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# 2007-2008 COACHELLA VALLEY MSHCP MONITORING FRAMEWORK PRIORITIES

## FINAL REPORT

by

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## Temporal Dynamics within the Coachella Valley's Aeolian Sand Communities

Our overall objective was to describe and model those variables that drive the population dynamics of species of conservation interest occupying the aeolian sand habitats of the Coachella Valley. Understanding these relationships is critical to enable biologists and land managers to discern between the typical fluctuations exhibited by natural populations, and population declines signaling a population at risk of extinction (Barrows et al. 2005). Driver-stressor relationships between populations and environmental conditions provide direction as to whether or not a change in management protocol is warranted in order to decrease risks of extinction, as well as where and how to focus that management (Barrows and Allen 2007a).

In arid environments increasing rainfall is typically correlated with increased productivity and abundance (Mayhew 1965, 1966; Pianka 1970; Ballinger 1977; Whitford and Creusere 1977; Dunham 1981; Abts 1987; Robinson 1990; Dickman et al. 1999; Castañeda-Gaytán et al. 2003; Germano and Williams 2005; Barrows 2006a). To the extent that this intuitive and empirically supported pattern dominates resource availability, a single metric (rainfall) allows ecologists to develop hypotheses for predicting the direction and magnitude of responses by consumers (e.g. Barrows 2006a). However, food webs in arid environments are not only mediated by temporal pulses in rainfall and subsequent primary productivity. Many of the arthropod primary consumers are detritivores, consuming resources that may accumulate below shrubs or even be moved from areas of higher primary productivity by the wind (Seely 1991). Under arid conditions macro invertebrates may replace bacteria as the primary decomposers and the abundance of their detritus-based resources maybe independent, or at least lag behind, pulses in primary productivity (Ayal et al. 2005). To the extent that those macro invertebrate detritivores become resources for insectivorous vertebrates there can be a cascade of abundance through a food web that lacks a temporal link to changes in precipitation.

Additionally, competitive interactions may play a role in constraining a species' access to resources, even if those resources are abundant. In granivorous desert rodents and harvester ants, short-term abundance responses to the removal of either class indicated a competitive interaction, although over a longer time span the rodents may facilitate harvester ant occurrence and abundance (Davidson et al. 1984). Rather than strictly resource-based, the fluctuating abundance of a population may be at least in part a response to interactions with competitors. The strength and interaction of these mechanisms for resource availability (primary productivity, detritus and competitive interference) creates a complexity that challenges *a priori* predictions. Here we evaluate these three mechanisms as alternative hypotheses explaining empirical observations of population dynamics in the Coachella Valley's sand dune communities over the past six years. We also report the results of an experimental approach for

understanding the strength of competitive interactions and resulting trophic cascades that result from those interactions.

Specific objectives for our research here were the:

- Identification of independent variables that are correlated with both positive and negative population growth in the focal aeolian sand community species.
- Identification of species interactions that restrict the population growth potential for those focal species.
- Experimental analysis of the potential interaction between rodents and the arthropod primary consumer and detritivore levels of the aeolian sand community food web.
- Conceptual and/or quantitative models of the population dynamics for the focal species as a tool for management decisions.

## Methods

Changes in lizard and small mammal populations were tracked on 132, 10 m x 100 m plots established across the aeolian sand habitats of the Coachella Valley. All of these plots were greater than 100 m from the preserve boundary to avoid previously described edge effects (Barrows et al. 2006). These included 44 plots located in relatively flat, stabilized sand fields, 26 plots located in active dunes, 36 plots in ephemeral sand fields, and 26 plots in stabilized dunes; numbers of plots roughly reflected the aerial extent of each of the four community types. Aeolian sand community classifications follow Barrows and Allen (2007b). All plots were located in a random-stratified distribution. Each plot was marked with a short wooden stake at the beginning, middle, and end so one's position with respect to the boundaries of the belt plot could be readily determined. Surveys were repeated 6 times per plot between June and July each year from 2002 through 2007. A power analysis was conducted after the first year and determined that six repetitions per plot was sufficient to detect between plot and between year differences when the mean plot difference was  $\geq 1.7$  lizards at  $\alpha = 0.05$ ,  $\beta = 0.80$  for a two sample z-test (for both fringe-toed lizards and flat-tailed horned lizards). All plots were  $\geq 50$  m apart; data for separate plots were considered independent.

The fine aeolian sand of the Coachella Valley presented an opportunity unique to sand dunes to quantify the occurrence and abundance of highly cryptic species occurring within each plot; each species' tracks could be readily distinguished from those from any other species. Lizard track identification criteria were developed by spending several weeks prior to surveys following tracks until animals were located and the species and age class were confirmed. Because late afternoon and evening breezes would wipe the sand clean, the next day's accumulation of tracks was not confused with those from the previous day. Accuracy of this method was evaluated by overlaying mark-recapture plots for flat-tailed horned lizards

(described below) over the 10m x 100m plots. A regression model ( $y = 0.1298x + 0.1665$ , with  $y$  = track-based population estimates and  $x$  = estimates from mark-recapture analyses) resulted in an  $R^2 = 0.9599$ ,  $p = 0.0006$ . On those days when the wind did not blow, tracks from the current day could be distinguished from those from previous days by determining whether or not the tracks of nocturnal arthropods crossed over the vertebrate's track. Surveys would begin after the sand surface temperature had risen sufficiently so that the lizards were active, usually  $\geq 35^\circ$  C. Surveys continued until late morning when the high angle of the sun reduced the observer's ability to distinguish and identify tracks. One or two observers working in tandem completed a survey on a given plot in 10-15 minutes, recording all fresh tracks observed within the 10 m wide belt. Tracks were followed off the plot if it was necessary to insure that the same individual was not crossing the same plot repeatedly, thus avoiding an inflated count of the individual lizards active on that plot.

Independent variables included ant abundance, beetle abundance (representing the detritivore guild), precipitation (including both current and previous year), and percent cover of annual plants. Arthropods were sampled using dry, un-baited pitfall traps in April of each year. Previous arthropod sampling efforts (Barrows, unpublished data) have indicated that in most years arthropod populations reached peak numbers in April. This was also the period when arthropod-eating lizards would be consuming resources necessary for egg production in the ensuing months. Three pitfall traps were placed on each plot; one at each end and another at the plot middle, and were collected within 24 hrs of being set. Beetle species included in this metric included: *Batulius setosus*, *Batuloides obesus*, *Cheriodes californica*, *Chilometopon abnorme*, *Chilometopon brachystomum*, *Chilometopon pallidum*, *Cnemodinus testoceus*, *Asbolus laevis*, *Edrotes barrowsi*, *Embaphion depressum*, *Niptus venticulus*, *Novelis picta*, and *Trigonoscuta imbricate*, and represented a sum of all individuals of all these species per plot per year. Species included were based on habitat relationships described in Barrows (2000). Ant data were summarized as the mean count per pitfall/plot. Sand compaction was measured at 25 points, 4 m apart, along the midline of each plot using a hand-held pocket penetrometer with an adapter foot for loose soils (Ben Meadows Company, Janesville, WI, USA). Rainfall was collected at a gauge located within 2 km of all plots, and was recorded as the current year's annual rainfall measured from July 1 to June 30.

Vegetation density, percent cover and species composition were measured on each of the plots, each year from 2003-2007. Perennial shrub density was recorded within the entire 10 m x 100 m treatment plot. Annual plant density and cover were measured within a 1 m<sup>2</sup> sampling frame placed at 12 locations along the midline of the plot. Four samples were taken on alternating sides of the center line leading into the plot from both the beginning and ending stakes; an additional four samples were taken at the center point (two on each side of the stake) of each plot. In each frame all individual plants were counted by species to determine their densities,

and each species was estimated for its percent cover. These values were then averaged for the 12 frames of each plot.

Pair-wise Pearson correlations were calculated between focal conservation species occurring on the Coachella Valley floor and both temporally variable and more temporally stable spatial drivers of observed changes in the relative abundance of those species over time. Temporal variables and their acronyms included in the correlation analyses were *n-annuals* - a measure of the percent cover of just native annual plants; *n-annuals+1yr* - a measure of native annuals the previous year, included to capture potential time lags in the response of the focal conservation species to the abundance of the resource; *all-anns* - a measure of the percent cover of both native and exotic annual plants; *all-anns+1yr* - providing the time lag analysis; *rain* - annual rainfall measured between July and June; and *rain+1yr* - providing the time lag analysis. Spatial variables with a higher degree of temporal stability included: *shrubs* - shrub density within each plot; *creosote* - creosote, *Larrea tridentata* density within each plot; and *sand* - mean sand compaction measured within each plot.

Models to explain spatial and temporal population dynamics were constructed using multivariate linear regressions with backwards stepwise analyses. The assumption of homogeneity of variances was met by modifying all variables using a square root ( $x+1$ ) transformation. For temporal analyses all years were combined whereas for spatial analyses individual years were analyzed separately. We selected a set of potential environmental drivers as hypotheses that could influence horned lizard occurrence and population dynamics. Using the stepwise analyses we were able to identify the most parsimonious model from the combination of the initial variables we selected by evaluating the efficacy of all variable combinations for explaining the patterns measured.

Our sampling design, which included measuring species and resource conditions on permanent plots annually, provided the benefit of measuring site-specific changes over time as well as the challenge of potential spatial autocorrelation when data over multiple years were combined into a single data set. We addressed this issue in two ways. First, using a logistic regression analysis we included the permanent plot locations as a class variable. If the plot locations explained a significant amount of the variance in the abundance of the species being analyzed then spatial autocorrelation was a problem; plot locations never provided a statistically significant contribution to any of the models. Secondly, we were willing to accept a greater chance of committing a Type I error in order to avoid potential problems associated with spatial autocorrelation by only accepting models that achieved a  $p \leq 0.001$  level of significance.

Ten experimental enclosures were constructed in April 2007 designed to exclude small mammal access while allowing free movement of ants and other arthropods. Each enclosure consisted of

a 10 m x 10 m square of wire mesh fencing. The mesh size was approximately 1 cm, and the fences were approximately 1 m high. Roughly 20-30 cm of the fence was buried beneath the soil surface to inhibit small mammals from burrowing into enclosures, leaving 70-80 cm above the ground. The 10 enclosures were interspersed within a grid with 25 points, each point 20 m apart. Enclosures were separated by non-fenced spaces so that no enclosure fence was closer than 10 m from an adjacent enclosure fence. The layout of the grid and enclosures is shown in Figure 1. Each cell within the grid was randomly selected to have food resources added (oatmeal flakes – “quick oats”) or not, resulting in food resources being added to cell numbers 2, 4, 6, 8, 9, 12, 13, 15, 16, 18, 19, 20, 22, 23, and 24. Cell numbers 1, 3, 5, 7, 10, 11, 14, 17, 21 and 25 received no added food.

Arthropods were sampled using dry, un-baited pitfall cups placed at or near the center of each cell. Pitfalls were set in the afternoon and the collected in the morning of the following day. Arthropod sampling occurred on 4 occasions in 2007: 5/1/2007, 7/10/2007, 10/12/2007, and on 11/8/2007. Active rodent burrows were also counted within each cell, on 5/10/2007, 5/21/2007, 5/31/2007, 6/2/2007, 6/17/2007, 6/25/2007, and 8/9/2007.

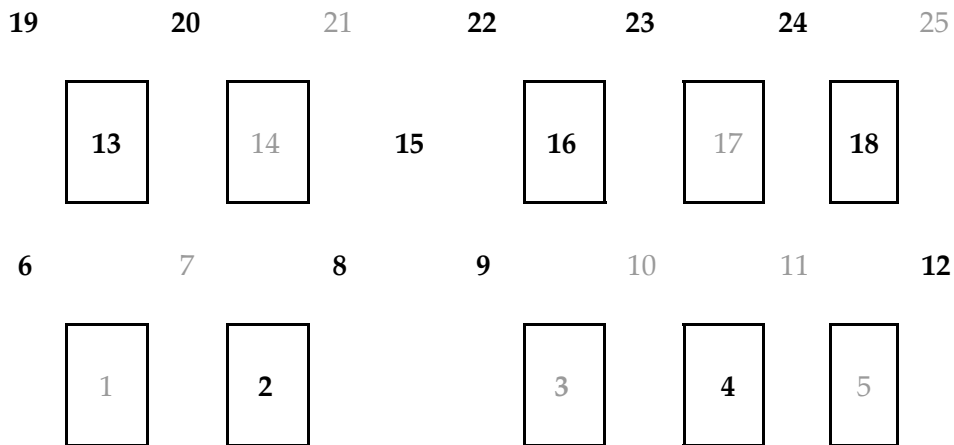


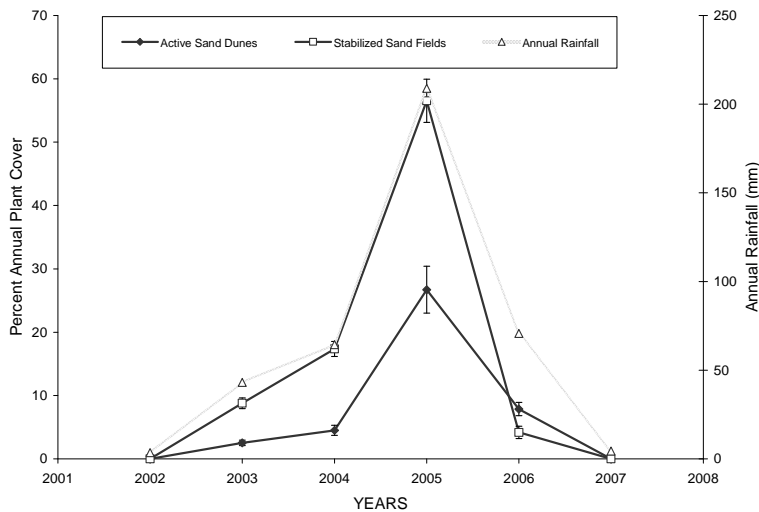
Figure 1 Schematic of the small mammal enclosure and arthropod sampling grid. Grid numbers in bold indicate cells where food resources were added, squares indicate enclosure locations.

## Results

- **Identify independent variables that are correlated with both positive and negative population growth in the focal aeolian sand community species.**

Over the 6 years of this study the Coachella Valley experienced the 2 driest years on record (2002 and 2007) along with one of the 5 wettest years (2005). The differences in rainfall inputs provided the setting for understanding how desert wildlife responds to changing food resource levels. Food resources include, but are not limited to, annual plants and/or the phytophagous arthropods associated with them, seeds and/or the seed-eating arthropods associated with them, and detritus and/or the arthropods detritus eating arthropods associated with it. Patterns of annual plant cover, harvester ant abundance (representing a seed eating guild) and sand dune beetle abundance (representing a detritivore guild) with respect to annual rainfall are shown in Figures 2, 3, and 4. Not surprisingly fluctuations in percent annual plant cover paralleled annual precipitation. In contrast, both harvester ant abundance and sand dune beetle abundance appeared to fluctuate in the opposite direction; highest numbers in these two groups corresponded with the lows in rainfall and vice versa. One difference between these arthropod groups was that the lowest point in harvester ant abundance occurred in 2005, while for beetles it was 2006.

To the extent that food resources provide the temporal impetus for population growth, then the pattern of abundance of annual plants, harvester ants and dune beetles, as diets for desert reptiles and small mammals, should partially or wholly drive the abundance of species higher within the food web.



**Figure 2 Percent cover of annual plants with respect to annual rainfall between 2002 and 2007 on the active dunes and stabilized sand fields of the Thousand Palms Preserve.**

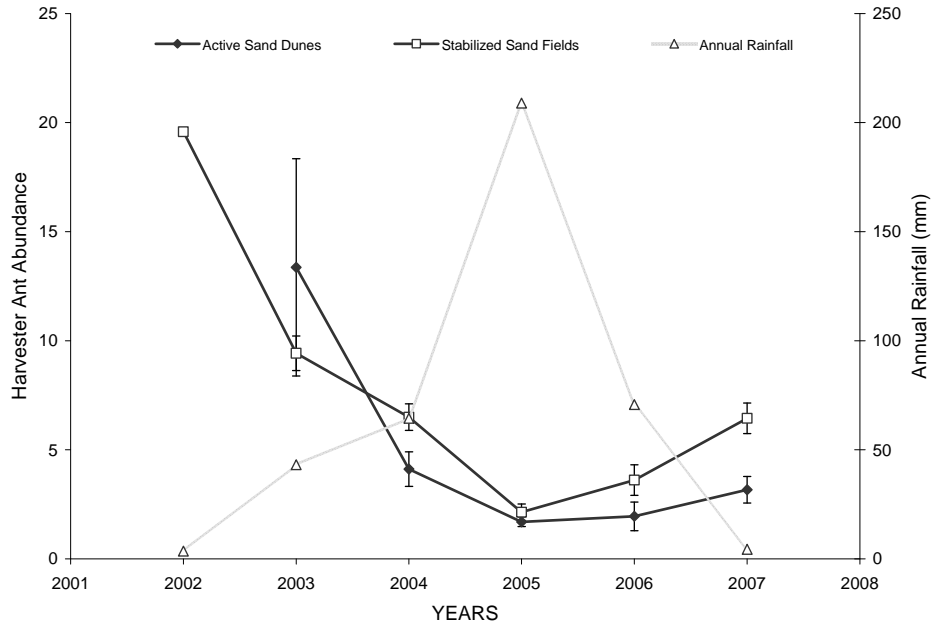


Figure 3 Harvester ant abundance (*Pogonomyrmex californicus* and *P. magnicanthus*) with respect to rainfall on active dunes and stabilized sand fields within the Thousand Palms Preserve, 2002-2007.

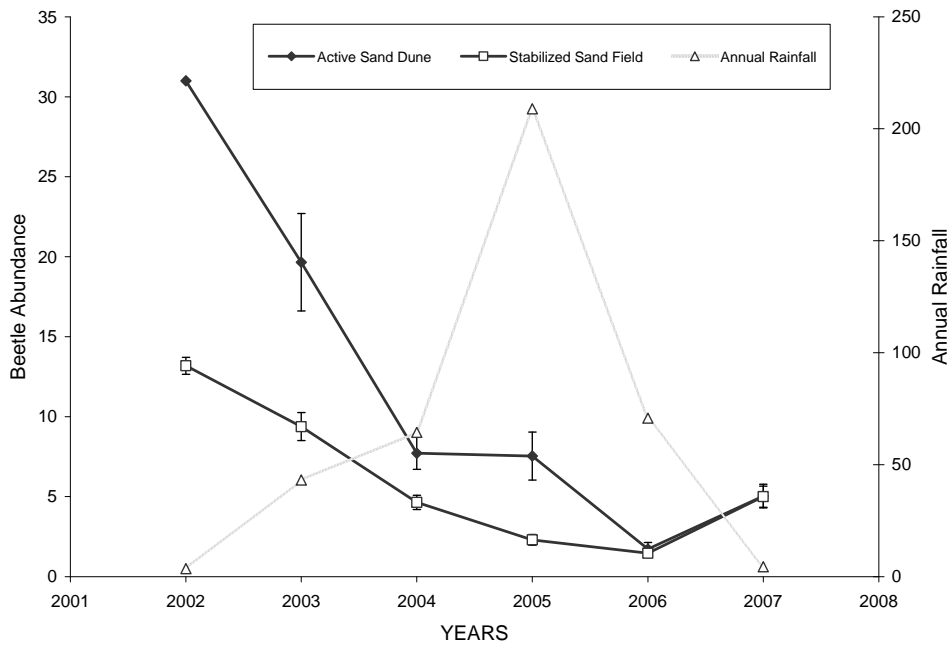


Figure 4 Sand dune beetle abundance (see methods for species included) with respect to rainfall on active dunes and stabilized sand fields within the Thousand Palms Preserve, 2002-2007.



The results of Pearson correlation analyses between aeolian sand-associated species and temporal and spatial (relatively temporally stable) variables are shown in Table 1. Lack of any statistically significant correlations for a species within an aeolian sand community types is often the result of low abundances of that species within that community type. A large portion of the temporal variation observed in the species analyzed correlates positively with annual plants and rainfall (directly or with a one year time lag). Those species include Coachella fringe-toed lizards, *Uma inornata*, zebra-tailed lizards, *Callisaurus draconoides*, western whiptails, *Aspidoscelis tigris*, sidewinders, *Crotalus cerastes*, round-tailed ground squirrels, *Spermophilus tereticaudus*, desert kangaroo rats, *Dipodomys deserti*, Merriam's kangaroo rats, *D. merriami*, Desert pocket mice, *Chaetodipus penicillatus*, Coachella Valley giant sand-treader crickets, *Macrobaenetes valgum*, and Coachella Valley milkvetch, *Astragalus lentiginosus* var *coachellae*. Of those species only the milkvetch showed a positive correlation to native annual plants and rainfall, but with a negative correlation to all annual plants, indicating a negative interaction with exotic annual plants. A smaller subset of the species analyzed revealed negative correlations or no correlations that were statistically significant with annual plants and/or rainfall. Those species included flat-tailed horned lizards, *Phrynosoma mcallii*, banded geckos, *Coleonyx variegatus*, shovel-nosed snakes, *Chionactis occipitalis*, and side-blotched lizards, *Uta stansburiana*. These species all correlated positively with harvester ant abundance and in some cases beetles as well.

**Table 1. Pair-wise Pearson correlations calculated between aeolian sand occurring species on the Coachella Valley floor and temporal and spatial variables. Correlation values depicted in bold print represent correlations that are statistically significant ( $p \leq 0.01$ , Bonferroni Test). Descriptions of variables are in the methods section.**

	beetles	ants	n-annuals	n-ann+1yr	all-anns	all-ann+1yr	rain	rain+yr	shrubs	creosote	sand
<b>Banded Gecko</b>											
Stabilized dunes	0.194	-0.043	-0.058	-0.147	-0.087	-0.032	-0.136	-0.194	-0.209	-0.113	-0.160
Stabilized sand fields	0.176	<b>0.312</b>	-0.192	-0.250	-0.213	-0.282	-0.250	-0.263	0.166	-0.014	<b>-0.322</b>
<b>Desert Iguana</b>											
Stabilized dunes	0.116	-0.045	-0.180	0.208	-0.122	0.172	-0.154	0.278	0.194	<b>0.308</b>	0.177
Ephemeral sand fields	0.124	-0.041	0.158	0.110	-0.226	-0.236	-0.080	0.006	-0.074	<b>-0.564</b>	-0.225
Active Dunes	-0.170	-0.070	0.239	0.037	0.292	0.119	0.175	0.040	0.293	<b>0.412</b>	0.048
Stabilized sand fields	0.000	-0.068	0.013	-0.035	-0.039	-0.053	-0.116	0.009	-0.075	0.093	0.152
<b>Flat-tailed horned</b>											
Active Dunes	-0.158	0.045	0.167	0.058	0.202	0.110	0.077	0.063	<b>0.379</b>	-0.034	<b>0.305</b>
Stabilized sand fields	<b>0.322</b>	<b>0.469</b>	<b>-0.374</b>	-0.051	<b>-0.435</b>	-0.064	<b>-0.443</b>	0.034	0.203	-0.135	<b>-0.494</b>

	beetles	ants	n-annuals	n-ann+1yr	all-anns	all-ann+1yr	rain	rain+yr	shrubs	creosote	sand
<b>Fringe-toed lizard</b>											
Stabilized dunes	-0.130	-0.278	-0.122	-0.038	-0.175	-0.167	-0.051	0.112	-0.125	-0.109	<b>-0.558</b>
Ephemeral sand fields	-0.157	-0.036	<b>-0.339</b>	-0.249	<b>-0.305</b>	-0.153	-0.020	0.095	-0.284	0.138	-0.263
Active Dunes	<b>-0.381</b>	-0.164	-0.016	0.302	-0.058	<b>0.346</b>	0.018	<b>0.589</b>	0.005	-0.072	-0.005
Stabilized sand fields	0.083	0.114	-0.216	0.038	-0.278	0.087	-0.221	0.170	0.224	-0.017	<b>-0.456</b>
<b>Shovel-nosed Snake</b>											
Stabilized dunes	0.144	-0.101	0.008	-0.095	-0.001	-0.025	-0.106	-0.091	-0.021	<b>0.416</b>	-0.303
Ephemeral sand fields	-0.063	0.063	-0.043	-0.099	0.152	-0.019	-0.159	-0.046	<b>0.315</b>	<b>0.465</b>	<b>-0.346</b>
Active Dunes	0.243	0.208	-0.184	-0.225	-0.212	-0.184	-0.287	<b>-0.305</b>	<b>0.374</b>	<b>0.345</b>	0.128
Stabilized sand fields	<b>0.342</b>	<b>0.390</b>	-0.200	<b>-0.329</b>	-0.234	<b>-0.398</b>	<b>-0.334</b>	<b>-0.466</b>	0.129	<b>0.384</b>	-0.201
<b>Side-blotched lizard</b>											
Western Stabilized	-0.009	<b>0.539</b>	-0.027	-0.001	-0.045	0.219	0.100	0.207	<b>0.566</b>	-0.206	<b>0.305</b>
Ephemeral sand fields	-0.110	0.014	-0.027	0.134	-0.006	0.217	0.114	0.215	0.026	0.106	0.059
Active Dunes	-0.172	-0.077	-0.090	0.042	0.052	0.238	0.130	0.205	0.154	-0.060	0.113
Stabilized sand fields	-0.126	-0.033	-0.136	0.002	-0.146	-0.003	-0.180	0.172	0.172	0.138	0.003
<b>Sidewinder</b>											
Stabilized dunes	-0.080	-0.052	-0.122	<b>0.590</b>	-0.202	<b>0.562</b>	-0.062	<b>0.752</b>	0.258	0.046	-0.047
Ephemeral sand fields	0.013	-0.052	0.197	-0.055	0.110	-0.077	-0.023	-0.182	-0.179	0.029	-0.149
Active Dunes	-0.056	-0.087	-0.138	0.155	-0.112	<b>0.451</b>	-0.128	<b>0.334</b>	0.217	0.244	0.026
Stabilized sand fields	0.007	0.107	-0.146	-0.002	-0.148	-0.078	-0.153	-0.105	0.142	0.089	-0.056
<b>Western whiptail</b>											
Stabilized dunes	-0.178	0.067	-0.124	-0.070	-0.040	-0.175	-0.076	-0.046	<b>0.495</b>	0.160	<b>0.349</b>
Ephemeral sand fields	-0.184	0.034	-0.079	-0.028	<b>0.393</b>	0.171	-0.098	0.038	<b>0.556</b>	<b>0.484</b>	-0.175
Active Dunes	0.076	-0.045	0.002	0.017	0.023	0.034	-0.055	-0.053	0.250	0.253	0.068
Stabilized sand fields	0.189	-0.025	-0.122	-0.097	-0.141	-0.092	-0.235	-0.098	0.064	<b>0.313</b>	-0.021
<b>Zebra-tailed Lizard</b>											
Stabilized dunes	-0.037	0.056	<b>-0.459</b>	-0.127	<b>-0.469</b>	-0.239	<b>-0.490</b>	0.128	0.103	-0.045	-0.105
Ephemeral sand fields	-0.029	-0.174	<b>-0.449</b>	0.103	<b>-0.422</b>	-0.149	-0.050	<b>0.358</b>	-0.026	-0.046	-0.221
Active Dunes	-0.121	-0.051	-0.031	<b>0.310</b>	0.013	<b>0.373</b>	-0.019	<b>0.337</b>	-0.084	-0.104	0.178
Stabilized sand fields	-0.114	0.034	-0.075	0.043	-0.074	0.263	-0.004	0.249	-0.019	-0.009	0.131

	beetles	ants	n-annuals	n-ann+1yr	all-anns	all-ann+1yr	rain	rain+yr	shrubs	creosote	sand
<b>Round-tailed ground</b>											
Stabilized dunes	0.385	-0.094	0.068	0.146	0.145	<b>0.355</b>	0.170	0.188	0.144	-0.102	-0.037
Ephemeral sand fields	-0.304	0.079	0.042	-0.060	<b>0.311</b>	<b>0.374</b>	0.072	0.148	0.216	<b>0.676</b>	-0.096
Active Dunes	-0.100	-0.156	0.240	0.260	<b>0.504</b>	0.284	<b>0.477</b>	<b>0.409</b>	0.136	<b>0.302</b>	-0.057
Stabilized sand fields	0.015	-0.272	0.199	0.166	0.248	0.115	0.234	0.029	-0.020	<b>0.321</b>	0.219
<b>Desert kangaroo rat</b>											
Stabilized dunes	0.044	0.164	0.316	0.119	<b>0.315</b>	0.251	0.225	-0.014	-0.011	0.092	0.161
Ephemeral sand fields	0.033	0.077	-0.023	<b>0.384</b>	0.009	0.137	0.022	<b>0.520</b>	0.240	-0.101	-0.083
Active Dunes	-0.232	-0.196	<b>0.400</b>	<b>0.540</b>	<b>0.493</b>	<b>0.495</b>	<b>0.474</b>	<b>0.619</b>	0.234	0.183	0.061
Stabilized sand fields	-0.356	-0.376	0.292	<b>0.664</b>	0.266	<b>0.604</b>	<b>0.478</b>	<b>0.527</b>	0.006	-0.118	0.030
<b>Merriam's kangaroo rat</b>											
Stabilized dunes	-0.002	-0.192	<b>0.473</b>	<b>0.583</b>	<b>0.496</b>	<b>0.611</b>	<b>0.574</b>	<b>0.404</b>	<b>0.363</b>	<b>0.320</b>	0.263
Ephemeral sand fields	-0.178	-0.093	-0.051	<b>0.392</b>	-0.129	<b>0.476</b>	0.172	<b>0.800</b>	0.080	0.184	0.000
Active Dunes	-0.146	-0.310	0.012	<b>0.445</b>	0.234	<b>0.626</b>	0.149	<b>0.639</b>	0.180	0.023	0.209
Stabilized sand fields	-0.270	-0.394	0.100	<b>0.503</b>	<b>0.421</b>	<b>0.566</b>	<b>0.544</b>	<b>0.467</b>	-0.050	0.071	<b>0.416</b>
<b>Desert Pocket Mouse</b>											
Stabilized dunes	0.1716	0.1095	-0.2363	0.1869	-0.2447	<b>0.4637</b>	- 0.2364	<b>0.4981</b>	<b>0.3317</b>	- 0.0781	0.0652
Ephemeral sand fields	-0.1933	-0.0611	<b>-0.3508</b>	0.1522	-0.1389	0.2645	- 0.0513	<b>0.6182</b>	0.2010	<b>0.4547</b>	- 0.1916
Active Dunes	-0.2954	-0.0907	-0.0946	<b>0.3360</b>	0.1249	<b>0.5689</b>	0.1422	<b>0.6427</b>	0.1575	0.0437	0.1102
Stabilized sand fields	-0.2712	0.0131	-0.1551	0.2442	-0.1340	<b>0.3767</b>	0.0017	<b>0.4290</b>	0.2089	- 0.0249	0.0503
<b>Sand Treader Cricket</b>											
Stabilized dunes	-0.108	-0.192	0.260	<b>0.318</b>	0.057	0.049	<b>0.367</b>	-0.003	-0.093	0.260	<b>-0.368</b>
Ephemeral sand fields	-0.252	0.038	-0.120	-0.251	-0.114	-0.117	<b>0.308</b>	0.105	-0.151	0.186	-0.220
Active Dunes	-0.134	-0.135	<b>0.341</b>	<b>0.413</b>	0.285	<b>0.365</b>	<b>0.380</b>	<b>0.467</b>	-0.025	-0.043	-0.101
Stabilized sand fields	-0.169	-0.131	<b>0.319</b>	-0.015	0.265	-0.087	<b>0.298</b>	-0.137	-0.014	-0.068	0.112
<b>Coachella Valley</b>											
Stabilized dunes	0.082	-0.078	-0.076	-0.103	0.157	-0.097	0.255	-0.011	0.143	-0.060	-0.097
Ephemeral sand fields	-0.118	0.036	-0.143	-0.260	-0.119	-0.136	<b>0.352</b>	0.068	-0.214	0.133	-0.199
Active Dunes	0.119	0.024	<b>0.419</b>	-0.126	0.158	-0.185	0.289	-0.207	-0.026	0.087	-0.113
Stabilized sand fields	0.192	-0.031	0.277	-0.104	0.139	-0.118	0.046	-0.193	-0.022	0.034	0.098

	beetles	ants	n-annuals	n- ann+1yr	all-anns	all- ann+1yr	rain	rain+yr	shrubs	creosote	sand
<b>Burrowing Owl</b>											
Stabilized dunes	-0.182	0.010	-0.253	0.360	-0.349	0.175	-0.019	<b>0.585</b>	0.218	-0.026	-0.184
Active Dunes	-0.262	-0.118	0.038	<b>0.430</b>	0.001	<b>0.329</b>	0.061	<b>0.462</b>	-0.165	-0.140	-0.036
Stabilized sand fields	-0.160	-0.017	-0.236	0.236	-0.214	0.283	-0.171	<b>0.287</b>	-0.073	0.069	0.175

- Identification of species interactions that restrict the population growth potential for those focal species.

Using correlative analyses is only one step in identifying species interactions. Opposite patterns of abundance of species pairs at the same location may indicate different patterns of resource use or they could indicate interactions between species. If there are species interactions, those could involve competition for common resources. An additional step for identifying species interactions is to examine the basic natural history of species pairs, looking for species who both co-occur in space and time and who have similar diets (i.e. for potential competitive interactions). For example, the patterns in small rodents' abundance for those species surveyed in our research parallel the abundance of rainfall (Fig. 5). In contrast, a suite of reptiles occurring in the same stabilized sand field community show a nearly opposite temporal change in abundance with respect to rainfall (Fig. 6). At first glance this appears to be an indication of some level of interaction between these rodents and reptiles. However, the rodents are largely granivores whereas the reptiles are insectivorous. No direct competitive or predatory relationships are likely.

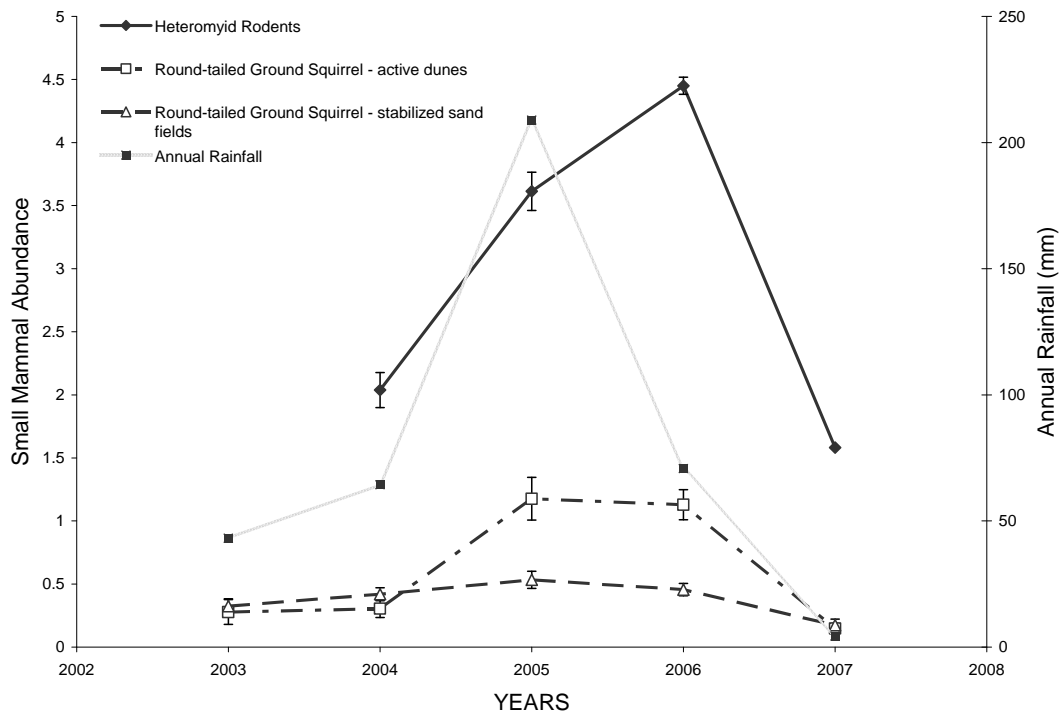


Figure 5 Small mammal abundance with respect to rainfall. Heteromyiid rodents include combined abundances for *Dipodomys deserti*, *D. merriami*, and *Chaetodipus penicillatus*. These data were collected from the stabilized sand field habitats.

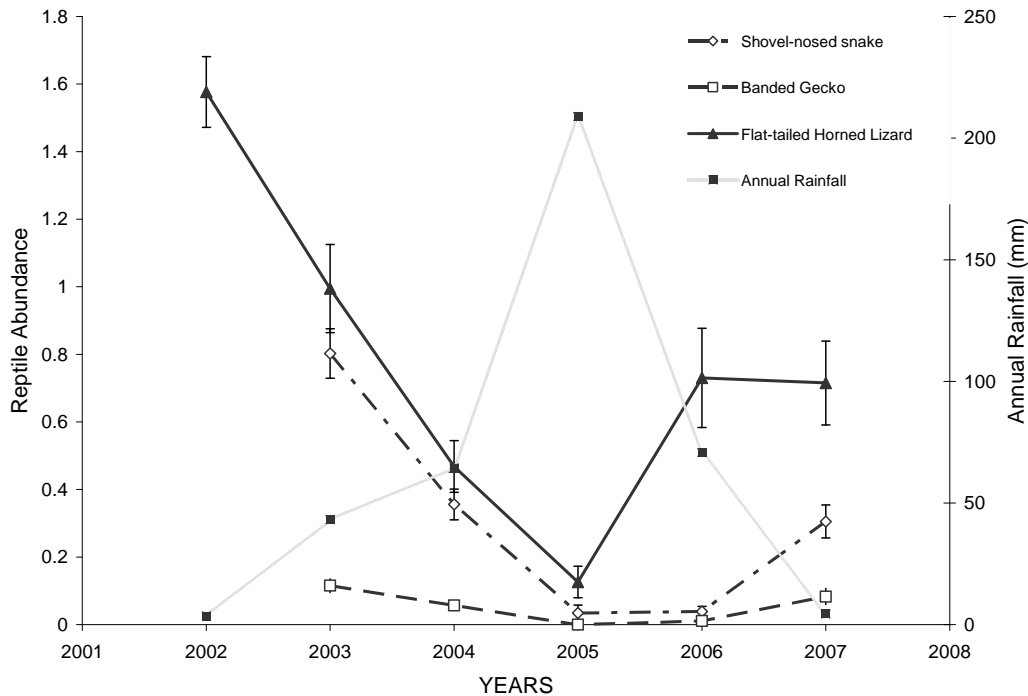


Figure 6 Changes in temporal abundance of three reptile species with respect to rainfall.

There is a potential interaction between harvester ants, which are granivorous as well as detritivores, and the small rodents. Harvester ants are the primary prey for flat-tailed horned lizards and form an important dietary component for other reptiles as well. The patterns of abundance for harvester ants and rodents are shown in Fig. 7. A competitive interaction between the ants and rodents, where the rodents restrict access for the ants to seed resources produced during wet periods would have the potential for a cascade effect on to those reptiles that depend on the ants for food. While the correlative data indicate the possibility of a competitive interaction, direct evidence for such an interaction requires experimental manipulations where resource variables and access to those resources can be controlled.

- **Experimental analysis of the potential interaction between rodents and the arthropod primary consumer and detritivore levels of the aeolian sand community food web.**

In order to answer the question of whether granivorous rodents and harvester ants compete for food resources, with the consequence of reduced ant abundance during periods of peak rodent abundance, we established a series of experimental plots. The plots were designed to allow free movement of harvester ants but to exclude rodent access. Each of the plots was paired with a control plot where there was no rodent exclusion; on a random subset of both the enclosure and

control plots food resources (dry instant oatmeal) were provided and replenished on all plots whenever the ants in the enclosure plots depleted their food supply.

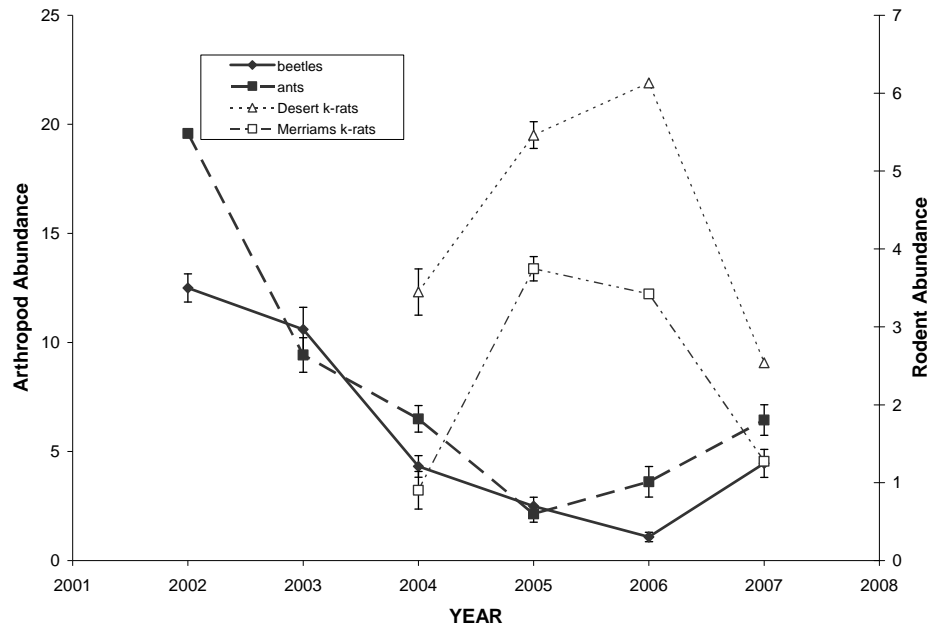


Figure 7 Patterns of abundance of arthropods and two Heteromyiid rodents on the stabilized sand field community.

Rodents responded immediately to the added food resources (as indicated by the number of active burrows within a 5 m radius circle surrounding plot center) (Fig. 8). There was a statistically significant difference in the number of active rodent burrows between non-exclosure plots where food was added and where it wasn't within two weeks (the first survey) after the first food resources were added (One-way ANOVA; d. f. = 1,  $F = 10.032$ ,  $p = 0.00742$ ). The cumulative difference mirrored this pattern (One-way ANOVA; d. f. = 1,  $F = 21.833$ ,  $p = 0.00044$ ). As is evident in Fig. 8, our rodent exclosures were imperfect in their design; some rodents were able to gain access to the food resources within the exclosures. However the rodent activity within the exclosures was significantly less than on the non-exclosure, open plots (One-way ANOVA; d. f. = 1,  $F = 37.373$ ,  $p = 0.00004$ ).

Harvester ant abundance was not different between the four experimental treatments at the first survey conducted in May 2007 (Fig. 9). In subsequent surveys, beginning in July 2007, there was a significant increase in the abundance of harvester ants on the enclosure with added food treatments versus all other plots (One-way ANOVA; d. f. = 3,  $F = 3.944$ ,  $p = 0.0232$ ). For the other treatments (exclosure without added food, open access with added food, open access with no

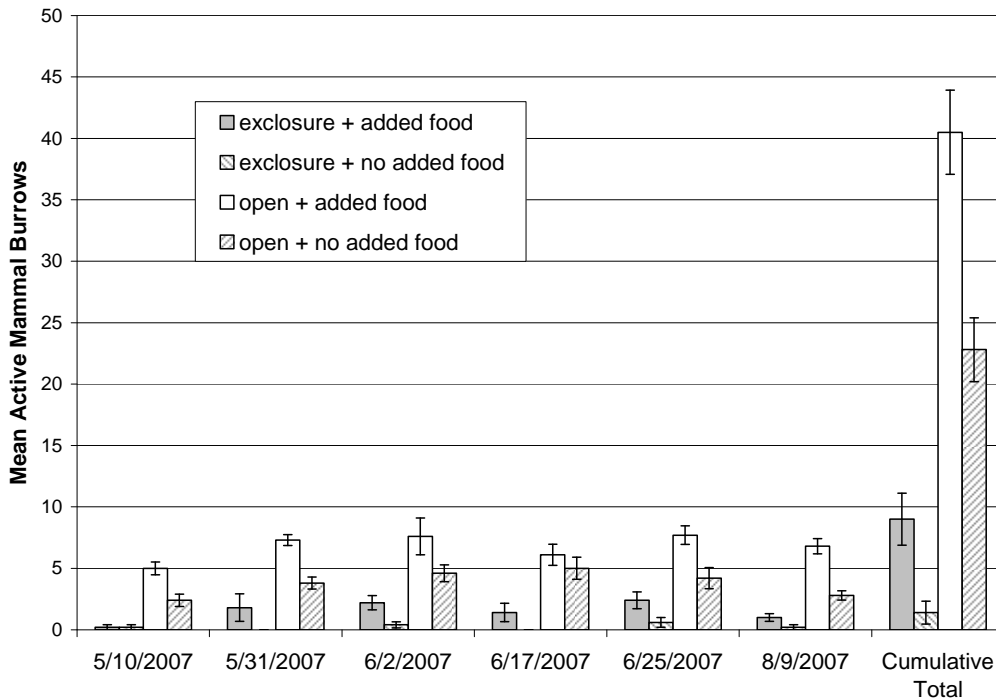


Figure 8 Abundance of active burrows associated with different experimental plot types

added food) there were no observed differences (One-way ANOVA; d. f. = 2, F = 0.938, p = 0.412). The harvester ants did not respond as quickly to added food resources as did the rodents, and then they only responded when rodents were excluded. This result provides direct evidence for competition between ants and rodents.

- **Conceptual and/or quantitative models of the population dynamics for the focal species as a tool for management decisions.**

We employed multiple linear regression analyses to develop models of temporal and spatial abundance for the aeolian sand species of the Coachella Valley. The basic model structure is as follows:

$$Y = \alpha + \beta_1 * X_1 + \beta_2 * X_2 + \beta_3 * X_3 \dots$$

Where Y is the dependent variable (in this case the spatial-temporal variation of a species),  $\alpha$  is the constant and  $\beta_i$  and  $X_i$  are the coefficient and independent, explanatory variables. We used a backward-stepwise approach to developing the regression model. This begins with a full model (all variables included) and then removes or re-adds individual independent variables until the most parsimonious model is achieved while optimizing both  $R^2$  and the statistical significance of the model within the available independent variable set. The final model is composed of



variable relationships that are orthogonal, or in other words covariance among the variables is minimized.

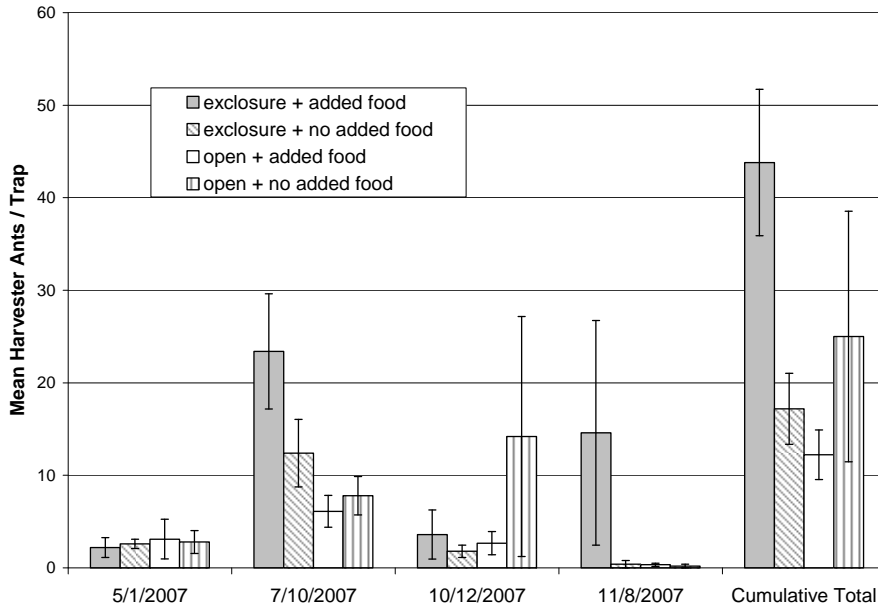


Figure 9 Harvester ant abundance with respect to the experimental treatments.

One obvious result for all species is that the independent variables (and whether they were negative or positive) that comprised their multivariate models were different within each of the four aeolian sand community types. In the following models for those species at the focus of conservation efforts, values represent the  $\beta_i$  coefficient, relative abundance is per plot (1000 m<sup>2</sup>).

### Coachella Fringe-toed Lizard

Independent Variables	Active Dunes	Stabilized Dunes	Stabilized Sand Fields	Ephemeral Sand Fields
Beetles				-0.052
Native Annual Plants				-0.100
Native Annual Plants +1yr			-0.029	-0.089
Annuals incl. exotic spp.	-0.055	0.126		-0.038
Annuals incl. exotic spp.+1yr	-0.108	-0.122		0.038
Annual Rain				0.034
Annual Rain +1yr	0.116	0.058	0.036	
Shrubs	18.430		5.866	-4.358
Creosote Bush			17.231	

Sand Compaction		-1.619	-1.021	-0.058
constant	-16.896	3.864	-19.982	7.118
<i>P</i>	< 0.001	< 0.001	< 0.001	< 0.001
<i>R</i> <sup>2</sup>	0.510	0.489	0.424	0.441
mean relative abundance 2002-2007	3.474	1.289	0.505	0.541

**Flat-tailed horned lizard**

Independent Variables	Active Sand Dunes	Stabilized Sand Fields
Harvester Ants		0.047
Native Annual Plants		-0.019
Native Annual Plants +1yr	-0.022	
All annual plants incl. exotic spp.	0.006	
All annuals incl. exotic spp.+1yr	0.013	
Annual Rain +1yr		0.012
Shrubs	10.248	3.398
Creosote Bush	-22.990	
Sand Compaction	0.111	-0.671
constant	13.551	-1.457
<i>P</i>	< 0.001	< 0.001
<i>R</i> <sup>2</sup>	0.285	0.382
mean relative abundance 2002-2007	0.057	0.686

**Round-tailed ground squirrel**

Independent Variables	Active Dunes	Stabilized Dunes	Stabilized Sand Fields	Ephemeral Sand Fields
Native Annual Plants	-0.051	-0.638	0.016	0.049
Native Annual Plants +1yr			0.032	-0.096
Annuals incl. exotic spp.	0.106	0.134		
Annuals incl. exotic spp.+1yr		0.100		0.033

Independent Variables	Active Dunes	Stabilized Dunes	Stabilized Sand Fields	Ephemeral Sand Fields
Annual Rain		0.127		
Annual Rain +1yr	0.026	-0.061	-0.007	0.025
Shrubs				
Creosote Bush	62.305	-34.937	26.247	33.462
Sand Compaction	-0.469	0	0	0
constant	-60.667	37.075	-25.168	-32.172
<i>P</i>	< 0.001	< 0.001	< 0.001	< 0.001
<i>R</i> <sup>2</sup>	0.530	0.649	0.206	0.589
mean relative abundance 2003-2007	0.612	2.857	0.400	0.518

### Coachella Valley Giant Sand-treader Cricket

Independent Variables	Active Dunes	Stabilized Dunes	Ephemeral Sand Fields
Beetles			-0.261
Harvester Ants	0.332		
Native Annual Plants	0.434	0.644	0.207
Native Annual Plants +1yr		0.213	-0.272
Annuals incl. exotic spp.	-0.274	-0.678	-0.233
Annuals incl. exotic spp.+1yr		-0.140	
Annual Rain	0.244	0.277	0.180
Annual Rain +1yr	0.332		0.079
Creosote Bush		50.308	64.945
Sand Compaction			0.762
constant	-2.791	-50.117	-71.869
<i>P</i>	< 0.001	< 0.001	< 0.001
<i>R</i> <sup>2</sup>	0.767	0.785	0.778
mean relative abundance 2003-2007	10.809	3.932	3.825

### Coachella Valley Milkvetch

Independent Variables	Active Sand Dunes	Ephemeral Sand Fields
Beetles		-0.004
Native Annual Plants		-0.004
Native Annual Plants +1yr	-0.031	-0.009
Annuals incl. exotic spp.	-0.023	-0.004

Independent Variables	Active Sand Dunes	Ephemeral Sand Fields
Annual Rain	0.016	0.006
Annual Rain + 1yr	0.020	
Creosote Bush		0.029
Sand Compaction		-0.055
constant	0.874	0.297
<i>P</i>	< 0.001	< 0.001
<i>R</i> <sup>2</sup>	0.291	0.557
mean relative abundance 2004-2007	0.003	0.020

### Burrowing Owl

Independent Variables	Active Dunes	Stabilized Dunes	Stabilized Sand Fields
Native Annual Plants +1yr	0.020		0.004
Annuals incl. exotic spp.	-0.004		
Annuals incl. exotic spp.+1yr	-0.009	-0.024	0.004
Annual Rain			-0.004
Annual Rain +1yr	0.006	0.031	
Shrubs	-2.696		
Sand Compaction			0.031
Desert Pocket Mouse		0.882	-0.015
constant	3.677	-0.066	0.980
<i>P</i>	< 0.001	< 0.001	< 0.001
<i>R</i> <sup>2</sup>	0.303	0.640	0.221
mean relative abundance 2003-2007	0.041	0.176	0.021

### Discussion

There are important generalizations that can be drawn from these results. One is that within each of the previously defined community types (Barrows and Allen 2007b) the variables that influence the relative abundances of a given species can be very different. Broad statements that a given variable drives the occurrence and abundance of a species throughout this aeolian sand landscape, or any other complex landscape, should be treated with caution. As an example Ball et al. (2005) stressed the importance of honey mesquite, *Prosopis glandulosa*, over creosote in

defining suitable habitat for round-tailed ground squirrels in the Coachella Valley. They speculated that the squirrels could not subsist on creosote in the dry conditions of this region and so required mesquite. Our results indicate more complicated habitat relationships. We demonstrated that the squirrels are more abundant in the stabilized sand dunes where mesquite is often present, and there exists a strong negative relationship to creosote. However, in each of the other communities where mesquite was absent the squirrels showed strong positive associations with higher creosote densities and appeared to be able to sustain populations, albeit at lower densities, without mesquite.

Another example originates from our multiple linear regression models for the occurrence of flat-tailed horned lizards. On active dunes where sands are typically less compacted (Barrows and Allen 2007b) these lizards are found in the most compacted sites; whereas on stabilized sand fields that have more compacted sands, the lizards are found on the less compacted sites. These results indicate that for the aeolian sand landscape, flat-tailed horned lizards have a non-linear correlation with sand compaction. This relationship only appears linear, and so becomes statistically significant using linear regressions, when the landscape is partitioned into more homogeneous community types. It is not surprising for species to have non-linear relationships across environmental gradients, and so the identification of distinct community types and a partitioned sampling scheme that allows the communities to be analyzed separately, as we have done here, is critical to the identification of temporal and spatial drivers of species' occurrences.

A general observation evident from our data is that for species with narrow habitat requirements, variables that are typically temporally labile drive their occurrence within their preferred habitats. If we assume that these communities capture more of a homogeneous habitat character, then in a community where a species' preferred habitat is found, all locations are more or less equally suitable and spatial variables such as sand compaction or shrub density become less important as variables associated with the abundance of that species. In those instances, temporal variables like those describing food resource availability have a much higher explanatory value. Alternatively, in peripheral or suboptimal habitats or communities, the same species are restricted to micro-habitats where their narrower habitat requirements occur and so spatial variables become more important descriptors of their occurrence. These generalizations explain much of the between community variability in variable correlates and linear regression models we identified.

While generalizations are important in science, explicit information is important to land managers. In order to avoid both Type I and Type II decision errors (Type I - determining a population decline is a signal for a new management strategy when in fact none is necessary; and, Type II - failing to identify signals of populations in need of adaptive management), we need to partition natural population dynamics from population indicators depicting a trajectory

toward extinction (Barrows et al. 2005). By modeling the effect of independent variables on population dynamics, we can begin to separate typical fluctuations that are of no conservation concern from those that are. It is also important to identify signals of populations at risk of extinction as early as possible. The near extinctions of California Condors (*Gymnogyps californianus*), Peregrine falcons (*Falco peregrinus*), or whooping cranes (*Grus americanus*) required expensive efforts to reverse, efforts that might have been less expensive and more effective had the declines and cause and effect relationships been identified much earlier. The following are species-specific interpretations for six focal conservation species from our analyses.

### **Coachella fringe-toed lizard**

Coachella fringe-toed lizards occur in all four identified aeolian sand community types of the Coachella Valley. Annual rainfall, usually with a one year time lag, was identified as a consistent positive temporal driver of fringe-toed lizard abundance.

Throughout our study the fringe-toed lizards' highest density was on active sand dunes, although previous densities within ephemeral sand fields reached or exceeded those found on active dunes (Barrows et al. 1995). The Pearson's correlation results for this species on active dunes follow the pattern described above for a species within its preferred habitat; only temporally labile variables were statistically significant. The regression model did add shrub density. Fringe-toed lizards are more common on active dunes with some shrubs as opposed to sites that lack vegetation. Shrub density has a non-linear relationship to fringe-toed lizard abundance as shown by the negative coefficient for shrub density for the ephemeral sand field model, a community with the highest shrub density of all the aeolian communities here; some shrubs are beneficial but both high and low extremes of shrub density are associated with lower fringe-toed lizard numbers. Active dunes were the only community where less compacted sand was not identified as an explanatory variable. Loosely compacted sands are important indicators for high habitat quality for this and other fringe-toed lizards (Barrows 1997, 2006a; Garcia de la Peña 2007), however the active sand community is typified by loosely compacted sands (Barrows and Allen 2007b) so the lizards had no gradient upon which to discriminate.

The negative correlation between the lizards' abundance and a measure of the percent cover of all annual plants, including exotics in the regression model, when there was no correlation to just native annuals, indicates sensitivity to exotic annual plants. This sensitivity was previously identified through an experimental analysis of the impacts of Sahara mustard (*Brassica tournefortii*) on the entire aeolian sand biota in the Coachella Valley (Barrows 2006b; Barrows et al., in review). Fringe-toed lizards along with sand-trader crickets and Coachella Valley milkvetch all showed negative correlations to annual plants when exotic species were included.

The regression model for fringe-toed lizards occurring within ephemeral sand fields included eight independent variables, indicating complex interactions between this lizard and its habitat there. This complexity may reflect the ephemeral sand fields' different perennial plant associations and the lizards' diet there, which is largely vegetarian compared to a more insectivorous diet elsewhere in the valley (Barrows 2006a). The palatable perennial shrubs that dominate this community can have delayed or extended responses to rainfall inputs and so confound temporal cause and effect relationships. Another factor is that previously high densities of fringe-toed lizards occurring on ephemeral sand fields corresponded to a period when there was a much thicker layer of aeolian sand covering the coarse sand, gravel and rocks that form a base and matrix for this community type (M. Fisher pers. comm.). Volume of the aeolian sand layer was not incorporated into our analyses, but would likely be an important explanatory variable for the abundance and distribution of fringe-toed lizards within ephemeral sand fields. The current, relatively lower volume of aeolian sand covering the ephemeral sand field community is, as its name implies, expected to be a temporary condition.

The only community type where creosote was identified as an explanatory variable for the lizards' abundance was the stabilized sand field. Creosote tended to precipitate large sand hummocks on the leeward side of the plant. These hummocks were islands of deep, loose sand in a matrix of more stabilized sand, and so were favored by the fringe-toed lizards occurring there.

### **Flat-tailed horned lizards**

Flat-tailed horned lizards are currently restricted to the active dunes and stabilized sand fields at the eastern end of the aeolian sand landscape, with their highest abundance in stabilized sand fields. Harvester ant abundance, their primary food resource (Pianka and Parker 1975; Turner and Medica 1982), was identified within that community type is a major driver of the lizards' temporal abundance. Although a one year time-lag of annual rainfall also explained some of the variance in the lizards' temporal abundance, rainfall appears out of synch (even with a one year time lag) with the more synchronized harvester ant and flat-tailed horned lizard abundances as seen in Figures 3 and 6. These patterns prompted an experimental approach to determine whether the ants' response to food resources is delayed, or whether there are other factors involved.

Our experimental exclusion of rodents from food resources available to harvester ants corroborated previous research (Davidson et al. 1984; MacKay 1991); high rodent populations compete with and suppress harvester ant population growth. This finding has implications to interpreting population fluctuations in species whose diet is restricted to or dominated by harvester ants. While the ultimate driver of resource abundance in deserts is rainfall, an abiotic input, biotic interactions such as competition can cause population fluctuations to be

asynchronous with rainfall. For flat-tailed horned lizards, along with banded geckos and shovel-nosed snakes, population dynamics that are asynchronous with rainfall patterns are not by themselves a signal that their populations are at risk of extinction. Rather a measure of the abundance of more proximate population drivers, in this case harvester ants, needs to be evaluated. Harvester ants' mean abundance over 5-6 years was 2-3 times greater in stabilized sand fields than in any of the other aeolian sand community types, providing added understanding as to why this was the preferred habitat for this species.

Flat-tailed horned lizard populations showed no negative correlations with measures of exotic plant species abundance. They are vulnerable to predation from shrikes (*Lanius ludovicianus*) and kestrels (*Falco sparverius*) (Barrows et al. 2006). While native to the arid southwest, these predators probably rarely if ever occurred on aeolian sand communities during the breeding season due to a lack of suitable nesting sites. The anthropogenic landscape surrounding the remaining natural communities has provided ample nesting sites for these birds who then hunt particularly along the reserve boundaries creating a clear edge effect (Barrows et al. 2006). Flat-tailed horned lizard populations are therefore negatively impacted by two biotic influences, indirectly through competition between their primary prey and rodents, and directly through anthropogenically enhanced predation.

### **Round-tailed ground squirrels**

Like fringe-toed lizards, round-tailed ground squirrels are found throughout the aeolian sand landscape of the Coachella Valley. Unlike the lizards, the squirrels' abundance is not negatively correlated with increases in sand compaction, and there are positive correlations with increased annual plant cover when exotic species are included. These relationships indicate a low sensitivity to typical stressors such as lost ecosystem processes and invasive annual plants. The abundance of round-tailed ground squirrels on the stabilized sand dune community could lead to a prediction that their temporal abundance there is independent of fluxes in annual rainfall as the honey mesquite are believed to be tapping deeper groundwater sources. Nevertheless, the squirrel population has a dynamic character there, as in the other sand communities, is correlated with rainfall and the abundance of annual vegetation. Spatial correlations with creosote are discussed above.

### **Coachella Valley giant sand-treader crickets**

Sand-treader crickets are a fossorial insect that digs burrows in aeolian sand deposits. The burrows typically extend to the interface between the dry surface sand and the deeper, water saturated sand layer. The crickets' temporal population dynamics correlated with annual rainfall and native annual plant cover. They were negatively associated with annual plant cover when exotic species were included, indicating a sensitivity to invasive weeds. Like fringe-toed lizards their highest abundances were measured in the active sand dune community, and there



occurrence was positively associated with creosote only in communities where deep aeolian sand can be in short supply (stabilized and ephemeral sand fields). Like the fringe-toed lizard this association is likely due to the large sand hummocks that often precipitate on the leeward side of creosote bushes.

### **Coachella Valley milkvetch**

The abundance of this endangered milkvetch was correlated with annual rainfall. With higher rainfall and windier – coarser sand conditions for seed scarification, the milkvetch are more abundant in the western, ephemeral sand community. The linear regression model coefficients for all measures of annual plant cover were negative indicating the open wind swept sand where the milkvetch are typically found. Any scale of stabilization (within plot, across community types) is associated with reduced milkvetch occurrences. In both the stabilized sand dune and sand field communities milkvetch are rare and are absent from most plots.

There is a tendency for the milkvetch in the western ephemeral sand fields to have a biennial growth pattern; plants germinating in a particularly wet year can often survive the summer and then flower and fruit profusely the following fall and winter if there are early fall rains. Milkvetch occurring on the active dunes of the eastern valley are much less likely to exhibit this biennial character due to the hotter drier summers, although in exceptionally wet years biennial plants can be found there. On the active dunes milkvetch reproduction usually is restricted to a single season. Invasive exotic annual plants are relatively uncommon on both ephemeral sand fields and active dunes and so there is usually little impact on milkvetch. In 2005, an exceptionally wet year, there were dense patches of Sahara mustard on the active dunes. Where the milkvetch and mustard were spatially coincident there was a negative impact on the flowering and seed pod production of the milkvetch (Barrows 2006b; Barrows et al. in review).

### **Burrowing owls**

Burrowing owl abundance on the Coachella Valley aeolian sand landscape was correlated with annual rain (a one year time-lag) and on the stabilized dunes where they were most abundant, to the abundance of pocket mice, a favored prey species (Barrows 1989). At the onset of our data collection in 2002, a severe drought year, burrowing owls were only detected on a single plot. The following years, with increasing rainfall, saw a steady increase in burrowing owls to a peak in 2006, one year after the high rainfall in 2005. They were negatively associated with higher annual plant cover (when exotic species were included) and shrub density. The avoidance of dense vegetation was likely a predator detection strategy as well as a preference for foraging in more open areas.

Burrowing owls were rare on the ephemeral sand field community. The strong late afternoon and night time winds that are typical for this community would make crepuscular foraging all but impossible for the owls on most evenings.

### **Final thoughts**

Our data demonstrate both the complexity inherent in those factors that drive the population dynamics of biodiversity in arid lands, as well as the potential to then use that knowledge to focus management efforts. Species such as Coachella Valley fringe-toed lizards, milkvetch and sand-treader crickets are closely tied to dynamic environments; any stressor that pushes those habitats to a more stabilized state should be addressed with appropriate management without hesitation. Fortunately the active dunes and ephemeral sand fields demonstrate considerable resistance to invasive species such as Sahara mustard and Mediterranean grasses, species that could promote stabilization. Only in extreme wet years, such as 2005, did a threshold for resistance appear to be breached on active dunes and these invasive plants began to gain dominance on active dunes. However, with a return to drier conditions in the following years, the active dunes demonstrated resilience by quickly re-establishing open, dynamic surface conditions. Under a consecutive wet year scenario, control of invasive plants on the active dunes would yield measurable benefits in terms of positive response by those native species that are sensitive to stabilization. Understanding community-level resistance and resilience to stressors, as well as the sensitivity of the species that comprise that community to those stressors, can provide managers with the information they require to make management triage decisions.

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As always such activities and accomplishments can only be made from contributions and interactions with several CCB staff and faculty affiliates. This team met regularly over the course of the project period.

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