Coachella Valley
Multiple Species Habitat Conservation Plan/
Natural Community Conservation Plan

Monitoring Program

Draft Monitoring Protocols
for the Aeolian Sand Communities and Covered Species

Prepared for the
Coachella Valley Conservation Commission
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Coachella Valley’s Multiple Species Habitat Conservation & Natural Community Conservation Plan

Monitoring Protocols for the Aeolian Sand Communities

Including:
Active Sand Dunes
Ephemeral Sand Fields
Stabilized Sand Fields
Stabilized Sand Dunes (Mesquite Hummocks)

And Covered Species:
Coachella Valley Fringe-toed Lizard (Uma inornata)
Flat-tailed Horned Lizard (Phrynosoma mcallii)
Giant Sand-treader Cricket (Macrobaenetes valgum)
Coachella Valley Milkvetch (Astragalus lentiginosus var couchellae)
Round-tailed Ground Squirrel (Spermophilus tereticaudus)
Coachella Valley Jerusalem Cricket (Stenopelmatus cauhilaensis)

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INTRODUCTION
There are two aspects of the monitoring framework presented here that are unique. First, this framework is explicitly science-based. In addition to providing abundance and occurrence data, our approach focuses on hypothesis driven questions that assess the risk stressors pose to meeting conservation objectives (Barrows et al. 2005). The effectiveness of this framework requires an experimental design that examines the performance of populations with or without a particular stressor, and long-term data sets that establish the temporal influence of stressors along with the resilience of populations when a stressor’s impact is reduced. This approach leads to the identification of cause and effect relationships for population dynamics, allowing the separation of typical changes in populations from those beginning a trajectory toward local extinction (Barrows and Allen 2007a).

Second, this framework embraces the multiple species – community basis for the conservation design and goals of the Coachella Valley MSHCP-NCCP. This approach creates efficiency, but more importantly develops a view of the impacts of environmental stressors and management options across the breadth of biodiversity and multiple scales at which stressors can have impacts within designated conservation areas (Barrows et al. 2005).

AEOLIAN SAND COMMUNITIES
Community Descriptions
The naturally occurring aeolian sand communities of the Coachella Valley floor include active dunes, stabilized dunes (also referred to as mesquite hummocks), ephemeral sand fields, and stabilized sand fields (also referred to as active sand fields). These communities were initially defined based on distinct geomorphologies (Table 1), but also have distinct species associations and abundances (Barrows and Allen 2007).

Those communities that have undergone the greatest amount of loss due to human development include the active sand dunes and stabilized sand fields which would have occupied much of the central portion of the valley floor. As much as 83%-95% of these communities have been lost (Barrows et al 2008). Another community which has lost much of its original extent is the stabilized dune, or mesquite hummock community type. Most of that loss occurred in the eastern portions of the valley in what are now the cities of La Quinta, Indio and Coachella. Ephemeral sand fields have been least impacted by human development, likely due to the high intensity wind and sand movement characterizing this community, making it less hospitable to human uses. The general locations where these communities still occur are shown in Figure 1.
Table 1. Geomorphic characteristics and species associations of the four community divisions of the Coachella Valley aeolian sand landscape. Species in bold type are those whose populations can reach the highest abundance when habitat conditions are appropriate.

<table>
<thead>
<tr>
<th>Geomorphic and Habitat Characteristics</th>
<th>Active Dunes</th>
<th>Stabilized Sand Fields</th>
<th>Ephemeral Sand Fields</th>
<th>Stabilized Dunes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aeolian sand depth</td>
<td>&gt; 3 m</td>
<td>0-2 m</td>
<td>0-2 m</td>
<td>&gt; 3 m</td>
</tr>
<tr>
<td>Base substrate</td>
<td>aeolian sand</td>
<td>silt, cemented sands</td>
<td>gravel, rocks</td>
<td>aeolian sand</td>
</tr>
<tr>
<td>Shrub Density</td>
<td>sparse</td>
<td>moderate</td>
<td>moderate</td>
<td>dense</td>
</tr>
<tr>
<td>Wind velocity</td>
<td>moderate</td>
<td>moderate</td>
<td>high</td>
<td>moderate</td>
</tr>
<tr>
<td>Sand movement</td>
<td>high</td>
<td>moderate</td>
<td>very high</td>
<td>low</td>
</tr>
<tr>
<td>Precipitation gradient</td>
<td>extreme aridity</td>
<td>extreme aridity</td>
<td>moderate to relatively mesic</td>
<td>moderate</td>
</tr>
</tbody>
</table>

Covered species primarily associated with this community
- fringe-toed lizard
- sand-treader cricket
- milkvetch
- round-tailed ground squirrel
- flat-tailed horned lizard
- fringe-toed lizard
- sand-treader cricket
- milkvetch
- round-tailed ground squirrel

Figure 1. General location of the four naturally occurring aeolian sand communities of the Coachella Valley. Small sand deposits in the Indio Hills are not shown at this scale.
Conceptual models can provide valuable tools in clarifying hypotheses as to how natural systems are formed, function, and how stressors may impact those systems (Barrows et al. 2005). A conceptual model for the development of the Coachella Valley aeolian sand communities is depicted in Figure 2. This model is unique to this valley due to the unidirectional (northwest) nature of winds strong enough to catalyze aeolian sand transport and the strong west to east gradient in precipitation. Identified stressors include barriers limiting fluvial inputs of sand (up stream damming and/or channelization), barriers to aeolian sand transport (wind breaks), and stabilization due to the spread of invasive vegetation.

**Figure 2.** Conceptual models of the processes and patterns of the occurrence of the four aeolian sand communities of the Coachella Valley. Additionally, stressors and the impacts they could have on those communities are shown as well. Numbers correspond to research questions and monitoring objectives described below.

The model indicates the likely loss of both ephemeral sand fields and active dunes if either sand inputs or wind velocity are blocked. The more stabilized habitats will likely persist longer, but they too will degrade over time. The models also indicate that the honey mesquite, *Prosopis glandulosa*, which is usually associated with stabilized dunes, could be negatively impacted with
changes in the availability of permanent water at their root zone. Finally, active dunes may be the most sensitive to the effects of invasive plant species. On ephemeral sand fields, the intense wind and sand movement appears to limit the establishment of invasive species. Active dunes are also somewhat resilient to invasive species, though less so than ephemeral sand fields, however the potential for stabilization of active dunes appears to be much greater, with negative impacts to active dune associated endemic species (Barrows et al. in press).

The interaction of potential stressors with covered species’ populations is shown conceptually in Figure 3. This and Figure 2 capture hypotheses as to interactions of stressors, as well as identify research questions that test the utility of those hypotheses and the level of risk stressors pose to the sustainability of the community composition and the populations of covered species therein.

**Figure 3.** Covered species focused conceptual model indicating likely influences to population dynamics. Red dashed pathways indicate stressors, black solid lines indicate drivers. Colored boxes indicate anthropogenic sources. Numbers correspond to research questions and monitoring objectives described below.

*Initial Research Questions (to be addressed with monitoring data)*

Numbers in bold correspond to color-coded portions of the conceptual models.
Monitoring Protocols for the Aeolian Sand Communities

- (1) What are the rates of sand transport for each of the aeolian communities? Are within community sand transport rates changing in a consistent trajectory, or are the rates oscillating around a mean?
- (1) Are sand depths and extent (volume) changing in a consistent trajectory, or are the rates oscillating around a mean?
- (1) Is the aerial extent of the aeolian sand communities changing in a consistent trajectory?
- (1) How does landscape pattern (patchiness, juxtaposition of community types) influence population abundance and species richness?
- (2) Is the apparent senescence of mesquite on stabilized dunes the result of reduced upwelling along earthquake fault zones, over-drafting of aquifers, climate patterns, disease, or old age?
- (2) How does the loss of honey mesquite on stabilized dunes impact species composition and abundance there?
- (3) Are species negatively impacted by “edge effects” – altered boundary processes – as a result of habitat fragmentation? (vehicle mortality – predation pressure from suburban-augmented predators – exotic/invasive species interactions)
- (3) Are species loosing genetic fitness due to fragmentation? (population isolation – increase genetic homogeneity – reduced reproductive responses and/or survivorship to positive resource inputs)
- (4) Are species responding negatively to invasive species occurrences? (reduced native annual plant species)
- (4) Are native arthropods responding negatively to invasive species? (reduced abundance and/or species richness)
- (4) Are food webs becoming less complex and potentially less robust and resilient to changing conditions?
- (4) Are invasive species resulting in increased sand compaction and stabilization?
- (4) Are invasive species impacts creating trajectories in habitat conditions with likely long-term population declines, or are the impacts ephemeral, with no long-term consequences?
- (5) How do populations respond (relative numbers, reproductive response, survivorship, mortality) to changes in resources (rain, annual plants, detritus, arthropods) across a gradient of conditions?
- (5) Which species are most sensitive to the effects of climate change?
- Are management actions resulting in desired outcomes?

Surveys will be designed so that data collected can contribute to these research questions. The questions also are not designed to provide threshold values, beyond which management actions are indicated. Rather they are designed to assess the risks that given stressors pose to the goal of the MSHCP/NCCP of protecting sustainable populations and communities. If a high risk stressor is having a negative impact and if that impact may have long-term consequences, then remedial management should be considered and if practical employed as soon as possible.
Monitoring Objectives

Sand Transport – Metrics to be collected:
- Aerial extent of each community type
- Mean and plot-specific sand transport rates within each community type
- Mean and plot specific change in aeolian sand depth within each community type
- Percent cover of aeolian sand versus gravel/rocks or silt/cemented sand in the ephemeral and stabilized sand field communities
- Mean and plot specific sand compaction within each community type

Mesquite on Stabilized Dunes – Metrics to be collected:
- Quantify health of mesquite on stabilized dunes (e.g. proportion of dead branches).
- Groundwater depths compared with mesquite health.
- Water isotope signatures for water within the plants, at deep groundwater levels and at perched, shallow groundwater sources.
- Well depth records for locations near degraded versus healthy mesquite.
- Species associations with healthy versus degraded/senescent mesquite on stable dunes

Shallow groundwater depths will be measured with ground penetrating radar employed along the gradient of mesquite health conditions. Water samples for isotope analyses will be collected by 1) distilling water directly from the plant tissue, 2) digging down to shallow water sources, and 3) collecting water from nearby well sources. Well depth records will be requested from the Coachella Valley Water District.

Urbanization and Fragmentation – Metrics to be collected:
- Species distributions with respect to conservation area edges
- Occurrence of predators (feral and natural)
- Occurrence of off-road vehicle trespass
- Reproductive recruitment rates for selected species
- Periodic analyses of genetic heterogeneity for selected covered species

Invasive Species – Metrics to be collected:
- Measure the occurrence (density and percentage cover) of invasive exotic annual plants as well as the same metrics for native annual plants.
- Measure the patterns of occurrence of invasive and native species at the landscape level.
- Measure the relative abundance of native versus exotic species
- Determine variables (e.g. sand quality and quantity; rainfall) that favor invasive species and natives.
- Determine the influence of atmospheric pollutants (nitrogen, phosphorous) on the invasive behavior and success of exotic and native plant species.
- Measure the degree to which invasive species affect sand stability and aeolian transport as compared to the effect of native species.
• Determine the effectiveness of control efforts.

The ultimate objective for these data will be for constructing a management model for if, when and how to implement control measures for invasive annual species. Methods for measuring annual species densities, percentage cover, and sand compaction and aeolian sand transport are described below. Satellite imagery will be employed to measure landscape-level patterns of occurrence. Sensors will be deployed to measure carbon, nitrogen and phosphorus levels in the near ground atmosphere.

Community Trajectories/Biotic Sustainability/Effect of Climate Change – Metrics to be collected:

• Occurrence and changes in relative abundance of species with respect to resources including annual rainfall patterns, annual plants, perennial plants, arthropods, exotic species and sand characteristics
• Occurrence and changes in relative abundance of species with respect to the East-West temperature and precipitation gradient across the Coachella Valley

Sand Transport Monitoring Methodology

Using high-resolution satellite imagery and ground-truthing, the aerial extent of each of the aeolian community types will be mapped into GIS layers at least every three years.

Sand traps (Lancaster and Baas 1998) will be distributed across each of the aeolian community types to measure sand transport rates. At least one sand trap will be placed at each monitoring plot (described below). On each plot a metal rod will be permanently placed; sand depth will be measured from the top of the rod (constant height) to the sand surface. In conjunction with annual plant monitoring (see below) the relative percent cover of aeolian sand, cemented sand/silt, and gravel/rocks will be visually estimated in 12 1m squares within each monitoring plot annually.

Biotic Monitoring Methodology

Since 2002 monitoring protocols have been under development for species occurring within the aeolian sand communities of the Coachella Valley. The criteria described briefly above are evaluated here with respect to the monitoring protocols for two of the aeolian sand community reptiles, the Coachella Valley fringe-toed lizard, *Uma inornata*, the flat-tailed horned lizard, *Phrynosoma mcallii*, sand treader crickets, *Macrobaenetes valgum*, round-tailed ground squirrel, *Spermophilus tereticaudus*, and Coachella Valley milkvetch, *Astragalus lentiginosus var coachellae*. The approach adopted here includes measures of food resources, cover, sand conditions, species associations (including small mammals and terrestrial birds) and food web linkages (potential predator and prey species) layered onto each plot, and so is community based by design. A
separate survey methodology has been developed for the Coachella Valley Jerusalem cricket, *Stenopelmatus cauhilaensis*, which is described following that for the other five covered aeolian sand obligate species.

The basic design of the recommended surveys includes a set of randomly placed study plots, each 10 m x 100 m (0.1 ha) (Fig 4). The distribution of current plots is shown in Figures 5 and 6. Each plot is marked with a short wooden stake at the beginning, middle, and end so that a biologist conducting surveys can easily determine their position within each plot. The stakes are shorter than the surrounding vegetation so that they will not become perches for predatory birds and have a biased impact on the species being surveyed. Between January and July data are collected each year for sand-treader crickets (January-February) annual and perennial vegetation, including Coachella Valley milkvetch (February to March), arthropods (April), sand compaction (May), and vertebrates (May through July, and for a sub-set of those plots again in September and October).

**100 m**

![Schematic of basic plot design](image)

**10 m**

**Figure 4.** Schematic of basic plot design (not to scale). The twelve small squares represent locations for 1 m² frame placement for annual vegetation density and cover estimates. The solid circles represent the approximate location of three arthropod pitfall traps (always removed after sampling occurs).

**Accuracy and Survey Methods**

**Reptiles** - The fine aeolian sand of the Coachella Valley’s dune fields provide an opportunity unique to sand dunes (and perhaps snow fields) to quantify the occurrence and abundance of terrestrial species occurring within plots by enumerating numbers of individuals of each species by tracks they left as they moved across or within each plot. An exception to this assumption is an arboreal lizard species, *Urosaurus graciosus*. Long-tailed brush lizards leave distinctive tracks in the sand when moving between shrubs, but the majority of their time is spent in shrubs.
Figure 5. Distribution of the 150 monitoring plots (green dots) superimposed on the modeled distribution of current potential habitat for the Coachella Valley fringe-toed lizard. Potential habitat (HSI ≥ 0.333) was modeled using a Mahalanobis D² analysis (Barrows et al. 2008). Red dots are located on small isolated sand patches where annual presence-absence surveys occur.

Figure 6. Distribution of the 150 monitoring plots (green dots) superimposed on the modeled distribution of current potential habitat for the flat-tailed horned lizard. Potential habitat (HSI ≥ 0.333) was modeled using a Mahalanobis D² analysis (Barrows et al. 2008). Red dots are located on small isolated sand patches where annual presence-absence surveys occur.
where they are not detectable using tracking. Their relative abundances using the proposed protocol are likely underestimates of their true occurrences. Another potential exception is the nocturnal banded gecko, Coleonyx variegatus. These geckos leave distinctive tracks in fine aeolian sands, but their slow moving gait and light foot-falls may not leave impressions in the coarser sands that characterize the ephemeral sand fields, where they have not been detected. The geckos’ delicate skin probably doesn’t tolerate the high velocity winds and sand movement occurring almost nightly on the ephemeral sand field community, and so if present at all they likely occur at low densities there. Final exceptions are several snake species known to occur within the aeolian sand communities but whose tracks are not sufficiently distinctive to allow confident species identifications. These include Arizona elegans, Phyllorhynchus decurtatus, and Salvadora grahamiae. Excepting those species, each of the reptile species occurring on the aeolian sands can be identified to species and age class by their diagnostic tracks, and so variability in detection plaguing many other survey methods, caused by differences in activity times, cryptic coloration, or stealthy behavior, are largely nullified. We have found this survey method to be robust in the sense that we are able to detect species occurrences even when they are rare in the area being surveyed. Extensive training is required before biologists conducting tracking surveys can be proficient at species identification and enumeration, training levels similar to what would be required for conducting avian surveys where both sightings and vocalizations are used for identification.

As our recommended plot size (0.1 ha) is less than the home range for many of the species we survey, our tracking data were not equivalent to density data, although for at least Phrynosoma mcallii when we compared tracking data to mark and recapture derived densities there was a close proportional relationship \( R^2 = 0.9599 \) and \( P = 0.0006; \) Barrows and Allen, in press). Our tracking data are most accurately characterized as the number individuals of each species that occurred on each plot each survey day, averaged over six independent surveys per season; for reporting purposes we refer to this statistic as the mean relative abundance of each species / 0.01 ha (the plot area). In 2002 we conducted a power analysis and determined that 6 repetitions per plot were sufficient to detect between plot and year differences when the mean plot difference was ≥ 1.7 lizards at \( \alpha = 0.05, \beta = 0.80 \) for a two sample z-test. Because they are essentially ratios and so do not require precise population estimates, a mean relative abundance of the lizards can readily be incorporated to measures of reproductive success (mean relative abundance of hatchlings surveyed in the fall / mean relative abundance of adults surveyed in the late spring, or mean relative abundance of juveniles surveyed in the late spring / mean relative abundance of adults surveyed in the late spring), and population growth (natural log of the product of the mean relative abundance of all lizards surveyed in the late spring in year 2 / mean relative abundance of all lizards surveyed in the late spring in year 1). Data for each plot is considered
independent, although in rare instances an individual could move from one plot to another and be recorded as occurring on both plots (between plot distance was ≥ 50 m).

Reptile surveys occur between May and July. Due to the timing of our surveys reproductive responses had an apparent one year lag to temporally variable environmental conditions. The reproductive responses (hatchling lizards and snakes) emerged from late summer through early winter, depending on the number and timing of clutches the adult reptiles produced. There is no single period in the fall when the total hatchling cohorts are present and active on the sand surface. The total reproductive effort is thus measured during the following year’s survey period. Nevertheless a selected number of plots (62) have been surveyed in the fall (September-October). These plots provide a snapshot of the lizards’ reproductive effort and provide a basis for estimates of reproductive success. All surveys would begin each morning after the sand surface temperature had risen sufficiently (35°C) so that diurnal reptiles were active. Consistent time of day and temperature reduces those variables’ contributions to between survey variability. Surveys continue until late morning when the high angle of the sun reduces the observer’s ability to distinguish and identify the tracks across the sand, and coincides with the cessation of activity for the diurnal reptiles due to high surface temperatures. One observer can complete a survey on a given plot in 10-15 minutes, recording all fresh tracks observed within the plot; depending on the travel time between plots that observer could survey 10-15 plots/day. We used track characteristics to identify individuals as well in order to quantify species’ abundance. Track size, unique features, and following tracks off of the plots helped insure that each counted track represented a unique individual for each survey. Because late afternoon and evening breezes usually “wipe the sand clean” the next day’s accumulation of tracks should not be confused with those from the previous day.

*Sand-treader Crickets* – Sand treader crickets are nocturnal, moisture sensitive insects. The crickets’ first instars emerge coincident with winter rains and appear to be at maximum densities in January-February. After apparently incurring incremental mortality (inferred by their lower densities), the crickets reach adult size by April and by June usually disappear altogether.

Between 2003 and 2008 we compared two methods, pitfall trapping and detections via the cricket’s characteristic “Δ” or delta-shaped burrow excavations. The species-specific burrow excavation shape was confirmed by excavating over 100 burrows. The burrows enter the sand at a shallow angle and generally extend 20-50 cm until the cricket reaches water-saturated sand, usually 5-20 cm below the sand surface during the winter months. Not all are occupied; the crickets appear to dig a new burrow each evening, leaving previous burrows vacant and visible until winds remove the excavations. Excavating the burrows to locate live crickets results in
relatively high cricket mortality; once exposed to sunlight, daytime temperatures and low humidity the crickets expire quickly. The same is true for pitfall trapping. For burrow surveys we count all fresh burrows within the entire 10 m x 100 m plot (one survey/plot) in January-February, when their abundance is at its peak. Using this method, for determining fresh versus older burrows, the surveyor requires training and experience. Freshly excavated burrow sand is usually darker (still has residual moisture) than older burrow sand. Pitfall trapping occurs when total arthropod species richness and abundance is assessed in April.

Burrow counts were superior to pitfalls in detecting sand-treader crickets. As an example in 2008, a typical year from the perspective of sand-treader crickets, on all plots 724 crickets were detected using burrow counts, whereas 19 were trapped in pitfalls; burrow counts recorded the crickets on 75% of all plots surveyed whereas pitfalls recorded them on just 8%.

Coachella Valley Milkvetch – Coachella Valley milkvetch are annual or sometimes biennial plants. The biennial habit is generally restricted to the western, cooler-wetter portion of the Coachella Valley and to years when high levels of sand moisture stay close to the surface through the summer. These plants usually occur at low densities so we have employed a total count / 10 m x 100 m plot survey protocol. The counts occur coincident to the general vegetation surveys in February-March, but are re-surveyed coincident with the arthropod surveys in April and sand compaction data collection in May to ensure all plants are counted. Data are reported as densities (plants/m²).

Round-tailed ground squirrels – There are two detection methods that work within the proposed monitoring design, tracking and recording the squirrels warning calls. In 2008 when the squirrel population was relatively low, out of 171 total detections, 91% were by tracking and 20% were by vocalizations (at many sites squirrels were both heard and detected by tracks). In 2006 when the squirrels were at a population high, again 91% of over 700 detections were by tracks, and 33% were by their calls. Using just calls alone (locations where no tracks were seen) only 9% of the squirrels were detected in both years. Nevertheless we use both methods in tandem to achieve the maximum detection rate.

Sampling habitat heterogeneity

Originally 150 plots were established in order to assess the level of habitat heterogeneity that occurs across the aeolian sand communities of the Coachella Valley (Figs 4 and 5). Each plot was surveyed for at least three years within the 2002 to 2008; however 77 were surveyed in each year from 2003 to 2008. Many of those were deemed either redundant or were designed to answer a specific research questions regarding the impact of suburban edges of the population trajectories of the species that comprise the sand communities (Barrows et al., 2006). From that
set of 150, the core of 96 study plots has been identified to assess the temporal and spatial variability within aeolian sand habitats across the Coachella Valley. Study sites were located in a stratified random manner whenever possible, stratified by four community types as defined by Barrows and Allen (2007b) (Table 1). Core plots constituted only those occurring ≥ 100 m from suburban-natural area edges were included here to avoid previously described edge effects (Barrows et al. 2006). The stratification included: 24 plots in “active sand dunes”; 17 plots in “stable dunes”; 31 plots in “stabilized sand fields” (forming the habitat matrix surrounding active dune patches in the east valley); and 24 plots in “ephemeral sand fields”. Ephemeral sand fields are located in the western, windiest portion of the valley where wind energy exceeded sand supply (Griffiths et al., 2004) and so the aeolian sands have a much shorter residence interval than the other community types considered here. The dominance of honey mesquite, *Prosopis glandulosa*, on the stable dunes created a logistical problem as dense mesquite copses were impenetrable. Plots there were thus confined to open areas and so were non-randomly placed. Data from these plots characterized those open areas but not the community as a whole. Using GIS software (ArcView 3.2, ESRI) we calculated the extent of the open areas (13%) versus the mesquite copses and other dense vegetation (87%) and then adjusted the relative abundance of those reptiles restricted to the open areas (i.e. *Uma inornata*, *Dipsosaurus dorsalis*, *Callisaurus draconoides*, *Phrynosoma platyrhinos*) downward proportionately. Examples of differential abundances when stratified by community type for the target species are shown in Figs 7-11.

Limit observer impacts

Our method, focused on enumerating individuals by the tracks they left and sightings of active individuals requires no handling of any lizard, cricket or squirrel nor chasing that could constitute harassment (however brief). Therefore this protocol limits observer impacts to the extent possible.

Putting survey data in an ecological context

All vertebrates are surveyed simultaneously using their tracks as the main metric of abundance and providing a community-level measure of the species occurring on that habitat. In addition resources available to those species were assessed.

*Habitat Measures.* - All perennial shrubs are counted by species within the 0.1 ha plots. Annual plants were counted and cover estimated in a 1 m² frame placed at 12 locations along the midline of each plot. Four samples were taken on alternating sides of the center line at each end point, and two samples were taken on each side of the center point. In each frame all individual plants were counted by species to determine species densities, and for each species we made a visual estimate of its percent cover within each frame. These values were then averaged for each
Figure 7. Patterns of abundance for the Coachella Valley fringe-toed lizard across the aeolian sand community types. Rainfall is off-set by one year to match the lizards’ demographic responses.

Figure 8. Patterns of abundance for the flat-tailed horned lizard across the aeolian sand community types. Rainfall is off-set by one year to match the lizards’ demographic responses.
Figure 9. Patterns of abundance for the round-tailed ground squirrel across the aeolian sand community types.

Figure 10. Patterns of abundance for the Coachella Valley milkvetch across the aeolian sand community types.
Figure 11. Patterns of abundance for the Coachella Valley giant sand treader cricket across the aeolian sand community types.

species for the 12 frames of each plot. Annual plant data presented in our analyses were all measures of percent cover.

Sand compaction has been described as a key habitat variable for *Uma inornata* (Barrows, 1997, 2006). Sand compaction is measured at 25 points, approximately 4 m apart, along the plot midline, each year, using a hand-held pocket penetrometer with an adapter foot for loose soils (Ben Meadows Company, Janesville, WI, USA). Data are recorded as the force (kg / cm²) required for the penetrometer “foot” to go beneath the sand surface.

**Arthropod Sampling** – We sample arthropods using dry, un-baited pitfall traps. Previous sampling had shown April to be a peak activity period for the harvester ants and arthropod abundance and species richness, thus pitfall surveys are confined to this month alone. The pitfall traps measure 11 cm wide at the mouth, 14 cm deep, 1.0 L in volume (Fabri-Kal Corp., model no. PK32T 21), and include a tight fitting funnel that inhibited the ability of the ants to escape once they had fallen into the trap. A board measuring 20 cm x 20 cm x 0.5 cm is placed over the pitfall trap and elevated 1-2 cm with three wooden blocks, providing shade and cover for the arthropods captured by the trap. We place three pitfall traps within each plot, one at each end and the third at the plot middle. We collect the contents within 24 hrs of opening the
traps. Arthropod data are summarized as the mean number counted per species per pitfall per plot.

Providing information resource managers can use

To date focused hypothesis driven surveys have yielded insights as to the impacts of suburban edges to the natural habitats and possible management responses (Barrows et al. 2006). Additional data collected from these plots have provided key information as to the impacts of invasive plant species such as Russian thistle, *Salsola tragus*, (Barrows 1997) and Sahara mustard, *Brassica tournefortii*, (Barrows et al. 2009), enabling managers to use informed triage in setting priorities toward controlling these species.

Alternative Methodologies

Mark-recapture techniques have been used for both the fringe-toed lizard and flat-tailed horned lizard studies in the Coachella Valley and have provided important insights into the biology of these species. This approach can yield a close approximation of population size on study plots, as well as territory size, reproductive activity at the scale of individuals, longevity (at least residence times on plots), and changes in body size and condition with respect to age and season. For research and/or management questions in which these fine-scale metrics provide critical insights, a mark-recapture approach is superior to the tracking method described above. Fisher and Muth (1989) have developed a permanent marking technique and have found it to have no measurable impact on the lizards when employed by experienced biologists. For shorter term studies ink can suffice to mark the lizards.

When questions are focused at larger scales (population, community, landscape) the labor intensive nature of a mark and recapture approach can limit the number of plots that can be surveyed simultaneously across environmental gradients, limiting temporal comparisons between plots, statistical robustness, and the ability capture the heterogeneity of a dune landscape. The proposed “tracking” protocol is superior for defining relationships between the lizards (their patterns of occupancy, population trajectories and dynamics, reproductive success, population growth) and environmental gradients (such as habitat characteristics, edge effects, effects of invasive species at different densities, patch size, sand characteristics, rainfall patterns) across larger scales.

Coachella Valley Jerusalem Crickets

The Coachella Valley Jerusalem Cricket (CVJC), *Stenopelmatus cahuilaensis*, has a narrow distribution, restricted to southern California’s western Coachella Valley. According to Weissman (pers. comm.), CVJC require high humidity and cooler temperatures than occur in the central Coachella Valley. He suggested that other than soil texture, the distribution of the
species is most likely based on both temperature and moisture gradients. This apparent sensitivity to both heat and desiccation indicates CVJC may be either relicts from a wetter-cooler climatic regime or may only opportunistically enter the desert during wetter periods. From the eastern Coachella Valley up the San Gorgonio grade there are distinct east to west gradients with a steady drop in temperature and increase in precipitation as the elevation increases from Sea Level to 790 m. This temperature-precipitation gradient may be a key to understanding the current and future CVJC distribution in the face of projected climate change scenarios. The known historic and current distribution of his species is shown in Figure 12.

\[\text{Figure 12.} \text{ Coachella Valley Jerusalem cricket historic and current distributions, estimated by a minimum convex polygon of known locations. Red polygon approximates the historic distribution; the green polygon approximates its current distribution. Orange circles indicate cricket locations (historic and current).}\]

\textbf{Accuracy and Survey Methods}

Due to the cricket’s general rarity, nocturnal behavior and no distinctive or readily observable tracks (as they often occur in more stabilized, coarser aeolian deposits), the same survey approach described for the species above will not work for this species. Previous survey efforts have shown lifting and searching under debris to be an effective detection method. However, debris are not randomly or regularly distributed across the desert. In order to sample in those areas without extensive debris we have developed a 60 cm x 60 cm cover board – termed a detection tile – design that provides an adequate substitute for debris. The tiles are meant to mimic debris, however we found that only by insulating the tiles with sand piled on top and when “irrigating” the area below the tile with water to keep the sand damp, did the detection
efficiency approach that of the debris searches. Pitfall traps were time consuming to establish and maintain and had by far the worst detection success. They also had the negative aspect of increasing the mortality rate of any creature that became trapped.

In a preliminary study to determine the best detection methodology we conducted a total of 2158 searches under random debris, 1389 searches under detection tiles, and 240 searches in pitfall traps. Overall detections were very low, 1.9% of the debris yielded a cricket, 1.0 % of the detection tiles, and 0.4 % of the pitfalls. When both the weather/soil moisture was suitable for above ground cricket activity and the searches were within the crickets’ occupied range (i.e. at least one cricket was found at the site and day being surveyed), the success rate under debris rose to 16.0% and under detection tiles rose to 2.9%. Only one cricket was ever detected using pitfalls so a similar comparison for that method was not possible. Not only were there more crickets detected with this method but the cost other than the labor for conducting the search was essentially zero.

Detections appeared to vary with soil moisture, so when the sand below the debris dried out days or weeks after a rain event, detections approached zero. For example, twenty-three days after the last heavy rain, over 50 pieces of debris were upended along a sandy, little-used dirt road resulting in no CVJC captures. The sand beneath all lifted pieces was quite dry. Two weeks later, following a heavy rain on the previous day, approximately 20 pieces of debris were overturned along the same road, resulting in the discovery of four CVJCs. The ground surface beneath all debris articles was quite moist. All of the objects under which CVJCs were found had previously been upended on the previous survey. Surveys should occur in January and February, when soil moisture is more likely to be high.

Sampling habitat heterogeneity
Debris searches are opportunistic, and occur wherever there is accumulated solid debris (even small items, even cow dung can yield crickets). Detection tiles are envisioned to fill in surveying gaps to better define the distribution and habitat characteristics of this species. As such they are not randomly placed. Where occurrence data from a site/habitat type is desired, a cluster of 4-6 tiles is placed. The resulting data are limited to presence/absence and a defined distribution. This species may be particularly sensitive to drought-related climate change effects and so documentation of changes in its distribution is critical.

Limit observer impacts
Surveying under debris and/or detection tiles has no known effect on survivorship as long as the debris is carefully replaced. In previous surveys individual crickets were repeatedly observed under the same debris. Other potential methods, including pitfalls (very low detection
rates) and excavating root areas (presumed even lower detection rates) increase the rate of cricket mortality.

**Putting survey data in an ecological context**

*Habitat Measures* – GPS location, a sand sample, and vegetation type data are collected for each survey site.

**DATA ANALYSES**

Using a stratified random array of permanent plots, sufficient in number to allow for statistical tests of hypotheses, facilitates changing the scale of analyses to determine how a species’ sensitivity to environmental change varies with that scale. There is no *a priori* ability to know what scale is best to detect sensitivity to change, at a plot, a dune (patch), a conservation unit (a reserve), a natural community, or across the entire aeolian sand landscape. A finer scale approach may aide in the early detection of negative impacts of environmental change; once such effects are apparent at a larger, community or landscape scale, management options to control those effects will likely be more difficult and costly. A monitoring framework should provide flexibility to analyze data at all of these scales.

Detecting change often requires a time series analysis; using permanent plots to detect temporal change could make larger scale analyses susceptible to spatial autocorrelation where statistically significant levels of change may be confounded by plot-specific idiosyncrasies. Population levels within plots could be unrelated to the variables analyzed within the plot but be related to resources beyond the plot boundary. This issue can be addressed in two ways. First, test whether spatial autocorrelation is an issue by including spatial coordinates as covariates in any model. As an example, by using a logistic regression and including the permanent plot locations as a class variable you can determine if the plot locations explain a significant amount of the variance in the data; if so then spatial autocorrelation may be a problem. If spatial autocorrelation problem is a concern, by accepting a greater chance of committing a Type II error, for instance by using a threshold of $p \leq 0.001$ rather than the more traditional $p \leq 0.05$, problems associated with spatial autocorrelation can be avoided (Andrea Atkinson, pers. comm.).

Analysis tools can vary with the research questions being addressed and the background of the person conducting the analysis. We argue that basic question is not a relatively simplistic $N_{t1} \neq N_{t2}$ versus $N_{t1} = N_{t2}$ when determining whether there has been a change over time of a population, but rather what variable or variable set explains the variance observed in $N$ over time and space. Populations change; the critical questions are what variables explain that change and especially in the case of a negative population shift, is there a negative trajectory
that could lead to extinction. The question could be expressed as a linear regression \( Y = \alpha + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 \ldots \) where \( Y \) is the dependent variable (such as the variance in population size), \( \alpha \) is the constant and \( \beta_i \) and \( X_i \) are the coefficient and independent, explanatory variables.

The use of continuous variables in a model often allows for greater levels of discrimination between a hypothesis and null hypothesis. With continuous data hypotheses can evaluated with parametric tests as long as all variables meet the assumption of homogeneity of variances. Environmental data are notoriously asymmetric in their distributions but can often be adjusted to meet this assumption by using a square root \((x+1)\) transformation. When dependent data are categorical (i.e. presence or absence) and/or when the assumptions inherent in parametric tests cannot be met, then there are non-parametric test options. A logistic regression is such a non-parametric approach. Categorical dependent variables can be presence or absence, or can include subjective divisions of abundance (absent – low – medium – high). While the results lack the same power of hypothesis discrimination associated with continuous data/parametric tests, they still can provide valuable insights as to the independent variables’ ability to explain the variance in the occurrence of the species being analyzed.

Regardless of the modeling tools being used to identify what variables explain the variance in the dependent variables, (linear regression, discriminant analysis, logistic regression, program MARK, niche modeling, etc), it is important to keep the number of independent variables in the model at or less than a 1-10 ratio with the total number of observations. Here observations = separate plots where data were collected, and so for every 10 plots just one independent variable should be added to the model. Violating this axiom, creating models where the number of independent variables exceeds this 1-10 ratio, runs the risk of over-fitting the model, in other words creating a model that explains only the patterns of abundance measured on the plots but with little ability to extrapolate to the regions outside of the plot boundaries.

The analysis objectives should be to 1) identify whether the populations of protected species are on a trajectory that could lead to extinction, and 2) what factors (independent variables) are driving that population change. Rather than a two-step process we argue that this should be accomplished with a single modeling approach, where the model identifies which independent variables explain the variance in the population of a target species. The relative importance of each independent variable included in the model should be partitioned so its relative importance can be determined. This approach provides a rich learning framework, providing biologists and managers with objective insights as to resource requirements and stressors for the species under their stewardship. With the stratified sampling approach, along with plots set along the temperature and precipitation gradients of the Coachella Valley, we can measure how species’ requirements and stressors change by community and by their position along those
gradients. The fine scale nature of surveying permanent plots allows us to identify the early onset of the effect of stressors and where appropriate have managers address those impacts.

**LITERATURE CITED**


APPENDIX 1 - VERTEBRATES DATA SHEET

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**REPTILES** - Tracks = (A=adults or H=hatchlings when applicable) Sightings = S (incl. perpendicular distance from plot center line)

- CV Fringe-toed Lizard: Tracks, Sighting
- Flat-tailed Horned Lizard: Tracks, Sighting
- Desert Horned Lizard: Tracks, Sighting
- Desert Iguana: Tracks, Sighting
- Zebra-tailed Lizard: Tracks, Sighting
- Western Whiptail: Tracks, Sighting
- Side-blotched Lizard: Tracks, Sighting
- Leopard Lizard: Tracks, Sighting
- Long-tailed Brush Lizard: Tracks, Sighting
- Banded Gecko: Tracks, Sighting
- Sidewinder: Tracks, Sighting
- Shovel-nosed Snake: Tracks, Sighting
- Coachwhip: Tracks, Sighting
- Other (specify): Tracks, Sighting

**MAMMALS** - Tracks = T, Vocals = V, Sightings = S

- RT Ground Squirrel: T/V/S
- Desert K-rat (LG): T/S
- Merriam's K-rat (SM): T/S
- Palm Springs P-mouse (SM): T/S
- Desert Pocket Mouse (LG): T/S
- Jackrabbit: T/S
- Cottontail: T/S
- Kit Fox: T/S
- Coyote/Dog: T/S
- Woodrat: T/S
- Other mammals (specify): T/S

**INSECTS** - (burrow)

- Sand breeder Cricket:  

**BIRDS** - Tracks = T, Vocals = V, Sightings = S (incl. distance)

- Kestrel: T/V/S
- Mourning Dove: T/V/S
- Roadrunner: T/V/S
- Raven: T/V/S
- Verdin: T/V/S
- Shrike: T/V/S
- Mockingbird: T/V/S
- LeConte's Thrasher: T/V/S
- House Finch: T/V/S
- Burrowing Owl: T/V/S
- Western Meadowlark: T/V/S
- Horned Lark: T/V/S
- Other birds (specify): T/V/S
## APPENDIX 2 - PERENNIAL PLANT DATASHEET

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<td>Sisymbrium sp</td>
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<td>Stephanohera exigua</td>
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<td>Stillingia linearifolia</td>
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### APPENDIX 4 – ARTHROPOD DATASHEET

| Date | Plot Cluster | Plot | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C |
| % filled with sand | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

#### ANTS
- Messor pergandei
- Myrmecocystus flaviceps
- Myrmecocystus kennedyi
- Myrmecocystus tenuirocis
- Pogonomyrmex californicus
- Pogonomyrmex magnacanthus
- Dorymyrmex sp.
- Forelius prunosus
- Pheidole barbata
- Solenopsis xyloni

#### BEETLES
- Anobiidae
  - Neptus ventriculus
- Carabidae
  - Carabid larva
  - Calosoma pravicolis
  - Calosoma larvae
  - Tetragonoderus pallidus
- Chrysomelidae sp.
- Coccinellidae sp. - (lady bug)
- Curculionidae
  - Ophryastes desertus
  - Ophryastes varus
  - Trigonosouts imbricata
- Derestidae - Novelis picta
- Elateridae sp.
- Meloidae sp.
  - Cysteodemus armatus
  - Phodaga alticeps - wing lifter
- Melyridae sp.
- Scarabaeidae - Diploaxis fimbriata
  - Anomalia flavila
- Tenebrionidae sp.
- Tenebrionidae larva
  - Araeodes chizius hardyi
  - Asbolus laevis
  - Asbolus verrucosa
  - Asidina confuens
  - Batolius setosus
  - Batoliodes obesus
  - Ceriodes californica
  - Chlaemetocon abnorme
  - Chlaemetocon brachystomum
  - Chlaemetocon pallidum
  - Cnemodinus testaceus
  - Cryptoglossa muricata
  - Edroteles barrowsi
  - Edroteles ventricosus
  - Eleodes armata
  - Embaphion depressum
  - Eupsophus castaneus
  - Eusatus difficilis