Cynomys ludovicianus*), and Burrowing Owls (*Athene cunicularia hypogea*). In Minnesota, she has worked in Gopher Snake (*Pituophis catenifer*) conservation and tall-grass prairie and oak savanna conservation and restoration for the Minnesota Department of Natural Resources. She is shown obtaining the mass of a hatchling Blainville's Horned Lizard. (Photographed by Amy Kuritsubo).

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APPENDIX. Soil and habitat characteristics of three study locations of Blainville's Horned Lizard (*Phrynosoma blainvillii*) in the San Joaquin Valley in Kings and Tulare counties, California, USA. Acronyms are SRLFS = Sandridge loamy fine sand; WL = Westcamp loam; PSL = Posochanet silt loam; EFSL = Excelsior fine sandy loam. An entry for Westcamp Silt Loam (WSL) for Atwell Location 1 and Excelsior sandy loam (ESL) for Atwell Location 2 were not included because they accounted for < 1% of total area at each site.

	Soil Type			
	SRLFS	WL	PSL	EFSL
Atwell: Location 1				
Percentage of Area (approx.)	53%	34%	7%	7%
Drainage Class	Somewhat excessively drained; moderately rapid permeability	Somewhat poorly drained; very slow permeability	Moderately well drained; slow permeability	Well drained; moderately slow permeability
Percent Sand	80.3	32.9	7.3	65.7
Percent Silt	16.7	67.8	68.0	15.4
Percent Clay	3.0	23.0	24.8	11.5
Associated Habitat Series	California Annual Grassland	Seepweed	California Annual Grassland	Seepweed/California Annual Grassland
Habitat Characteristics	40% sparse vegetation,	30% dense vegetation,	50% medium-dense vegetation	Northern half resembles Seepweed habitat; southern half resembles California Annual Grassland.
	20% bare ground	25% bare ground	20% bare ground	35% sparse vegetation
	20% shrubs	20% shrubs	20% shrubs	35% shrubs
	10% dense vegetation	15% sparse vegetation	10% dense vegetation	20% bare ground
	10% medium-dense vegetation	10% medium-dense vegetation		10% medium-dense vegetation
Associated Herbaceous Species	Shrubs: *Isocoma acradenia*;	Shrubs: *Suaeda moquinii*, *Frankenia salina*;	Shrubs: *Isocoma acradenia*;	Shrubs: *Suaeda moquinii*, *Frankenia salina*;
	Forbs: *Amsinkia menziesii*, *Centromadia pungens*;	Forbs: *Centromadia pungens*, *Lasthenia californica* and *L. minor*;	Forbs: *Amsinkia menziesii*, *Hemizonia pungens*;	Forbs: *Amsinkia menziesii*, *Centromadia pungens*, *Lasthenia californica* and *L. minor*;
Atwell: Location 2				
Percentage of Area (approx.)	45%	24%	30%	--
Drainage Class	Somewhat excessively drained; moderately rapid permeability	Somewhat poorly drained; very slow permeability	Moderately well drained; slow permeability	--
Percent Sand	80.3	32.9	7.3	--
Percent Silt	16.7	67.8	68.0	
Percent Clay	3.0	23.0	24.8	
Associated Habitat Series	California Annual Grassland	Seepweed	California Annual Grassland	--
Habitat Characteristics	Vertical structure of dense non-native annual grass and scattered shrubs;	Vertical structure of dense non-native annual grass and scattered shrubs;	Vertical structure of dense non-native annual grass and scattered shrubs;	--

	60% dense vegetation	60% dense vegetation	80% dense vegetation	
	20% medium-dense vegetation	10% bare ground	20% bare ground	
	20% bare ground	30% shrubs	10% shrubs	
	5% shrubs			
Associated Herbaceous Species	Shrubs: *Isocoma acradenia*;	Shrubs: *Suaeda moquinii*, *Frankenia salina*;	Shrubs: *Isocoma acradenia*;	--
	Forbs: *Amsinkia menziesii*, *Centromadia pungens*	Forbs: *Centromadia pungens*	Forbs: *Amsinkia menziesii*, *Centromadia pungens*	
	Grasses: Non-native annual	Grasses: Non-native annual	Grasses: Non-native annual	

Semitropic Ridge

	Garces Silt Loam	Lethent Silt Loam	Milham	Nahrub
Percentage of Area (approx.)	40%	40%	15%	5%
Drainage Class	Well drained; very low permeability	Moderately well drained; very low to mod. permeability	Well drained; moderately high permeability	Well drained; very low to mod. low permeability
Percent Sand	39.2	24.6	61.8	26.1
Percent Silt	33.5	36.1	22.2	28.9
Percent Clay	27.4	39.3	16.0	45.0
Associated Habitat Series	Valley Saltbush scrub	Grasslands	Valley Saltbush Scrub	Grasslands
Habitat Characteristics	40% sparse vegetation	30% dense vegetation	50% medium-dense vegetation	60% medium-dense vegetation
	30% bare ground	30% medium-dense vegetation	20% dense vegetation	20% dense vegetation
	20% shrubs	10% shrubs	20% shrubs	5% shrubs
	5% dense vegetation	15% sparse vegetation	5% sparse vegetation	10% sparse vegetation
	5% medium-dense vegetation	15% bare ground	5% bare ground	5% bare ground
	Shrubs: *Atriplex spinifera*	Shrubs: *Atriplex spinifera*	Shrubs: *Atriplex spinifera*	Shrubs: *Atriplex spinifera*
	Forbs: *Amsinkia menziesii*, *Centromadia pungens*; *Lasthenia californica* and *L. minor*;	Forbs: *Amsinkia menziesii*, *Centromadia pungens*;	Forbs: *Amsinkia menziesii*, *Centromadia pungens*;	*Amsinkia menziesii*, *Centromadia pungens*;
Associated Herbaceous Species	Grasses: *Bromus rubens, Sporobolus airoides*	Grasses: *Bromus rubens, Sporobolus airoides*	Grasses: *Bromus rubens, Sporobolus airoides*	Grasses: *Bromus rubens, Sporobolus airoides*