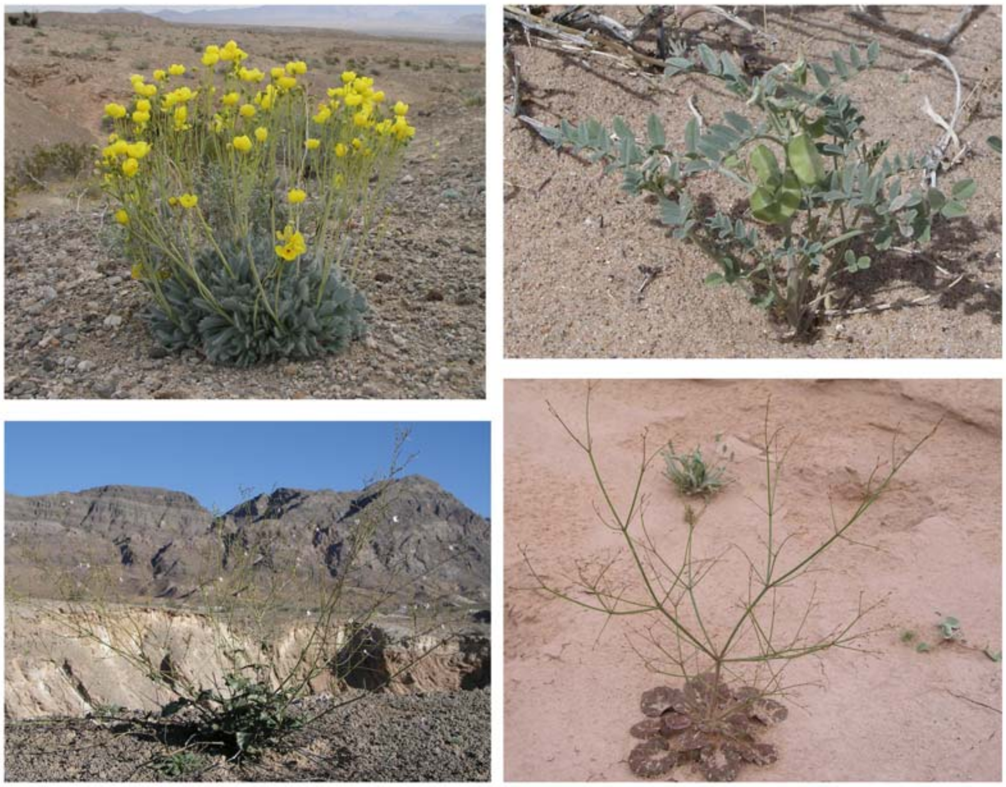

Inventory, Research and Monitoring for Covered Plant Species

PROJECT REPORT

2008-2010

For work performed by

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EXECUTIVE SUMMARY

The Clark County Multiple Species Habitat Conservation Plan (MSHCP) objectives for the four covered species *Arctomecon californica* Torr. & Frém. (Las Vegas bearpoppy), *Anulocaulis leiosolenus* (Torr.) Standl. var. *leiosolenus* (ringstem), *Astragalus geyeri* A. Gray var. var. *triquetrus* M.E. Jones (threecorner milkvetch), and *Eriogonum viscidulum* J.T. Howell (sticky buckwheat) are 1) no net unmitigated loss or fragmentation of habitat in intensively managed areas; and 2) maintain stable or increasing populations within these areas. The project, "Inventory, Research and Monitoring for Covered Plant Species" was developed to build upon existing knowledge, continue to inventory, describe habitat parameters including weather data, and conduct population monitoring pursuant of these objectives.

Surveys were conducted in known habitat to evaluate modern habitat and population conditions. In addition to surveys in known habitat, 20% of survey effort occurred in areas containing no known historical or current occurrences of each species to assess and refine boundaries of species distributions. Monitoring protocols were developed for each species and plans implemented for a year 2007 pilot study to determine appropriate experimental designs for long-term monitoring. Sampling designs were modified, and in 2008 long-term monitoring frameworks were established at six Las Vegas bearpoppy, three ringstem, three threecorner milkvetch and two sticky buckwheat sites. In 2009 sites were resampled. Over the course of 2008 & 2009, weather stations were installed at each monitoring site with the intent of long-term data collection and maintenance by the National Park Service.

Frameworks and data collected varied by species, to best ascertain specific population and habitat parameters of interest. Analysis of the first two years of data and recommendations based on research findings are detailed within this document.

The phenology and ecology of ringstem was uncertain, thus a study to increase knowledge of the species was developed and implemented. Monitoring was designed to follow the development of the plants from the rosette stage through bolting, flowering, and fruit development. Plant phenological stage, floral phenological stage, stalk measurements, and number of leaves were recorded. The findings of this study are also presented within this report.

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INTRODUCTION

The project, "Inventory, research and monitoring for covered plant species" was designed to address Clark County Multiple Species Habitat Conservation Plan (MSHCP) goals for four covered plant species: *Arctomecon californica* Torr. & Frém. (Las Vegas bearpoppy), *Anulocaulis leiosolenus* (Torr.) Standl. var. *leiosolenus* (ringstem), *Astragalus geyeri* A. Gray var. *triquetrus* M.E. Jones (threecorner milkvetch) and *Eriogonum viscidulum* J.T. Howell (sticky buckwheat). MSHCP goals were 1) no net unmitigated loss or fragmentation of habitat in intensively managed areas; and 2) maintain stable or increasing populations within these areas.

In addition to addressing County goals and objectives, this project supported National Park Service (NPS) compliance with federal management guidelines. NPS Management Policies direct managers at Lake Mead National Recreation Area (LMNRA) to survey for, protect and manage state and locally listed species and other native species of special concern (NPS, 2002). These directives are to be achieved by maintaining the species' natural distribution and abundance (NPS, 2002). Long-term monitoring of plant populations is essential to determine whether change occurs in specific population parameters such as mean density per unit area, species frequency and cover composed by the rare species.

The specific long-term monitoring objectives for the four covered species populations occurring on Bureau of Land Management (BLM) and NPS lands within Clark County are:

1. Maintain the current density (for Las Vegas bearpoppy and ringstem, within 30% of the baseline measurement calculated from an average of the first 3 years; for threecorner milkvetch and sticky buckwheat, within 30% of the baseline measurement calculated from a year of average to above average rainfall) over the next 10 years. The sampling objective is to be 80% sure of detecting a 30% change in density of target species.

2. Correlate the abiotic factors of rainfall, temperature, relative humidity, soil chemistry, soil crust cover and species, and soil compaction with the density of Las Vegas bearpoppy over the next 10 years.

3. Detect changes in species richness and cover of native and non-native plant species over the next 10 years. For Las Vegas bearpoppy and ringstem, species richness – within 30% of the first measurement and species cover – within 30% of the baseline measurement calculated from an average of the first 3 years; for threecorner milkvetch and sticky buckwheat, species richness and species cover within 30% of the first measurement taken in average to above average rainfall years. The sampling objective is to be 80% sure of detecting a 30% change in species richness and cover of native and non-native plant species.

These are measurable goals, however, without long-term data it is impossible to determine whether population numbers remain within their historic range of variation. Population numbers and locations within habitats can fluctuate wildly from year to year depending on precipitation and other factors (Niles *et al.*, 1995; Knight, 1992). Habitat loss and fragmentation are equally difficult to document if habitat parameters are not well defined. Annual species' habitat is particularly challenging to map since individuals may exist only in the seedbank until cued to germinate by certain environmental conditions. The current study was needed to determine present species distributions and provide baseline information on the population vitality of the four covered species. In addition, studies of current habitat conditions and associated vegetation communities were designed to arm managers with information to conserve rare plant habitat.

This inventory, research and monitoring project of the four covered species built upon existing knowledge by augmenting previous inventory efforts, gathering baseline climatic data near each monitoring site, establishing long-term monitoring frameworks and conducting population monitoring across federal land boundaries within Clark County. Surveys were conducted in known habitat to evaluate modern habitat and population conditions. In addition to surveys in known habitat, 20% of survey effort occurred in areas containing no known historical or current occurrences of each species. The intent of this surveying was to assess and refine boundaries of species distributions. In addition, monitoring protocols were developed for each species and plans implemented for a 2007 pilot year study to determine an appropriate experimental design for long-term monitoring. After evaluating the pilot year data, sampling designs were modified in order to decrease variability among sampling units and to increase statistical power (enabling analyses to detect actual differences among the data). By increasing the number of study sites, decreasing the number of plots per site, and changing the shape and size of the plots, a better representation of overall status and trends could be obtained with the 2008 and 2009 monitoring, while still providing valuable data at the population level (Sutter *et al.*, 2009).

MANAGEMENT ACTIONS ADDRESSED

The following MSHCP (RECON, 2000) conservation management actions were addressed by this project (2005-NPS-535-P).

- Conservation Management Action NPS (3) - Cooperate in the identification, development, and implementation of research projects located on Federal lands. Emphasis shall be placed on research that addresses management concerns and the conservation of Covered and Evaluation Species.

- Conservation Management Action NPS (6) - Coordinate inventory of *Astragalus geyeri* var. *triquetrus* (threecorner milkvetch), and *Eriogonum viscidulum* (sticky buckwheat) with other survey efforts on Federal lands.

- Conservation Management Action NPS (15) - Monitor Las Vegas bearpoppy populations.

- Conservation Management Action NPS (37) - Include MSHCP Covered Species as sensitive species in evaluations of road construction or maintenance activities on Federal lands.

- Conservation Management Action NPS (51) - Assure full and continuing implementation of existing management policies and actions, and monitoring of sensitive habitats and species.

BACKGROUND OF COVERED PLANT SPECIES

LAS VEGAS BEARPOPPY

The Las Vegas bearpoppy is an endemic rare plant found on gypsum soils (Figure 1). Las Vegas bearpoppy is currently listed by the State of Nevada as critically endangered and is on the Nevada Natural Heritage Program's Sensitive List (ranks G3 S3-defined as very rare and local throughout its range) but it has not been listed as a federally endangered species. This species is listed as a covered species under the Clark County MSHCP (RECON, 2000).

Las Vegas bearpoppy was first discovered in 1844 near Las Vegas "on the banks of a creek" by John Charles Frémont (original specimen notes). The Holotype specimen resides at the New York Herbarium. Las Vegas bearpoppy has been documented from 108 populations in east-central Clark County, Nevada, and from eight sites in the Lake Mead and lower Grand Canyon areas of northwestern Mohave County, Arizona (Mistretta *et al.*, 1996). These sites are managed by BLM, NPS, State of Nevada, Department of Defense Nellis Air Force Base (NAFB), Hualapai Indian Reservation and private parties. The species' distribution ranges from south of the Temple Bar area of LMNRA to near the southern base of the Virgin Mountains, and from the lower Grand Canyon to the Las Vegas Valley (Mistretta *et al.*, 1996), it was also documented from a single collection in Washington County, Utah (Flora of North America, 1997). In Nevada, 91 populations at 78 sites have been documented recently enough to be presumed extant, as have all eight sites in Arizona (Mistretta *et al.*, 1996).

Conceptual models were developed to illustrate the environmental requirements and stressors of Las Vegas bearpoppy (Figure 2). Las Vegas bearpoppy is traditionally thought to occupy soils of high gypsum content (between 36% and 69% at some sites (Meyer, 1987)). The species is not associated with free water and is dependent on precipitation (Mistretta et al. 1996) and germination has been shown to require long-term cold stratification (Song, 2001). Dependence on fluctuations in regional rainfall patterns results in wide yearly population fluctuations (Mistretta *et al.*, 1996). Drohan and Merkler (2009) suggests not water availability directly, but another explanation of the cycle of population explosions for Las Vegas bearpoppy. Recruitment following certain winters with excessive rains may suggest that sulfate mineralogies, or some other chemistry, must be removed from the A horizon (diluted in the soil) before germination takes place. They found no gypsum in any of the A horizon samples collected in 2005 (Drohan and Merkler, 2009).

Tepedino and Hickerson (1996) studied the reproductive ecology of Las Vegas bearpoppy and noted that the flowers are incapable of producing fruits or seeds unless cross pollinated; therefore, they require pollinators. These authors also noted that the number and diversity of pollinators was much higher at un-fragmented sites within LMNRA than at the fragmented sites within Las Vegas Valley, and that specialist bees were conspicuously absent from sites near urban development within the Las Vegas Valley. Las Vegas bearpoppy flowers last for two days before senescence, and Tepedino and Hickerson (1996) showed that the flowers need the two complete days of receptivity to produce a full complement of fruits and seeds. In their study, open-pollinated (un-manipulated control flowers) produced fewer seeds per fruit than did flowers that were cross-pollinated by hand, suggesting that pollinators were a limiting factor in seed production. These authors identified ten insect species that pollinate Las Vegas bearpoppy flowers, of these ten species, nine were found at study sites in LMNRA while only five were present at sampled sites in Las Vegas Valley (Tepedino and Hickerson, 1996).

LasVegas bearpoppy plants distribute their seeds an average of 200 cm from the parent plant through a combination of wind, gravity, and ant dispersal (Megill, 2007). Other factors aside from primary dispersal such as; soil chemistry, biological crust structure and density, water accumulation, secondary dispersal, seed viability and seed mortality may play an important role in how Las Vegas bearpoppy plants are distributed across the landscape.

In addition, seed bank studies conducted in Las Vegas bearpoppy habitat found that Las Vegas bearpoppy seeds were estimated between 1.44 to 22.4 seeds per square meter (Walker *et al.*, 2007). It was also found that viability of Las Vegas bearpoppy seeds varied between populations from 10-31% (Walker *et al.*, 2007) and increased slightly with increased depth.

Las Vegas bearpoppy appears to remain present on some sites over many years while disappearing and reappearing on other sites (Powell, 1999). The sites on which Las Vegas bearpoppy plants remain active over long periods of time may be more important for the survival of pollinators or other associated species than the sites on which Las Vegas bearpoppy plants are ephemeral (Powell, 1999).

In1998, a long-term demographic study was implemented at seven Las Vegas bearpoppy sites by the NPS in cooperation with the BLM (Powell, 1999). This research effort was maintained through 2005 with an eighth transect added in 2003. Results from this demographic study revealed that Las Vegas bearpoppy populations appear to fluctuate across its range presumably influenced by environmental cues (Powell, 1999). Meyer and Forbis (2006) developed a population viability analysis (PVA) based on years of demographic data, seed bank, and seed longevity studies. Their preliminary PVA model indicated that small, fragmented populations (Las Vegas Valley populations) suffer from severe pollen limitation and set few seed (TNC, 2007).

The populations of interest (TNC, 2007; Figure 3) to which we make inferences are Bitter Spring Valley, Gale Hills, Gold Butte, Sunrise Valley, and Valley of Fire. The Government Wash and the Las Vegas Dunes populations either occur on private land or were dormant at the time of modern surveys and were not included in this project. The Las Vegas Valley population was not considered because it has largely been extirpated. The White Basin and Middle Point populations did not qualify for monitoring based on criteria described in the methods section of this document. The Arizona and Meadview NW populations do not occur in Clark County and were not included in this project.

According to the last major review of Las Vegas bearpoppy conducted by Mistretta *et al*. (1996) most of the potential habitat of the species had been surveyed, and it was estimated that the true total population was no more than 25% larger than that documented (Mistretta *et al.*, 1996). Morefield (2001) summarized the status of Las Vegas bearpoppy in 2001 with total estimated individuals at 445,000+, total estimated area of 20,614 acres, and a rapidly declining trend (Morefield, 2001; TNC, 2007).

Many of the fragmented populations of Las Vegas bearpoppy within the urban areas of Las Vegas Valley have likely been extirpated in recent years. At the time of the Nevada Heritage Program report in 1996 only 48 (44%) of the Nevada populations of Las Vegas bearpoppy were relatively intact and were considered secure from future development or encroachment (Mistretta et al., 1996). These 48 populations, however, comprised a majority of the known habitat and numbers of plants at that time. With such a limited number of Las Vegas bearpoppy populations considered safe from encroachment, it is important that the stability of these populations is monitored with the new, statistically viable monitoring frameworks. This will enable managers to detect a significant decline in numbers, which is important because if these populations fail, there are few additional populations to maintain the species existence.

An assessment of threats by TNC (2007) resulted in six threats being ranked as High or Very High. These include: casual vehicle use and trail development, highway and road construction and maintenance, urban development and sprawl, military training and facilities development, and gypsum mining. Conceptual models illustrating the effects of anthropogenic and introduced species as stressors on the Las Vegas bearpoppy were developed for this project (Figures 4 & 5). Specifically on the lands included in this monitoring project, the primary threats are utility corridor construction and maintenance, cattle and burro management, and off-highway vehicle (OHV) use. Surveys in 2005 at Las Vegas bearpoppy transect locations recorded evidence of old disturbance (i.e. motorcycle tracks, burro, horse, and foot prints) but little new disturbance (Bangle, 2005a). This may be attributed to the previous burro removals within LMNRA as well as other management actions to reduce off-road vehicles. Since 2005, cattle sightings have increased in the northern portion of LMNRA because of lake level declines (Bangle, *pers. obs.*). In 2009, cattle were spotted within 1 kilometer of gypsum rare plant habitat near Northshore Road and Overton Beach Road (road construction crew members, *pers. comm.*, 3/9/09) and preliminary surveys were conducted in the area to estimate the extent of the cattle trails.

RINGSTEM

The genus *Anulocaulis* (ringstem) is a taxonomically complex group of plants (Spellenberg, 1993) in the Nyctaginaceae (four-o'clock) family. *Anulocaulis* are long-lived perennials endemic to the arid regions of the south-western United States and adjacent Mexico. Ringstem (Figure 6) occurs within LMNRA in Clark County, Nevada; Mohave County, Arizona; New Mexico; Texas and Mexico (Chihuahua) (Flora of North America, 2003). Ringstem is listed as a covered species under the Clark County MSHCP and as a watch species on the Nevada Natural Heritage Program's Sensitive List (ranks G4, T3, S2-defined as imperiled in the state because of rarity due to very restricted range or very few populations). This variety is listed as a covered species under the MSHCP (RECON, 2000).

There are four recognized varieties of *Anulocaulis leiosolenus*, which in addition to *A. l. leiosolenus* includes: *A. l.* var. *gypsogenus* (Waterf.) Spellenb. & T. Wootten, var. *lasianthus* I.M. Johnst., and var. *howardii* Spellenb. & Wootton. An expert in the phylogenetics of the Nyctaginaceae family, Norm Douglas, described the distribution of *A. l. leiosolenus* as disjunct across its range and little is known about the ecology or biology of this species (Douglas, *pers. comm.*, August 2005). In Arizona, ringstem has been recorded from the Big Gyp Hills within LMNRA, the Grand Canyon (bottom of Bright Angel Trail) and from Camp Verde (located 86 miles north of Phoenix, Arizona). The New Mexico populations of ringstem are found along the southern portion of the Rio Grande down into Texas near El Paso and Ciudad Juarez, Mexico (Douglas, *pers. comm.*, August 2005). While there are four recognized varieties of *Anulocaulis leiosolenus*, the taxonomy of the genera, *Anulocaulis* spp. remains questionable (Douglas, 2007).

Conceptual models were developed to illustrate the environmental requirements of ringstem and stressors on the species (Figure 7). Ringstem is restricted to gypsum outcrops, rolling hills, and terraces within Mojave desert scrub (primarily creosote bush-white bursage) and salt desert scrub matrix ecological systems (Niles *et al.*, 1999).

The name "ringstem" comes from a sticky ring, approximately 1 cm in width that is present along the stems of the plant. The purpose for and composition of the sticky ring is currently unknown, however we assume that the function of the ring is to trap floral predators and reduce predation and damage. In some plant species its purpose has been found to limit aphids from establishing on the plant (McClellan and Boecklen, 1993). Ringstem flowers are short lived, open in the evening, and wither in the morning. Ringstem fruits are turbinate, woody pods containing one large seed. The shape of the plant's small fruit makes it primarily gravity dispersed (Douglas, 2007).

The most comprehensive surveys for ringstem were conducted in 2005 (Bangle, 2005b). Surveys were focused on gypsum soil habitats in the areas of Stewarts Point, Valley of Fire, Echo Wash, and Pinto Valley (old Road 99 and old Road 100) within LMNRA, and on BLM lands at Rainbow Gardens. Approximately 7,000 plants were recorded during that survey effort. This author knows of no prior, documented surveys for the species in Clark County. In the 1980s, Meyer measured ringstem abundance where it occurred in areas with Las Vegas bearpoppy and noted average density of 0.6 plants per 100 m^2 (Meyer, 1987).

Routine monitoring of ringstem has not occurred prior to the current monitoring project. Annual monitoring of this species will provide baseline information on the status of ringstem and possible threats to the species. Little information existed about the ecology or biology of this species prior to the current project. As part of the "Inventory, Research and Monitoring for Covered Plant Species" project, a phenology study was initiated in 2008. This research was designed to add to the scientific knowledge of the reproductive function of ringstem.

The populations of interest (TNC, 2007; Figure 8) to which we make inferences are the Overton Arm, East Black Mountains, and Lava Butte populations. The Muddy River, Gypsum Wash and West Black Mountains populations occur on private land or in areas difficult to access and were not included in this project. We were unable to re-locate the historical Gold Butte population. An assessment of threats by TNC (2007) resulted in one threat being ranked as High and six as Medium. These include: gypsum mining, casual vehicle use and trail development, rural/urban development and related sprawl, Federal land disposal, invasive plant species, wild horse and burro management, utility corridor construction and maintenance. Conceptual models illustrating the effects of anthropogenic and introduced species as stressors on ringstem were developed for this project (Figures 9 & 10). Specifically on the lands included in this monitoring project, the primary threats are utility corridor construction and maintenance, cattle and burro management, and OHV use.

THREECORNER MILKVETCH

Threecorner milkvetch (Figure 11) is a rare, sand loving, annual plant endemic to Clark and Lincoln Counties in southern Nevada and Mojave County in northwestern Arizona. This species is on the Nevada Natural Heritage Program's Sensitive List (ranks G2 S2-defined as imperiled), is listed as a covered species under the Clark County MSHCP, and has status as a critically endangered species in the State of Nevada. The northern and eastern most distributions of this species are at Sand Hollow Wash in Lincoln County and at Coon Creek in Mojave County. Threecorner milkvetch reaches a southern extension at Sandy Cove on the north shore of the Boulder Basin LMNRA and a western extension at Dry Lake Valley in Clark County. The highest concentration of populations is found in the Mormon Mesa area of Clark County on BLM (Niles *et al.*, 1995).

A conceptual model illustrating the environmental requirements for threecorner milkvetch was developed for this project (Figure 12). Threecorner milkvetch has a geographic distribution associated with a sedimentary deposit called the Muddy Creek Formation (Niles *et al.*, 1995). This formation is widely exposed in the hills along the Overton Arm, Virgin Basin, and Boulder Basin sections of LMNRA and extends northward along the Virgin River Valley and westward along the Muddy River and Meadow Valley Wash. Weathered sediments from this formation, re-deposited as aeolian or fluvial sand, provide the substrate upon which threecorner milkvetch is found (Niles *et al.*, 1995).

The most comprehensive survey for threecorner milkvetch was conducted by Niles *et al.* (1995). Niles *et al.* (1995) conducted surveys of all known and potential locations of threecorner milkvetch within LMNRA and adjacent regions of Nevada and Arizona and identified 19 threecorner milkvetch sites. No reliable estimate of the current status of this species is known due to limited range wide survey efforts and the ephemeral nature of the plant. Since then, surveys have been geographically limited and no systematic assessment of population status has occurred in the last ten years. Other partial surveys done since that time have found some new populations and have documented the extirpation of populations, but no new complete assessment has been conducted. In 2001, populations were estimated to support more than 4,094 individuals at 39 sites with an unknown area of habitat throughout Nevada (Morefield, 2001). After the record rainfall year of 2005, 8,000 plants were estimated on Sandy Cove (LMNRA), currently the largest known population of threecorner milkvetch (Bangle, 2005c).

In the mid-1990s, Niles *et al.* (1995) conducted surveys of all known and potential locations of threecorner milkvetch within LMNRA and adjacent regions of Nevada and Arizona. Niles *et al.* identified 19 threecorner milkvetch sites. Since then, surveys have been geographically limited and no systematic assessment of population status has occurred in the last ten years. Other partial surveys done since that time have found some new populations and have documented the extirpation of populations, but no new complete assessment has been completed.

The populations of interest (TNC, 2007; Figure 13) to which we make inferences are Ebony Cove, Sandy Cove, and Weiser Wash.

Threecorner milkvetch occurs on highly dynamic sandy soils. A conceptual model illustrating the potential positive and negative effects sand burial may have on the species was developed for this project (Figure 14).

Threecorner milkvetch requires open spaces and loose soils thus in areas heavily invaded by invasive species such as *Brassica tournefortii* (Sahara mustard), *Schismus arabicus* (Mediterranean grass), *Tamarix ramosissima* (saltcedar), and *Salsola* spp. (Russian thistle), threecorner milkvetch are not found. (Bangle, *pers. obs.*). An assessment of threats by TNC (2007) resulted in nine threats being ranked as High or Very High. These include: urban development and sprawl, OHV use and trail development, increased fire frequency and intensity, energy development, surface water development, invasive plant species, utility corridor construction and maintenance, Lake Mead inundation and shoreline fluctuation, and inappropriate agricultural practices. Several of these threats are site specific (energy development, Federal land disposal, legal OHV use), while others are more widespread. Specifically on the lands included in this monitoring project, the primary threats are urban development and sprawl, competition from invasive species, energy development, utility corridor construction and maintenance, and OHV use.

STICKY BUCKWHEAT

The genus *Eriogonum* (Polygonaceae) is endemic to North America. It is one of the most common and diverse genera in western North America, yet about one third of its species are rare or uncommon (Reveal, 2003).

*S*ticky buckwheat (Figure 15) is an annual plant endemic to Clark and Lincoln Counties in southern Nevada and Mojave County in northwestern Arizona (Howell, 1942). The northern and eastern most distributions of this rare species are found at Sand Hollow Wash in Lincoln County and just across the state border at Coon Creek in Mojave County. *S*ticky buckwheat reaches its southern and western extensions in Nevada at Middle Point within LMNRA and Weiser Wash on BLM land, respectively (Niles *et al.*, 1995). *S*ticky buckwheat is on the Nevada Natural Heritage Programs Sensitive List (ranks G2 S2-defined as imperiled), and has status as a critically endangered species in the State of Nevada.

*S*ticky buckwheat was first collected and described by Alice Eastwood and John T. Howell at the Riverside Bridge on the Virgin River, Clark County, Nevada (Howell, 1942). The holotype resides in the herbarium of the California Academy of Sciences in San Francisco, California. Sticky buckwheat (*Eriogonum viscidulum*) is closely related to *E. subreniforme* S. Watson, found in southern Utah, northern Arizona and northwest New Mexico (Reveal, 1978), but is distinguished from *E. subreniforme* by having yellow flowers and a unique viscid surface near the base of the plant which is often covered by sand particles.

Conceptual models illustrating the environmental requirements of sticky buckwheat were developed for this project (Figure 16). *S*ticky buckwheat prefers sandy, open habitats. It has a geographic distribution associated with a sedimentary deposit called the Muddy Creek Formation (Niles *et al.*, 1995). This formation is widely exposed in the hills along the Overton Arm, Virgin Basin, and Boulder Basin sections of LMNRA and extends northward along the Virgin River Valley and westward along the Muddy River and Meadow Valley Wash. Weathered sediments from this formation, re-deposited as aeolian or fluvial sand, provide the substrate upon which sticky buckwheat is found (Niles *et al.*, 1995). *S*ticky buckwheat abundance varies annually and is likely dependent on a specific range of temperature and moisture conditions (Bangle, *pers. obs.*).

In the mid-1990s, Niles *et al.* (1995) conducted an inventory (March through June 1995) of all known locations of sticky buckwheat, as well as searches for additional localities within LMNRA and adjacent regions of Nevada and Arizona. This was the most comprehensive survey for sticky buckwheat to date. Aerial reconnaissance was used to identify promising areas of suitable sticky buckwheat habitat for novel surveys. From this inventory effort, valuable knowledge was gained about the overall distribution and status of sticky buckwheat populations. Of the twenty-two locations where sticky buckwheat was located, 20,020 plants were recorded. In addition, it was reported that the Upper Muddy River population group had an estimated 7,128 plants in 1995 and of the sites surveyed this population was the highest density (Niles *et al.*, 1995). Since the extensive surveys of Niles et al., surveys for sticky buckwheat have been geographically limited and only select sites have been monitored, thus no systematic assessment of population status has occurred within the last ten years.

The population of interest (as described in TNC, 2007; Figure 17) to which we make inferences is the Lime Wash population. Two sub-populations were monitored within the Lime Wash population. Modern surveys at Black Mountains and Overton Arm populations found low densities of sticky buckwheat and thus were not included in the selection process. The health and status of the Toquop Wash, Upper Virgin Valley, Lower Virgin Valley, Upper Muddy River, Middle Muddy River, Lower Virgin River, Virgin River Confluence, and Bitter Ridge populations were unknown at the beginning of this project and therefore were not included in the random selection of populations for monitoring.

Conceptual models were developed which illustrate major stressors of sticky buckwheat, specifically inundation by Lake Mead water levels and plant and animal competitors (Figures 18 & 19). An assessment of threats by TNC (2007) resulted in seven threats being ranked as High. These threats include: rural development and sprawl, increased fire frequency and intensity, energy development, invasive plant species invasion, casual OHV use and trail development, surface water development, and agriculture practices. The aforementioned threats and others have affected populations and habitats both by direct mortality of individuals and loss or fragmentation of habitats (TNC, 2007). Specifically on the lands included in this monitoring project, primary threats are: competition from invasive species, inundation and shoreline fluctuation, and trampling and grazing (cattle, burros, horses).

Sticky buckwheat requires open spaces and loose soils; thus in areas heavily invaded by invasive species (such as Sahara mustard, Mediterranean grass, saltcedar, and Russian thistle), sticky buckwheat is not found.

METHODS AND MATERIALS:

LAS VEGAS BEARPOPPY – FIELD METHODS *(APPENDIX 1)*

Surveys were conducted in 2007, 2008, and 2009 at known Las Vegas bearpoppy locations. These included surveys of historical sites and an additional 20% in areas containing no known historical or currently known occurrences of this species.

At the time of the surveys, Mistretta *et al.* (1996) reported the most comprehensive and current listing of Las Vegas bearpoppy populations. These reports were used to re-assess existing populations. Sites were not evaluated if they occurred on private land, had been developed or were likely to be developed, occurred in Arizona, or had densities known to be 200 plants or less. Of the 104 sites listed in the document, 28 were re-evaluated for this project (Table 1; Figure 20). One new population was found in the Gale Hills area and was one of the sub-populations randomly selected for monitoring (Figure 21). When Las Vegas bearpoppy was located, the area was searched until no additional plants were located. Global positioning system GPS units (such as the Garmin GPSmap 76S model) were used to map polygons around these populations. In addition, estimates of the total number of individuals, associated plant species, threats and unusual disturbances were recorded.

Within each of the identified populations, the smaller Las Vegas bearpoppy patches were considered sub-populations and were selected for monitoring using a stratified random approach based on the following criteria, topographic location, accessibility (within 1 km from a road or shoreline), and size. Only one subpopulation within a population was chosen for monitoring. Inferences could only be made about the strata upon which plots occurred. All sub-populations randomly selected for monitoring were equally weighted by plot number and size. Each transect was subjectively placed within the Las Vegas bearpoppy patch so that it crossed the main portion of the patch. The rare plant plots were placed along the transect using a restricted random sampling manner with one plot placed randomly within each 33 or 34 meters. The community ecology plot was randomly placed along the 100-m transect.

A three-tiered approach to monitoring was used to address the management objectives (Figure 22). First, to address the trends in density of Las Vegas bearpoppy we placed a permanent 100-m transect at each selected sub-population. Three permanent plots (10 × 40 m) were placed along each transect. Data gathered included: percent cover, number of individuals, status of current year flowering/fruiting, plant condition and size class. Status of current year flowering/fruiting was described as Y/N, (Y if the plant flowered or fruiting this year, N if it did not). Size classes were measurements of the width of the poppy base (x & y, averaged) and were defined as: 1) 0-5 cm, 2) 6-12 cm, 3) 13-19 cm, 4) 20-26 cm, 5) 27-32 cm, and 6) >32 cm. It was ultimately determined that size classes would be combined into three classes (combining 1-2, 3 and 4-5). Condition was described as 1 = excellent, (no dead material, looking very vigorous), 2 = Good (little dead material and live material looking healthy), 3 = Fair (a lot of dead material and live material with low vigor), and 4 = Poor (mostly dead or dying). These classes were ultimately combined into two classes (1-2 and 3-5).

Second, to evaluate community composition at Las Vegas bearpoppy sites community ecology data was collected in 2008 and 2009 at each selected sub-population. One large permanent plot (50 × 50 m), divided into smaller quadrats (10 × 10 m), was placed along each transect and included at least one Las Vegas bearpoppy plot. Data gathered included: percent cover of all live plant species plus a tally of rare plants species per quadrat (Las Vegas bearpoppy and ringstem).

Third, abiotic data was collected in separate 1 × 1 m temporary plots placed along a plant separate transect laid in and out of high, low, and no density Las Vegas bearpoppy habitat. Areas of density along the transect were defined within a 20-meter wide area on each side of the transect (40-m band). Areas with an abundance of Las Vegas bearpoppy (estimated- several individuals occurring within 0-10 meters of each other within 40-m band) were considered high density areas; areas with considerably less Las Vegas bearpoppy individuals (estimated-not many individuals within 10 meters of each other within 40-m band) were considered low density areas; areas with no Las Vegas bearpoppy within 40-m band were considered no density areas. Five plots per density type were placed along the abiotic transect. Data gathered included: crust cover, plant species and cover, penetrometer readings, and distance to the six nearest target rare plants from center plot. A tally of all plant species located within the 40-m belt transect was recorded.

Abiotic data collected at each site included: rainfall, ambient temperature, and relative humidity. In addition at three of the five plots per density type, cryptogamic crust samples and soil samples were collected. Soil color and texture were recorded and soil analyses conducted (saturated paste/water soluble ions, %CaCo3, total carbon and total nitrogen, pH and EC, and phosphorus). The information gathered will be analyzed and presented with the companion project, (2005-NPS-609-E).

Mapping the target species within each rare plant plot was accomplished using paper grid maps instead of collecting a specific GPS coordinate for each plant. This manual mapping technique minimized the impact to the habitat because the researcher could stay on disturbance trails to map the plants instead of walking across undisturbed gypsum soil to mark each individual using a GPS unit.

Las Vegas bearpoppy populations were sampled in 2008 and 2009. Data collection took place in April and May each year.

The gypsum substrates Las Vegas bearpoppy occurs on sometimes have a substantial cryptogamic crust component that is considered sensitive to disturbance and easily damaged. Monitoring in such delicate habitat poses a problem for resource managers in that investigator impact may cause a significant amount of damage, which may be detrimental to the habitat dynamics and the plants found within this habitat. An integral part of the monitoring protocol was minimizing habitat disturbance. Disturbance trails and drainage channels were used as much as possible to move around within the habitat.

At each site, disturbance trails (burro trails, OHV tracks, and small drainages), which are common in this habitat, were utilized as much as possible to set up plots and collect data. The transect start and end points were permanently marked, as well as the corners of all plots (except 1 × 1 m plots) with an 8-inch nail and engraved washer. Meter tapes were used to mark the length of each transect and set up the plots in the first year of the study. A range finder and compass were used as much as possible the second year to place flagging at every 10-meter mark within the rare plant and community ecology plots which reduced the need to drag tapes across the habitat. Meter tapes were used for the perimeters of the larger community ecology plots to ensure accurate quadrat delineation.

LAS VEGAS BEARPOPPY – METHODS OF ANALYSIS

Total cover, richness, diversity, and the relative representation of life were estimated by mean values. Diversity was expressed as the numbers equivalent (aka effective number of species), but calculations used on the $\log_{10}$ transform of this value (Jost, 2006) which was back-transformed for reporting. All other values except richness were $\log_{10}$ transformed prior to estimation of the mean and confidence intervals. Confidence intervals using the normal distribution tended to underestimate the 95% confidence interval, so bootstrapped estimates based on 10,000 re-samples are reported. All analysis was completed in R 2.10.0 (R Development Core Team, 2009), and diversity and species richness was estimated using the 'vegetarian' package (Jost, 2006).

Six sites were available for examining patterns with climate variables. We used a Spearman rank correlation (rho) to estimate the relationship between the number of Las Vegas bearpoppy in a site and the climate variables for every month which had a full monthly data set available. Congruence of ranks, indicated by a low p-value associated with the correlation coefficient, was taken as a suggestion of an association for further study. No family-wise adjustment was made for the large number of p-values generated, as this was considered a preliminary study.

The potential relationships between quadrat-level species richness, species diversity, relative annual cover, relative perennial cover, relative shrub cover, and total cover (all except richness were $\log_{10}$+1 transformed to meet model expectations) and the number of Las Vegas bearpoppy individuals ($\log_{10}$+1 transformed) were fit using a mixed model ANOVA. The model included quadrat within site as a subject effect, and an unstructured covariance matrix (determined by corrected Akaike information criterion). Fixed effects were site, year, site by year, and each continuous independent variable above with year, site, and year by site interactions to examine heterogeneity of slopes. Spatial arrangement of quadrats was not available in this case, so this information is not incorporated into the analysis. In addition, the relative proportion of annual cover was analyzed alone because these data were not available in 2008. The minimum adequate model was determined by comparing nested models using AICC. Although significance was determined in the full model, slopes and least-squares means (lsmeans) were estimated in a model containing only the continuous independent variable of interest and its interactions with site and year. Covariance was not stable across sites, yielding misleading coefficients when the slopes were estimated from the full model. This analysis was performed in SAS v9.1 (SAS Institute, 2002-2003) 'proc mixed'.

The effect of a plant's size and condition on seeding success was modeled in a generalized linear model (glm) with binomial error. The initial five size classes (ranging from 1 to 5) were reduced to three (combining size class 1-2 and 4-5) because the extreme size classes were too small to gain a reliable estimate of their performance. The initial five condition classes (ranging from 1 to 5) were combined into two classes (1-2 and 3-5) for the same reason. Condition was not noted in

2008, so size was first modeled with site, size class, and their interaction as fixed effects in a separate model for each year (all sites were not measured in both years). The values for success in seeding were computed at the plot level within sites because the quadrat level yielded insufficient sample size to compute success. To examine the effect of condition and size together, we fit another glm, which included site, condition, and size class with all interactions. As before, the minimum adequate model was determined by AICC. For reporting, response values from the minimum adequate model were back-transformed to provide the lsmean and standard error (SE) for the proportion seeding for each treatment. Significant differences between treatment means were tested post-hoc for terms in the minimum adequate model. No adjustments were made for multiple comparisons due to the small sample and exploratory nature of the analysis.

RINGSTEM – FIELD METHODS *(APPENDIX 2)*

Inventories for ringstem were conducted in 2008 and 2009. The inventories included surveys of historical sites and an additional 20% in areas containing no known historical or currently known occurrences of this species. When Las Vegas bearpoppy was located, the area was searched until no additional plants were located. GPS units were used to map polygons around these populations. In addition, estimates of the total number of individuals, associated plant species, threats and unusual disturbances were recorded.

The methods and materials used for ringstem monitoring (Figures 23-25) were identical to those of Las Vegas bearpoppy except data gathered for ringstem also included percent cover, number of individuals, status of current year flower and seed production, number of stems (prior and current years), and number of leaves. Percent cover was classified as: 1) 0-1%, 2) 1-2%, 3) 2-5%, 4) 5-10%, 5)10-25%, 6)25-50%, 7) 50-75%, 8) 75-95% and 9) > 95%. These were ultimately analyzed using mean values. Status of current year flower and seed production was recorded as yes if flowered or fruited this year or no if it did not. When number of stems was counted, R was recorded if there was only a rosette present. Number of leaves included all leaves, plus the rosette and the first set of leaves above the rosette.

Two sites (Road 100 and Sunrise Hills) supported both Las Vegas bearpoppy and ringstem within the selected sub-populations, therefore the same set of plots were used for both species at these two sites. Separate maps and datasheets were used for each species.

Within each of the identified populations, the smaller ringstem patches were considered sub-populations and were selected for monitoring using a stratified random approach based on the following criteria: topographic location, accessibility (within 1 km from a road or shoreline), and size. Only one subpopulation within a population was chosen for monitoring. Inferences could only be made about the strata upon which plots occurred.

Disturbance trails and drainage channels were used as much as possible to sample ringstem, similar to monitoring Las Vegas bearpoppy. These were utilized to minimize investigator impact on the sensitive gypsum substrate in which ringstem grows.

RINGSTEM – METHODS OF ANALYSIS

Total cover, richness, diversity, and the relative representation of life forms were estimated by mean values. Diversity was expressed as the numbers equivalent (aka effective number of species), but calculations used the $\log_{10}$ transform of this value (Jost, 2006), which was back-transformed for reporting. All other values were $\log_{10}$ transformed prior to estimation of the mean and confidence intervals, and back-transformed in the report. Confidence intervals using the normal distribution tended to underestimate the 95% confidence interval, so bootstrapped estimates based on 10,000 re-samples are reported. All analysis was completed in R 2.10.0 (R Development Core Team, 2009), and diversity and species richness were estimated using the 'vegetarian' package (Jost, 2006).

Three sites were available for examining patterns with climate variables, so formal testing of the relationships between plants and these variables was not possible. Simple congruence of ranks between a certain plant variable and a given climate variable was taken as a suggestion of an association which might be the target of further study.

The potential relationships between quadrat-level species richness, species diversity, relative proportion of annual cover, relative proportion of perennial cover, relative proportion of shrub cover, and total cover (all except richness were $\log_{10}$+1 transformed to meet model expectations) and the number of ringstem individuals ($\log_{10}$+1 transformed) were fit using a mixed model ANOVA. A generalized linear model is more appropriate for these data (O'Hara and Kotze, 2010), but no stable solution could be obtained in this situation, most likely a consequence of the sample size in conjunction with the model's complexity. The model included quadrat within site as a subject effect, and a covariance matrix with compound symmetry (optimized by corrected Akaike information criterion; AICC). Fixed effects were site, year, site by year, and each continuous independent variable above (except proportion of annuals) with year, site, and year by site interactions to examine heterogeneity of slopes. Spatial arrangement of quadrats was not available in this case, so this information was not incorporated into the analysis. The relative proportion of annual cover was analyzed in a separate model because these data were not available in 2008. The minimum adequate model was determined by comparing nested models using AICC. Although significance was determined in the full model, slopes and least-squares means (lsmeans) were estimated in a model containing the categorical effects of site and year and the continuous independent variable of interest, with all possible interactions among them. Covariance among variables was not consistent across sites, yielding misleading coefficients when the slopes were estimated from the full model. This analysis was performed in SAS v9.1 (SAS Institute, 2002-2003) 'proc mixed'.

The effect of a plant's size on bolting success was modeled in a generalized linear model (glm) with binomial error. Size was estimated by the number of stems and number of leaves on each plant surveyed. The number of leaves was not noted in 2008, so the two size variables were handled in different models, although it should be noted that the two variables were moderately correlated (Spearman rank correlation (rho=0.596, n=113, P<0.0001). Numbers of leaves and stems provided sparse coverage of large portions of the function relating these variables to bolting success, so plants were grouped into those containing 1-10 stems (leaves) and greater than 11 stems (leaves). Success in bolting was modeled separately for each site and year because some sites did not have sufficient samples to estimate some parameters and some plants were measured in both years while others were not. The size variable was the fixed effect. For reporting, response values were back-transformed to provide the lsmean and standard error (SE) for the proportion bolting for each treatment.

RINGSTEM PHENOLOGY STUDY

In 2008, phenological observations of 21 marked individuals at each of three ringstem sites (Road 100, Echo Wash, Valley of Fire) within LMNRA were initiated (Figure 26). Monitoring was designed to follow the development of the plants from the rosette stage through bolting, flowering, and fruit development. Plants were observed every 7-14 days from May until November 2008 in concordance with the flowering period of ringstem. In 2009, we increased monitoring to every five days. Plant phenological stage, floral phenological stage (Figure 27), stalk measurements, and number of leaves were recorded. Ringstem plant phenological stage was classified as either rosette or bolting. There were five floral phenological stages of development defined: bud, defined by the presence of a stem; Stage 1 - open, stamens emerge and anthers drop pollen, stamens are generally tightly twisted; Stage 2 - pistil elongates; Stage 3 - stamens and pistil straighten and elongate; Stage 4 - corolla senesces, stamens dry and crinkled; and Stage 5. Number of leaves included all leaves, plus the rosette and the first set of leaves above the rosette.

Our goal was to understand the vegetative and reproductive phenology (timing) of ringstem; specifically to document information about the duration of flowering per plant, how many flowers and fruits a plant may produce, whether leaf number was related to timing of bolting and flowering, and whether leaf number and stem length determine reproductive output.

Results from 2008 sampling indicated that sampling did not occur at a sufficient frequency, therefore data analyses were limited to the 2009 calendar year to capture duration, dynamics among flowering stages, and plant morphological relationships (relationship between flowering duration and maximum leaf number, maximum number of stalks or maximum stalk height). All metrics involving flowering number or duration were limited to flowering individuals (i.e. plants that did not flower were not included as zeroes when calculating site-specific means). We calculated the proportion of total reproductive structures that were in each flowering stage (Σ (stage 1- stage 5) / each stage) to examine dynamics of the full range of floral production throughout the reproductive season. Phenological development across sites was examined by calculating the mean day of year (DOY) at which plants first had reproductive structures observed in each phase. Data were analyzed with one way analysis of variance (ANOVA) for each site. Flowering duration was defined as the number of days between observing a plant with reproductive structures in stage 1, and the last date that flowering structures in stage 4 were observed (represented as DOY).

Leaf number, stalk height, and stalk number were analyzed using a Repeated Measures ANOVA (RMA) with site as the main effect and data averaged by month as the repeated factor. Number of leaves and number of stalk data were log transformed to fit assumptions of normality (Wilks W statistic > 0.96 for all data after transformation). All data were analyzed using SAS software, SAS Inc (SAS Institute, 2002-2003). We performed a multiple regression analysis to examine which morphological characteristics (maximum leaf number, maximum number of stalks or maximum stalk height) predicted flowering duration.

THREECORNER MILKVETCH – FIELD METHODS *(APPENDIX 3)*

Populations were considered for monitoring based on size, time available to survey historical sites, and whether populations could be relocated at historical sites. Three populations were selected for monitoring (Figures 28 & 29). Inferences could only be made about the strata upon which plots occurred.

A grid-cell sampling approach to monitoring was selected (Figure 30). To address the trends in density of threecorner milkvetch, we placed 36 × 36 m permanent grids in the species habitat. The number of grids varied by site based on the extent of habitat and populations of threecorner milkvetch. Eighteen quadrats (6 × 12 m) were delineated within each grid (Figure 31). Community ecology data was collected within the same grids/quadrats each year.

Each grid location at the largest site, Sandy Cove (1.45 km^2), was selected randomly (using a stratified approach) by placing a “virtual grid” (in ArcMap 9.2) projected over known habitat after which random numbers were generated to select a coordinate (within the virtual grid). The randomly selected point translated to the southwest corner of each grid (eight grids at this site) and once onsite a compass bearing for each direction was recorded. The remaining two sites supported smaller populations of threecorner milkvetch, so we subjectively placed grids in areas where plants occurred (two grids at each site).

The corners of each permanent grid were recorded using a highly accurate GPS unit (2005 Trimble GeoXH). GPS coordinates were recorded at all grid corners including: easting, northing, elevation, and level of accuracy. The grids were relocated each monitoring year with the same GPS unit or a GPS unit with accuracy equivalent to the unit used the previous year.

Measuring tapes delineated grids and pin flags marked individual threecorner milkvetch plants for mapping. Individual GPS coordinates were not recorded for each plant; instead individual plant locations were recorded by marking plants on a field map (Figure 31) of each grid showing spatial arrangement within each quadrat. The field maps were digitized in the office after the field season was complete. Data gathered included, percent cover of all species, and number of threecorner milkvetch plants per quadrat. Cardboard cutouts representing 1% and 2% of quadrat area, plus a sample field map outlining different percentages, were also used as visual aids to increase the accuracy of percent cover estimates. Percent cover was classified as: 1) 0-1%, 2) 1-2%, 3) 2-5%, 4) 5-10%, 5)10-25%, 6)25-50%, 7) 50-75%, 8) 75-95% and 9) > 95%. These were ultimately analyzed using mean values.

Abiotic sampling at the site consisted of collecting soil samples at six randomly selected points in areas of high density (4 samples) and no density (2 samples). Soil analyses included, %CaCo3 (inorganic carbon), total carbon and nitrogen, pH, EC, and particle size. The information gathered will be analyzed and presented with the companion project, (2005-NPS-609-E). Rainfall, temperature, and relative humidity were collected at each site beginning in 2008.

Inventories for threecorner milkvetch were conducted in 2008 and 2009. The inventories included surveys of historical sites and an additional 20% in areas containing no known historical or currently known occurrences of this species. When threecorner milkvetch was located, the area was searched until no additional plants were found.

THREECORNER MILKVETCH – METHODS OF ANALYSIS

Total cover, richness, diversity, and the relative representation of life forms and native/non-native species were estimated by mean values. Diversity was expressed as the numbers equivalent (aka effective number of species), but calculations were done on the log transform of this value (Jost, 2006) and back-transformed for reporting. All other values were log transformed prior to estimation of the mean and confidence intervals. Confidence intervals using the normal distribution tended to underestimate the 95% confidence interval, so quantile-based bootstrapped estimates from 10,000 re-samples are reported. All analysis was completed in R 2.10.0 (R Development Core Team, 2009), and diversity and species richness was estimated using the 'vegetarian' package (Jost, 2006).

Rainfall, vapor density, and temperatures were quantified using monthly minima, maxima, mean, and interquartile range (iqr). Only months which had a complete set of data were used for a particular site.

Only three sites were available for examining patterns with climate variables, so both the analysis and results are qualitative and preliminary. The ranks for each of the plant variables within the 2009 sites was computed, and this was compared with the climate variables for every month having a full monthly data set available. The relative representation of life forms and natives/non-natives was used to avoid confounding total cover with life form and native representation. Congruence of ranks was taken as a suggestion of an association for further study.

The potential relationships between quadrat-level species richness, species diversity, annual cover, perennial cover, shrub cover, native cover, and non-native cover (all except richness log10+1 transformed to meet model expectations) and the number of threecorner milkvetch individuals (log10+1 transformed) within each site and year were fit using a mixed model ANOVA with grid as a random effect. The structure of the spatial covariance was chosen by comparing the Akaike information criterion corrected for small sample size (AICC) among alternatives. The best fit was a two-dimensional exponential geometrically anisotropic spatial covariance structure. The minimum adequate model was determined by comparing nested models using AICC. The model that optimized AICC is presented. This analysis was performed in SAS v9.1 (SAS Institute, 2002-2003).

STICKY BUCKWHEAT – FIELD METHODS *(APPENDIX 4)*

Populations were considered for monitoring based on size, time available to survey historical sites, and whether populations could be relocated at historical sites. One population was selected for monitoring (Figures 32 & 33). Inferences could only be made about the strata upon which the monitoring occurred.

Due to the nature of the habitat, terrain and location of sticky buckwheat plants, a systematic sampling approach for monitoring sticky buckwheat was used (Figure 34). Two 50 × 100-m macroplots were placed within the Lime Cove population. Each macroplot location was selected in a stratified random approach by placing a "virtual grid" (in ArcMap 9.2) over known habitat after which random numbers were generated and a point selected (within the virtual grid). This random point translated to the high water corner (left end when facing the lake) of the macroplot. The macroplots were divided into 10 transects (1 × 100 m) that ran more or less perpendicular to the shoreline beginning at high water. A random starting point was selected along the upper 50m edge of the macroplot for transect placement and each transect was spaced five meters apart. Quadrats (1 × 10 m) were placed along each transect beginning at zero with five meters separating each quadrat. The macroplots and transects were delineated using meter tapes and each quadrat was identified using flagging tied to stakes stretched across transects. Data was recorded on data sheets while in the field. Data gathered included: percent cover of all live plant species, percent cover of rock, sand, and litter and number of sticky buckwheat plants per m^2 within each quadrat. Percent cover was classified as: 1) 0-1%, 2) 1-2%, 3) 2-5%, 4) 5-10%, 5)10-25%, 6)25-50%, 7) 50-75%, 8) 75-95% and 9) > 95%. These were ultimately analyzed using mean values. Because the target species was an annual plant, individual GPS coordinates were not necessary for spatial analysis. Sticky buckwheat spatial distribution within the macroplot was estimated by recording the number of plants within 1 m^2 sections of each quadrat on a field map. The field map was digitized in ArcMap 9.2. Dead material of saltcedar and Russian thistle were recorded separately from live plants.

Abiotic sampling at the sites consisted of collecting soil samples at six randomly selected points per macroplot in areas of high density (4 samples) and no density (2 samples). Soil analyses included: %CaCo3 (inorganic carbon), total carbon and nitrogen, pH, EC, and particle size. The information gathered will be analyzed and presented with the companion project, (2005-NPS-609-E). Rainfall, temperature, and relative humidity were collected at each site beginning in 2008.

Inventories for sticky buckwheat were conducted in 2008. The inventories included surveys of historical sites and an additional 20% in areas containing no known historical or currently known occurrences of this species.

STICKY BUCKWHEAT – METHODS OF ANALYSIS

The same procedure was used for sticky buckwheat that was described above for threecorner milkvetch, with the following exceptions. For the quadrat-level analysis, the mid-points of cover classes for litter, sand, and rocks were log10+1 transformed and added. 'Tracks' was fit separately from the rest of the independent variables because of its effects on the residuals (Table 6). Only two sites were surveyed in 2009, so no relationships with environmental variables could be obtained.

For all four covered species a highly accurate GPS unit (primarily the 2005 Trimble GeoXL, but occasionally other similar units) was used to record easting, northing, and elevation at all plot corners. Occasionally, researchers needed to collect a plant within a plot for identification. Upon completion of monitoring each year, researchers entered data into the appropriate databases.

RESULTS

WEATHER DATA

Twelve weather stations were established specifically for this project. Due to difficulties acquiring the station equipment, the units were installed in late 2008 early 2009 after initial monitoring had begun (Tables 2-5). The absence of early weather data limited the extent to which the analyses of relationships between plant populations and site-specific temperature and precipitation conditions could be examined. This was one of the main limitations of this study. To ameliorate this absence, available climate data from several sources are presented in this report. We used supplemental datasets in order to better assess the hypothesis that micro-climate is correlated with rare plant recruitment/germination. The intention of the NPS was to establish weather gauges at all of the monitoring sites to record annual rainfall over time in order to correlate weather patterns with rare plant population densities. These weather gauges have been established and long-term maintenance is planned.

Below, survey and inventory notes along with data analyses for each monitoring site are provided by species. Thirteen perennial plant species were identified as commonly associated with gypsum habitat, and thus Las Vegas bearpoppy and ringstem, during this study (Table 6). Sixteen annual and perennial species were identified as commonly associated with sand habitat, and thus threecorner milkvetch and sticky buckwheat, during this study (Table 7).

LAS VEGAS BEARPOPPY AND RINGSTEM: *INVENTORY RESULTS AND OBSERVATIONS*

One new population of Las Vegas bearpoppy in the Gale Hills area (BLM) was documented during the 2008 inventories (Figure 35). It was approximated that 3,000 individuals were growing in the area. No ringstem was found at the site.

Surveys for ringstem were conducted at Echo Wash, Rainbow Gardens, Gold Butte, Muddy River, and the Sunrise Hills areas in 2008-2009. We were unable to re-locate the historical Gold Butte population.

Las Vegas bearpoppy and ringstem generally are found in open spaces. At each site surveyed, we observed within site patchy distributions (areas of high, low, and no density within same sub-population) of Las Vegas bearpoppy and ringstem. Within the project areas, neither species occurred in washes that cut through gypsum habitat, but did occur in small drainages within the habitat. There did not appear to be any slope or aspect preferences for either species.

Generally, biological soil crusts are abundant on gypsum substrate but abundance and distribution of either species in relation to abundance of crusts was not apparent. We observed plants of both species growing in disturbed patches (foot/hoof prints) within heavily crusted areas. We also observed significant cattle damage at the Las Vegas bearpoppy monitoring site on Gold Butte and heard cattle in the area on one occasion.

LAS VEGAS BEARPOPPY

MONITORING RESULTS

Field maps showed slight clumping within plots in densely populated areas. Total cover varied among sites, but was stable between 2008-2009 (Table 8). The relative make-up of total cover, however, changed between the two years in a site-specific fashion. Percent cover of Las Vegas bearpoppy trended downward at all sites, significantly so for Gale Hills, Gold Butte and Road 100. Annuals were not included in sampling in 2008, so the numbers for overall diversity and richness for this year are misleadingly low. Species richness and diversity trended upwards from 2008 to 2009, even when annuals were excluded, but these differences were not significant (Table 9).

The number of Las Vegas bearpoppy individuals declined across years at all sites except Sunrise Hills (Table 10). We observed no significant trends between the number of plants at a site and the temperature measured from May to November (Table 11). More data is needed to explore these patterns. The vapor density had a slightly stronger correlation with plant presence, with higher minimum or maximum humidity in November or May corresponding to more Las Vegas bearpoppy plants. Sites that had a greater range of vapor density values in June and August also tended to have more Las Vegas bearpoppy individuals (Table 11). Finally, higher rainfall in July was positively correlated with Las Vegas bearpoppy presence.

Very few seedlings were recorded in either year. A summary of the monthly precipitation from weather stations at the six Las Vegas bearpoppy monitoring sites from January 2009 through November 2009 is provided (Table 2). Weather data from these gauges are preliminary until data from complete growing seasons (September-March) are collected.

Many of the measures describing the biotic community had a significant relationship with the number of Las Vegas bearpoppy on a local scale. The relationship between Las Vegas bearpoppy numbers and species diversity, proportion of perennials, proportion of shrubs, and total cover varied significantly by site and year (Table 12). Species richness did not significantly predict Las Vegas bearpoppy numbers, alone or within sites or years. The proportion of annuals was related to Las Vegas bearpoppy in different ways among sites, but was consistent between years (Table 12). Slopes were estimated for each biotic community variable alone to avoid misleading coefficients. Trends are reviewed below; some are significant, while others are notable for their consistency in trends across sites. In all but one site, Sunrise Hills, biodiversity was a stronger predictor of Las Vegas bearpoppy numbers in 2009 than in 2008 (Table 13). The number of Las Vegas bearpoppy was negatively related to the proportion of annual species in all sites. The proportion of perennials was a positive predictor of Las Vegas bearpoppy in 2008, but a negative predictor in 2009 in five of the six sites. (Table 13). In almost all sites, the number of Las Vegas bearpoppy was negatively correlated with the proportion of shrubs. The coefficients are provided for species richness, although their magnitude corroborates the ANCOVA result that richness was not a strong determinant of Las Vegas bearpoppy numbers. Total cover was either a positive or a negative predictor of Las Vegas bearpoppy individuals, depending upon year and site (Table 13). The slope was weak or negative in 2008, while in 2009 the slope for total cover was positive and large (with the exception of Sunrise Hills). Sunrise Hills stands out as different from the other sites in a variety of ways from this table. More data are necessary in order to determine the true trends across the range of the species.

The size class of individual plants predicted seeding success, and this pattern was consistent across sites (Table 14). The smallest individuals had a 26-37% chance of seeding, while the largest individuals had a 92-96% chance of seeding (Table 15). The effect of a plant's condition on seeding was dependent on the size class of the plant (Table 16; Figure 36).

RINGSTEM

MONITORING RESULTS

Ringstem populations at the monitoring sites appeared to be increasing across years (Table 17). At the three sites we surveyed, total cover was consistent between years and was under 10% in all three sites, but there was some variation among the three sites (Table 18). The relative make-up of total cover was consistent between years for shrubs and perennials. Annuals were not measured in both years, but in 2009 less than 10% of all vegetative cover was annuals (Table 19). Percent cover of ringstem was also consistent between years, and was relatively equal among sites (Table 18). Annuals were not included in sampling 2008, so the numbers for overall diversity and richness for this year are slightly low. Richness and diversity values with and without annuals are presented, but annuals represented such a small portion of cover that results were unchanged. Species diversity and richness did not differ between years in Road 100 and Sunrise Hills, and the relative magnitude of those values suggests high evenness among species represented (Table 18). Richness and diversity increased in 2009 relative to 2008 in the Valley of Fire ringstem site at the quadrat level.

At the whole-plot level, annuals disproportionately contributed to species richness relative to their cover in 2009, but not 2008, for Road 100 and Sunrise Hills (Table 18). When annuals were excluded, the diversity values relative to richness at the whole-plot level suggested high species evenness in Road 100, moderate species evenness in Sunrise Hills, and fairly low species evenness in Valley of Fire ringstem site [due to *Yucca utahensis* McKelvey (Utah yucca), and *Sporobolus airoides* (Torr.) Torr. (alkali sacaton)]. The average cover by quadrat is provided in the 'vegetative community' tab of the output file to help interpret these results.

Several environmental variables were congruent in rank with plant variables in 2009 (Table 20). The proportion of annuals matched with the minimum temperature during three months. The proportion of perennials, total cover, and cover of ringstem all ranked the same as variation in temperature (IQR=interquartile range) and vapor density during several months, maximum vapor density during July, and rainfall in July. Diversity and richness values matched with minimum, maximum and average vapor density, in addition to variation in temperature. More data are needed to verify these patterns.

Many of the measures describing the biotic community had a significant relationship with the number of ringstem on a local scale. The relationship between ringstem numbers and species diversity (both linear and quadratic portions), proportion of perennials, proportion of shrubs, and total cover varied significantly by site and year (Table 21). Species richness did not significantly

predict ringstem numbers, alone or within sites or years. The proportion of annuals was related to ringstem in different ways among sites in 2009 (Table 21).
Slopes were estimated for each biotic community variable alone to avoid misleading coefficients. Trends are reviewed below; some are significant, while others are notable for their consistency in trends across sites. Diversity was not strongly related to ringstem in Sunrise Hills, but for the other two sites, the relationship was strongly concave, with low and high extreme values of diversity being associated with low numbers of ringstem. Intermediate levels of diversity were associated with higher numbers of ringstem in Road 100 and the Valley of Fire ringstem site (Table 22). The relationship between the number of ringstem and the proportion of annual species had a negative trend in Road 100, but not in the other two sites. The proportion of perennials was a positive predictor of ringstem in 2008 for Road 100 and Sunrise Hills, but this relationship was weak, absent or negative in 2009 and for the Valley of Fire ringstem site in both years. Because shrub cover was negatively correlated with perennial cover, we observed a negative relationship between proportion shrubs and number of ringstem for Road 100 and Sunrise Hills in 2008, but weak or positive coefficients for 2009 at the Valley of Fire ringstem site (Table 22). The coefficients are provided for species richness, although their magnitude corroborates the ANCOVA result that richness was not a strong determinant of ringstem numbers. Total cover did not have a strong relationship with ringstem numbers, probably due to the low cover overall (Table 18).

The size of plants played a significant role in predicting bolting success across all sites as evaluated by AICC (supplementary material). Smaller plants' bolting success was highly dependent on the site, ranging from a low of 8% in 2008 Sunrise Hills to a high of 76% in Road 100 in 2008 (Table 23). Larger plants also varied by site, with a low of 57% in Sunrise Hills and a high of 100% in Road 100. We observed significant temporal variation in Sunrise Hills but not in Road 100. The number of leaves as a measure of size provided similar estimates of bolting success for 2009 (Table 24). It is notable that although the plants at the Valley of Fire ringstem site were substantially smaller than those at Sunrise Hills (Table 25), their bolting success was similar. The plants at the Road 100 site were both larger (Table 25) and had greater bolting success than plants at the other two sites (Tables 23, 24). More data are necessary in order to determine the true trends across the range of the species.

The complete statistical analysis of ringstem can be found in Appendix 7.

PHENOLOGY STUDY

To date, we have observed significant flower and fruit production in undamaged plants, with up to 181 buds and 26 open flowers on a given plant. Many of the plants in the study populations have suffered from chewed or broken stems across both years, assumedly from rabbits or local rodents and possibly wind damage.

Each site had plants that did not flower because of lack of bolting or stem damage (chewed or broken stems). Therefore, for flowering metrics the sample number ("n") was 16 at Echo Wash, 6 at Road 100, and 10 at the Valley of Fire ringstem site.

Maximum stalk height was the only morphologically significant predictor of flowering duration ($P = 0.0004$, $r^2 = 0.34$). No other variables (leaf number or number of flowering stems) were correlated with duration of flowering. There was no difference in length of flowering duration across sites ($P > 0.05$). Mean duration across sites was 130 ± 6 days.

Echo Wash and Road 100 consistently reached each flowering stage earlier than Valley of Fire (between six and eight days earlier), until the later stages (stage 4 & stage 5) where only Road 100 and Valley of Fire differed from each other ($P < 0.03$ for all analyses; Figure 37). Plants were consistently producing new buds (stage 1 flowers) almost throughout the entire growing season, only tapering off significantly in the last few sampling dates (late October – early November, Figure 38). Few of the stage 1 flowers made it to stage 5 (2% of 126 marked buds, Bangle, *pers. obs.*) and only on the last three sampling dates were more than 20% of the total number of reproductive structures on a given plant in stage 5. Because flowers open for just one evening, and if the flower is fertilized the ovary immediately begins to swell there are rarely more than 20% of the total number of reproductive structures on a plant comprised of flowers in stage 2 and stage 3. As expected, toward the end of the growing season a greater proportion were in stage 4 and 5, but the persistence of bud production kept the other stages generally below 40%.

Echo Wash and Valley of Fire populations had greater leaf numbers than did Road 100 overall, however, this overall response is coupled with a time interaction wherein plants at Echo Wash consistently lost leaves through time, while Valley of Fire retained leaf numbers throughout the year (Figure 39a). Plants at the Echo Wash site had greater stalk number and stalk height than at the other two sites (Figures 39b & 39c). However, while Road 100 produced more stalks than the Valley of Fire site, average stalk height was equivalent. Additionally, both Echo Wash and Road 100 lost stalks throughout the year, whereas Valley of Fire was relatively consistent. This may be due to more active herbivory at the other sites. Leaf number was a significant predictor of stalk number in a given plant ($P < 0.0001$, $r^2 = 0.83$), but not stalk height ($P > 0.05$; Figure 40). The relationship between leaf number and stalk number or stalk height did not differ among sites.

Initial pollinator observations were also conducted for this project. We observed that the white-lined sphinx moth (*Celerio lineate*) appeared to be the main nighttime pollinator; however flowers were also visited by a generalist bee (species unknown) in the early evening and morning.

THREECORNER MILKVETCH

SURVEY RESULTS

The Bark Bay, Meadows, and Lime Cove populations historically supported few individuals and no modern surveys have relocated any threecorner milkvetch at these locations. Modern surveys at California Wash, Mormon Mesa, and Muddy River populations found few to no threecorner milkvetch plants and were not included in the selection process. The health and status of the Mud Lake, Toquop Wash, Town Wash, Logandale, Valley of Fire, and Virgin River populations were unknown at the beginning of this project and thus were not considered. Although several areas that historically supported threecorner milkvetch were surveyed, surveys should not be considered comprehensive.

One new population was found from these surveys and was located on NPS land near the Valley of Fire Wash. This population may be an extension of the historical "Valley of Fire" population, but this new area was not known (to the previous 2 contract botanists at NPS) to support threecorner milkvetch and is thus reported as new in this document.

- Population found on 4/13/2009 – est. plants 50-100 (730,025E; 4,032,185N)
- Two threecorner milkvetch plants found on 4/13/2009 (730,275E; 4,032,952N)

MONITORING RESULTS

The number of threecorner milkvetch individuals declined across years at Sandy Cove (Table 26). All sites were similar in total cover, although Sandy Cove had significantly less total cover in 2009 than in 2008 (Table 27). Native cover was high in these sites compared to non-native cover. Between sites, non-native cover was substantially higher in 2009 at Weiser Wash and slightly higher in 2009 at Ebony Cove than at Sandy Cove. Sandy Cove in both years had lower quadrat-level richness and diversity than Ebony Cove and Weiser Wash in 2009. On the whole-plot scale, Sandy Cove had greater species richness, but lower species evenness than Ebony Cove and Weiser Wash, suggesting stronger dominance by the most common species, particularly the top two species (Table 28-29). More data are necessary in order to determine the true trends across the range of the species.

Complete statistical analyses of both sand species can be found in Appendix 8.

STICKY BUCKWHEAT

SURVEY RESULTS

In 2008, surveys for sticky buckwheat were conducted at Overton Beach Road and in the Black Mountains, NV area of LMNRA (from Ebony Cove to Middle Point). Approximately 100-150 plants were found at the Overton Beach Road site and 50-100 plants near Ebony Cove. No new populations were found.

MONITORING RESULTS

Sticky buckwheat populations at the monitoring sites appeared to be increasing across years (Table 30). Both sites were similar in total cover, perennial cover, and annual cover (Table 31). Shrub cover was significantly higher in the Glory Hole site compared to Lime Cove. Native cover was low in these sites compared to non-native cover. Native and non-native cover was approximately equal in the Lime Cove sites, while non-native cover was at least three-fold greater than native cover in Glory Hole. Glory Hole in 2008 had lower species richness than Glory Hole in 2009 or Lime Cove in either year, but diversity was lower in 2009 Glory Hole, suggesting a few dominants rather than a community with high evenness. On the whole-plot scale, sites in 2009 had greater species richness, but lower species diversity, than in 2008. This pattern suggests stronger dominance by a few species in 2009 compared to 2008 (Table 32). The relative representation of the most common species confirms this supposition, particularly for the most common species, which were all non-natives.

The presence of sticky buckwheat was positively related to native cover at Lime Cove and negatively related to non-native cover at Glory Hole (where non-native cover dwarfed native cover; Table 33). Native cover and species richness were moderately correlated (ρ=0.610; Spearman rank correlation). Diversity and richness were correlated (ρ=0.677). Annual cover and non-native cover were positively correlated (ρ=0.691), and non-native cover was negatively correlated with diversity (ρ=-0.696). More data are necessary in order to determine the true trends across the range of the species.

Complete statistical analyses of both sand species can be found in Appendix 8.

DISCUSSION:

LAS VEGAS BEARPOPPY

Very few seedlings were recorded either year of monitoring suggesting that environmental conditions may not have been suitable for a recruitment event. Wet, cold winters are thought to cause large recruitment events the following spring. Neither 2008 nor 2009 experienced heavy rainfall which may have contributed to low recruitment.

In the early stages of this long-term monitoring project it is difficult to state with any certainty whether rainfall and/or temperature have influenced the abundance of Las Vegas bearpoppy. These declines may be attributed to the normal fluctuations a Las Vegas bearpoppy population experiences as members of older cohorts die off. Since there was little to no recruitment in the last two years, we would expect to see some declines in the overall number of individuals across sites. Long-term monitoring will show trends over time in Las Vegas bearpoppy populations across the range of the species. It is with this long-term dataset that we may determine which variables such as rainfall, temperature, Rh, plant community composition, biological crust cover/composition, and soil chemistry contribute to the overall health and success of populations of Las Vegas bearpoppy.

RINGSTEM

Although five locations were surveyed for ringstem populations, surveys should not be considered complete for this species. This study did, however, expand the estimates of total population size across the species' local range.

The Nature Conservancy (2007) reported that ringstem populations are rare to non-existent on western exposures and flat sites. Although we didn't measure this variable in our study, our observations do not support this assumption. We noted no obvious aspect preference at any of the monitoring sites or other ringstem populations. In addition, the Valley of Fire site is almost completely flat and it supports a significant number of ringstem.

It appears that recruitment occurred in 2009 at all three monitoring locations. Little is known about the germination requirements of this species, so it is difficult to explain what caused the recruitment event. Long-term monitoring will add to our knowledge of the biology of this species. It is currently unknown how rainfall, temperature, Rh, plant community composition, biological crust cover/composition, and soil chemistry contribute to the overall health and success of ringstem populations.

THREECORNER MILKVETCH

Modern surveys of historical threecorner milkvetch populations should not be considered complete. Several historical populations were surveyed and very few threecorner milkvetch were found at each surveyed location. The new location near Valley of Fire Wash and surrounding areas within LMNRA should be surveyed again in a year of average to above average rainfall to obtain a better estimate of the population size.

It is currently unknown what environmental factors affect threecorner milkvetch success within each population. Winter annuals typically respond to increased seasonal rainfall by germinating at higher densities. Our observations in recent years support this, but more data from this long-term monitoring project are necessary to effectively correlate environmental factors such as rainfall and temperature to increased germination of threecorner milkvetch.

Large areas of the dunes around Sandy Cove have been covered with Mediterranean grass, which appears to be stabilizing the active portions of the dunes. If Mediterranean grass continues to spread, this invasive species may eventually alter the loose sand habitat enough that declines in the threecorner milkvetch population may occur. Exotic species of annual grasses are a major factor in stabilizing sand sheets and dune habitats throughout the range of threecorner milkvetch (TNC, 2007). There are other threecorner milkvetch populations outside of LMNRA that occur on somewhat stabilized sands and invasive annual grasses are also present at these sites. These threecorner milkvetch populations however, appear to be much smaller than at Sandy Cove, but whether these small population sizes result from the stabilized sands and invasive grasses is only speculation (Bangle, 2005c).

Invasive species may have an effect on threecorner milkvetch populations. The Weiser Wash site occurs on BLM lands where little to no Sahara mustard control has taken place. The data show there is an effect of invasive species on the presence of threecorner milkvetch at this site compared to the two sites located on NPS lands where active and consistent management of Sahara mustard has occurred. Other factors may contribute to an increased invasive species presence at Weiser Wash and a decrease of threecorner milkvetch. The data from this project was not designed to specifically track Sahara mustard populations and thus we can only make assumptions about how it is affecting the native annuals including threecorner milkvetch. This monitoring project was designed for long-term data collection at several sites across the range of the species. Information gathered from this dataset will increase our knowledge in how environmental factors and invasive species affect populations of threecorner milkvetch.

STICKY BUCKWHEAT

Modern surveys of historical sticky buckwheat habitat and additional potential habitat should not be considered complete. Even though no new populations were discovered from modern surveys, several sites were confirmed to still support sticky buckwheat (Middle Point, Cove north of Middle Point, Overton Beach Road, Klein Hole, and Virgin River Dunes).

Since sticky buckwheat is an annual plant species, and numbers within populations can vary broadly, it is likely these fluctuations are due to annual temperature and precipitation conditions.

Invasive species may have an effect on sticky buckwheat. The data show there is an effect of invasive species on the presence of sticky buckwheat Glory Hole. This indicates that saltcedar and Russian thistle may be out-competing sticky buckwheat by occupying open spaces and using valuable resources. Sahara mustard occurs at both sites but is found lower on the drawdown zone than sticky buckwheat, however, Sahara mustard is spreading and will likely invade the rare plant habitat in the area. More data are necessary to determine if invasive species have a negative effect on sticky buckwheat populations over time.

CONCLUSION:

Las Vegas bearpoppy appears to rely on high reproductive output and long lived seeds in the seed bank for population persistence (Mistretta *et al.*, 1996). This perspective is generally supported by overall patterns of decline in abundance across most years punctuated with large recruitment events in years of high rainfall. Data from the current study support the "boom and bust" hypothesis that characterizes the Las Vegas bearpoppy life cycle, however more data are needed to determine the exact range of temperature and rainfall needed to support healthy Las Vegas bearpoppy populations. The purpose of this research project was to begin to evaluate trends over time with the intention of monitoring these populations over the long term. These data are necessary in order for land managers to make more informed decisions about habitat viability, threat abatement, and species status assessments.

Typically, invasive species are not recorded in high densities on gypsum soil because of the harsh soil conditions. The recent spread of the invasive species African malcolmia may pose a more serious threat to gypsum habitat and Las Vegas bearpoppy and ringstem populations than other invasive species. African malcolmia prefers clay soils and to lesser extent soils with some percentage of gypsum (Bangle, *pers. obs.*; Abella *et al.*, 2008). Abella *et al.* (2008) reported that African malcolmia occurred on more than twice as many gypsum soil types than expected based on its distribution among all soil types evaluated. There is no evidence to suggest that this species requires or prefers gypsum as it was also recorded in 50 non-gypsum soil types (Abella *et al.*, 2008). However, several gypsum populations on NPS lands are bordered by dense populations of African malcolmia some of which are found growing among Las Vegas bearpoppy and ringstem plants. Research is needed to increase knowledge of this species' distribution and potential effects on rare plants and rare plant habitat.

Invasive species may be a serious threat to the overall health and success of threecorner milkvetch and sticky buckwheat populations. Our observations and preliminary data suggest that these rare plants may have already been affected. More research is needed to better understand the effects of invasive species such as Sahara mustard in sand habitat associated with threecorner milkvetch and sticky buckwheat. Sahara mustard grows much taller and larger than threecorner milkvetch and sticky buckwheat and may be a direct threat. This larger, invasive species may out-compete low growing native plants.

RECOMMENDATIONS AND FURTHER RESEARCH NEEDED:

Whether a population is decreasing, constant, or increasing is a powerful driver for management decisions about whether or when to intervene (Philippi *et al.*, 2001). It is recommended that this long-term monitoring program continues in order to develop a better understanding of what environmental stressors are affecting rare plant populations in Clark County over time.

The continuation of long-term monitoring of select populations of rare plants is vital for conservation of these four species. We can only speculate about how climate change may affect these rare plants and other plant species overtime. In addition to the valuable rare plant monitoring data collected throughout long-term studies, tracking change over time in the plant communities associated with Las Vegas bearpoppy, ringstem, threecorner milkvetch, and sticky buckwheat is invaluable and may be a good gauge for evaluating climate change effects.

LAS VEGAS BEARPOPPY AND RINGSTEM

Long term species conservation should be centered on the protection of large areas of occupied habitat, including adjacent non-gypsum habitat that can support pollinator populations during the periods when Las Vegas bearpoppy is present only as a seed bank (Meyer and Forbis, 2006).

Additional surveys should be conducted for ringstem as there are additional areas it is suspected to grow that have not yet been explored. How crust density and composition affect germination in Las Vegas bearpoppy and ringstem is unknown. Data from the abiotic plots may reveal a correlation between rare plant abundance and crust cover. The results from the abiotic plots and the soils analyses will be presented with the MSHCP funded project (2005-NPS-609-E) which was funded to support the work presented here.

The experimental design for both Las Vegas bearpoppy and ringstem appear to be suitable for gathering population estimates at select populations. We recommend continuing with the current methodologies described for both species. (Appendices 1 & 2).

We recommend that the Gale Hills site be excluded from further monitoring because the terrain proved to be challenging to move around in thus increasing investigator impact beyond what we felt was reasonable. A new site could be added in future monitoring years in place of this site.

THREECORNER MILKVETCH AND STICKY BUCKWHEAT

Although threecorner milkvetch and sticky buckwheat are listed as critically endangered under Nevada State law, there are concerns that the effectiveness of the State's permit process yields inadequate protection and mitigation.

In addition to surveys and monitoring within LMNRA, we recommend thoroughly surveying all threecorner milkvetch and sticky buckwheat known sites. This would allow for an evaluation of the current status of the species.

Since 1995, invasive species have played a role in altering the Mojave Desert ecosystem. Several threecorner milkvetch sites located on BLM lands have experienced invasions by Sahara mustard. The assessment of the overall status of threecorner milkvetch and sticky buckwheat appears vital following the 2005 population expansion of Sahara mustard to determine if new, more aggressive management strategies are necessary across their range. Once Sahara mustard has established on a site, control efforts could take years of removals to exhaust the seed bank if possible at all. Thus, annual mitigation efforts for this invasive plant appear necessary, particularly during wetter years (Bangle, 2005c).

Threecorner milkvetch occurs on loose sands. Threats to the three sites monitored during this project were from invasive species including Sahara mustard and Mediterranean grass. If these invasive plant species are allowed to establish extensive populations, then dune patches may become stabilized and unsuitable for threecorner milkvetch and other endemic sand-loving plants.

Specific concerns regarding invasive plant species within threecorner milkvetch and sticky buckwheat habitats have been expressed above. We reiterate here that the rare plant habitat supporting threecorner milkvetch and sticky buckwheat will require regular mitigation efforts to remove or reduce invasive species, particularly but not limited to Sahara mustard. Sahara mustard control methods have been tested and are recommended for inclusion into weed management strategies wherever Sahara mustard occurs as an invasive species (Bangle and Craig, *in prep*). For example, Triclopyr has been shown to significantly affect seed development in Sahara mustard when applied in the early fruiting stages of development; also, seeds from plants that are pulled and dropped in the field or pulled and separated from their rosettes germinate at significantly reduced rates. These control methods can help extend the window of opportunity for land managers to control Sahara mustard in the Southwest (Bangle and Craig, *in prep*).

Mediterranean grass and tumbleweed also appear damaging to threecorner milkvetch habitat. We recognize that attempting control of these additional invasive species throughout threecorner milkvetch and sticky buckwheat habitat is outside the current scope of reasonable recommendations, but in areas where habitat may become dominated and stabilized by these invasive plants, some efforts at restoring natural habitat conditions may be prudent.

Research on the vulnerability of sand dune and loose sand systems to stabilization effects of Mediterranean grass and other invasive plants should be initiated, along with monitoring efforts to determine long-term trends in the extent of unconsolidated versus stabilized sands. This information would help in developing specific management strategies for maintaining sandy habitats required by threecorner milkvetch and other rare plants at these sites.

A significant threat facing threecorner milkvetch and sticky buckwheat populations across their ranges is the development of wind and solar energy (Figure 41). Several of the potential development locations overlap with rare plant habitat and if developed could significantly reduce threecorner milkvetch and sticky buckwheat populations by eliminating suitable habitat further threatening these rare plant species. This threat confirms the need for thorough surveys of all known habitat for threecorner milkvetch and sticky buckwheat. If large patches of suitable habitat are eliminated because of energy development, it is critical that we know the health and status of the remaining populations so that land managers can make more informed decisions concerning the conservation of these species.

The threecorner milkvetch experimental design could be modified to increase the power and reduce the variability of the data. We recommend keeping the grid method and the same random locations used for this project but change the shape to a more long and linear grid and allowing for space in between sampling units thus establishing independence between sampling units.

It is also recommended that the experimental design for sticky buckwheat be modified. The design was tailored to the shoreline habitat along the Overton Arm of Lake Mead. In the future, additional sites should be monitored. Most of the remaining sites do not occur along the shoreline of Lake Mead. The specific design used for monitoring sticky buckwheat for this project would not work for other populations. A modified design is recommended.

FIGURES (PHOTOS AND MAPS)

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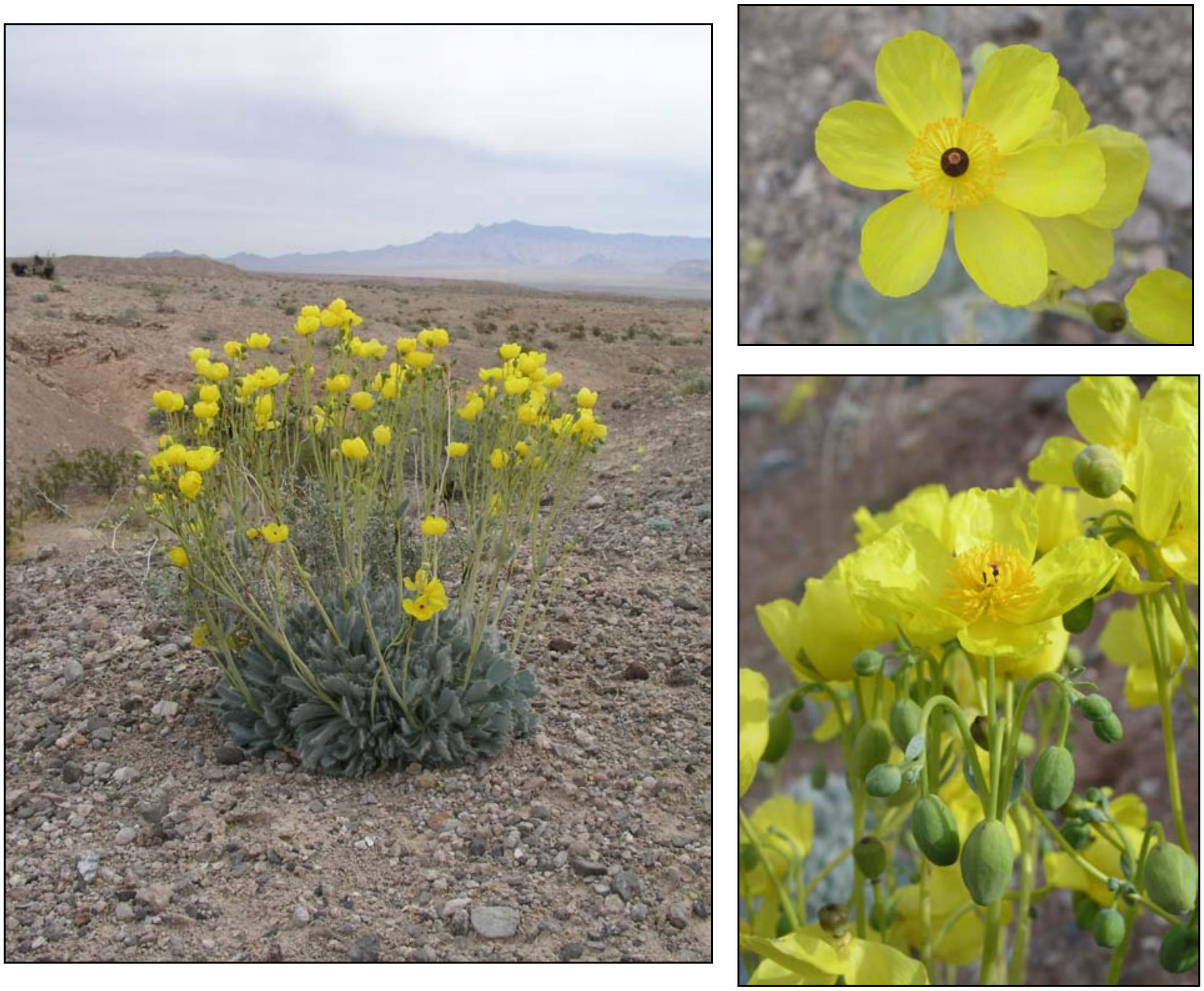


Figure 1. Photos of the Las Vegas bearpoppy. **A)** Las Vegas bearpoppy plant; **B)** Las Vegas bearpoppy flower; **C)** Las Vegas bearpoppy fruit.

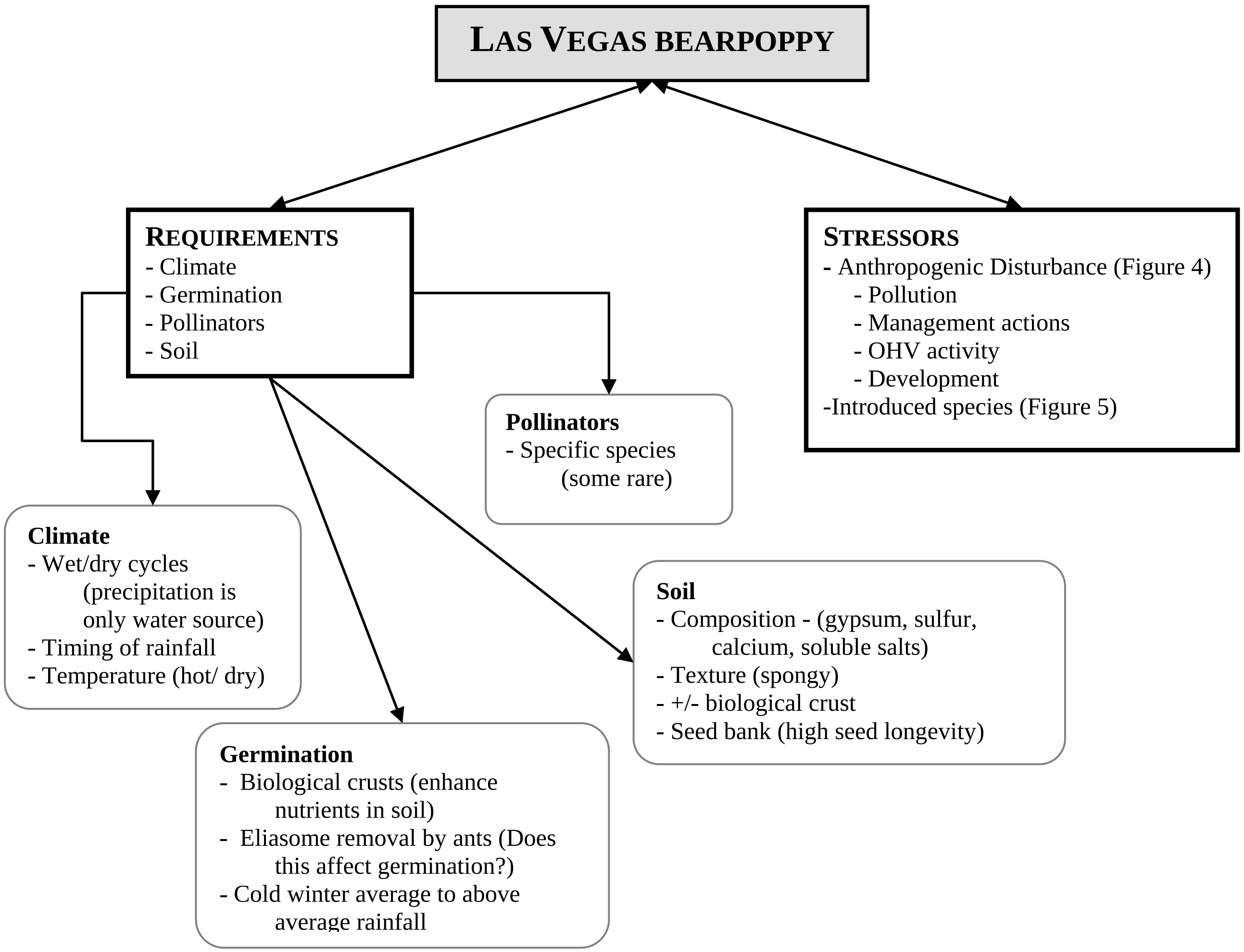


Figure 2. Conceptual model illustrating the requirements and stressors of Las Vegas bearpoppy.

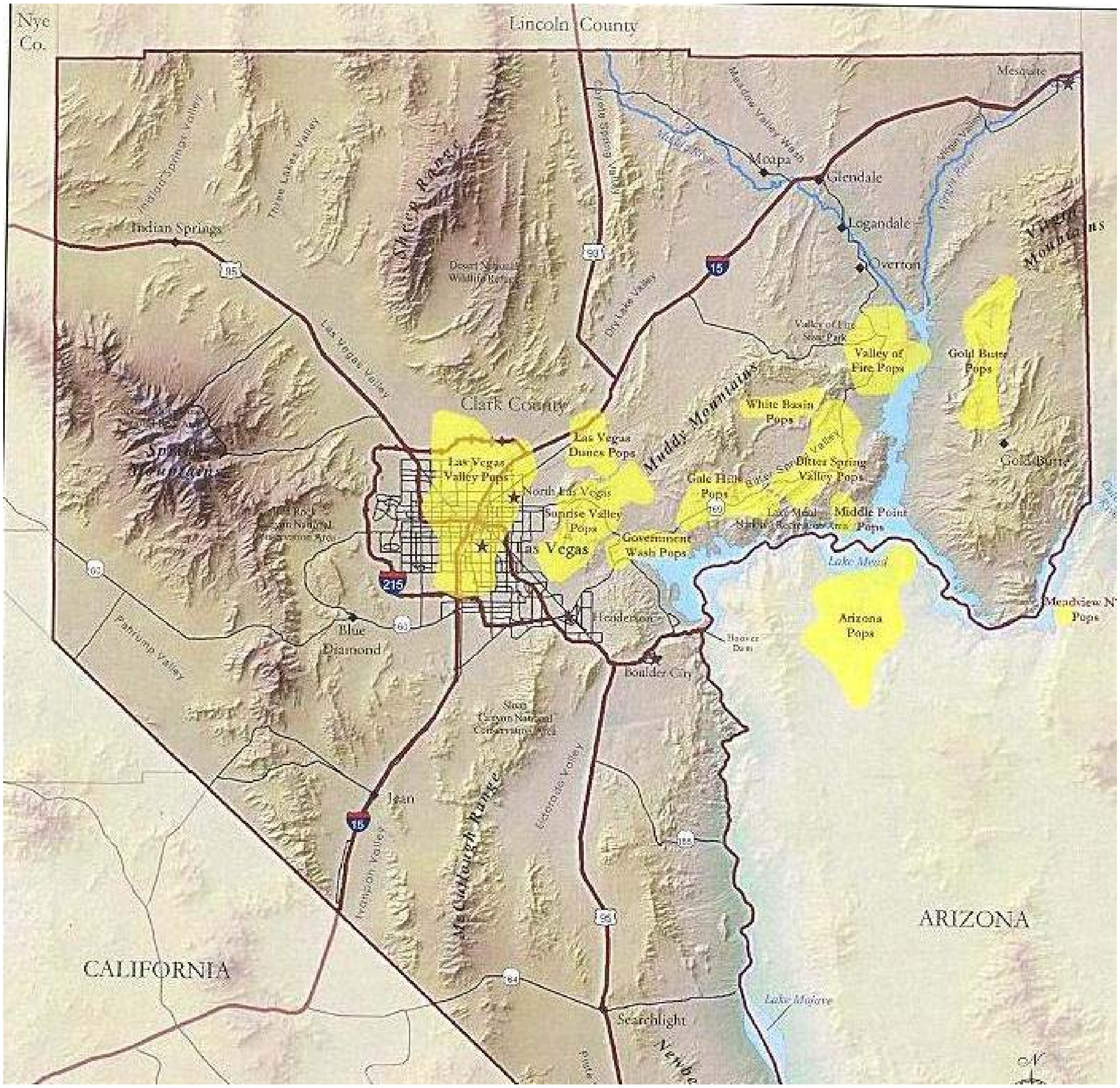


Figure 3. Reproduced from (TNC 2007) delineating the Clark County distribution of Las Vegas bearpoppy.

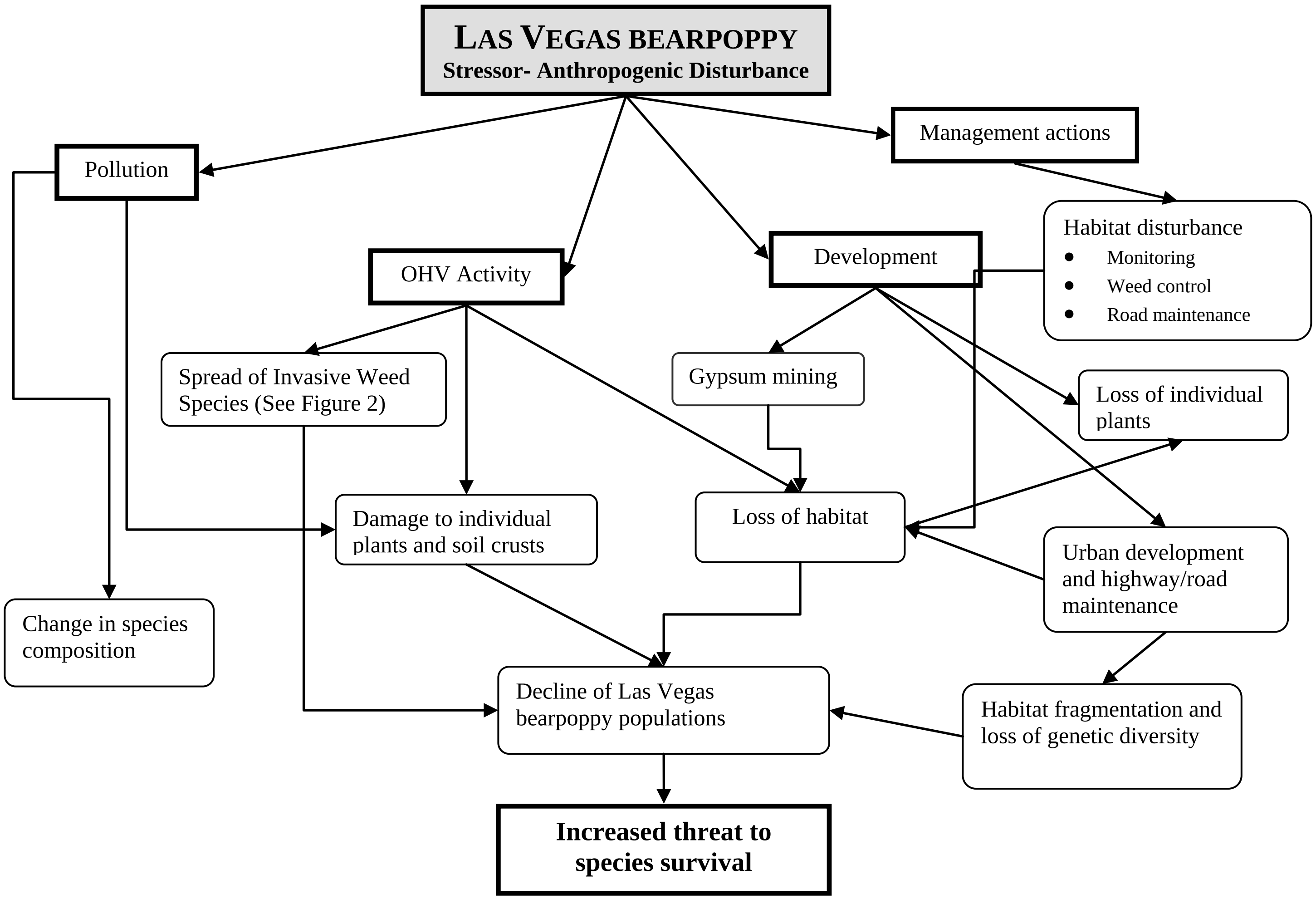


Figure 4. Conceptual model illustrating the effects of anthropogenic disturbance on Las Vegas bearpoppy habitat and populations.

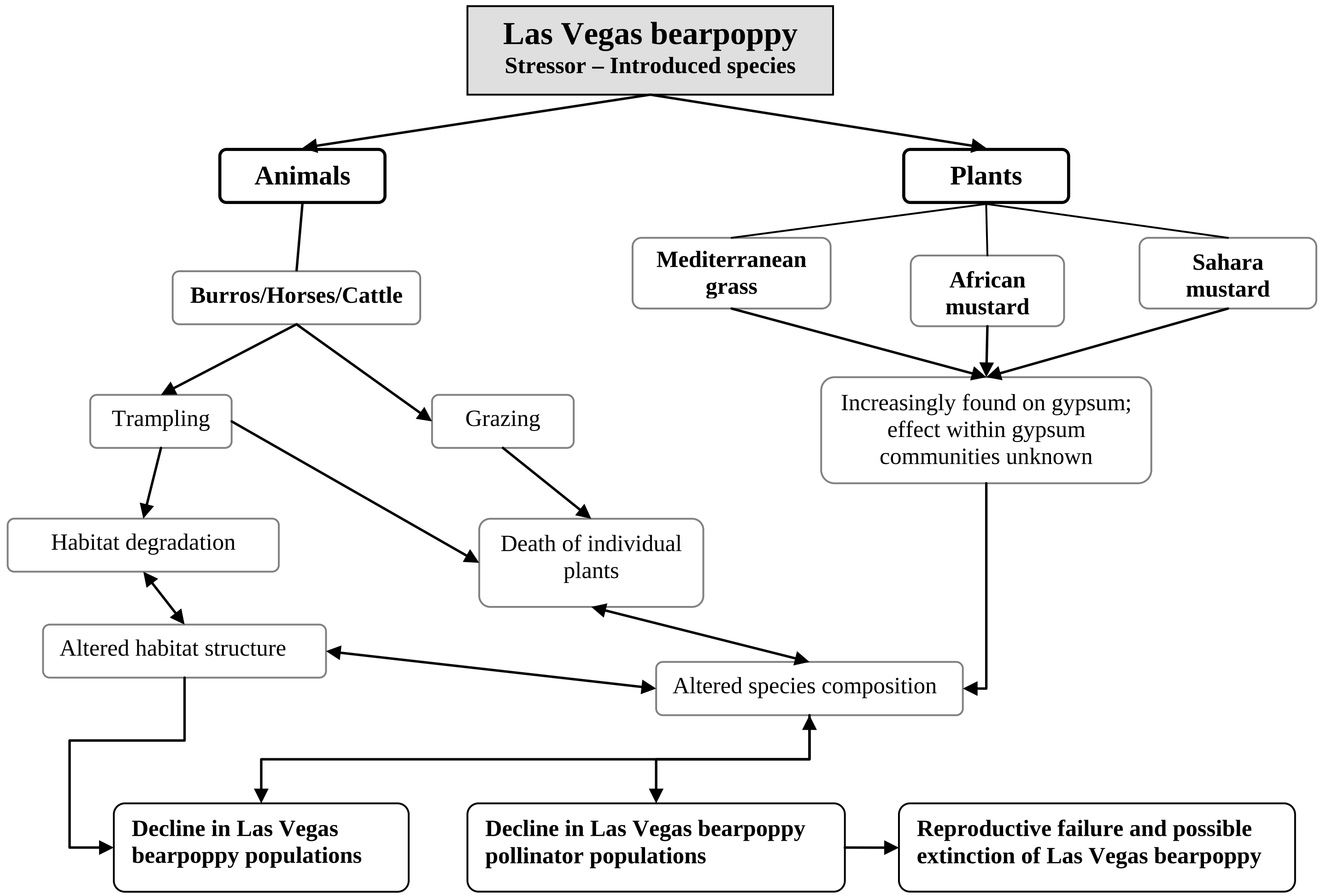


Figure 5. Conceptual model illustrating the effects of invasive species on Las Vegas bearpoppy.

Figure 6. Photos of ringstem. **A)** Ringstem plant; **B)** Ringstem sticky node; **C)** Ringstem flower.

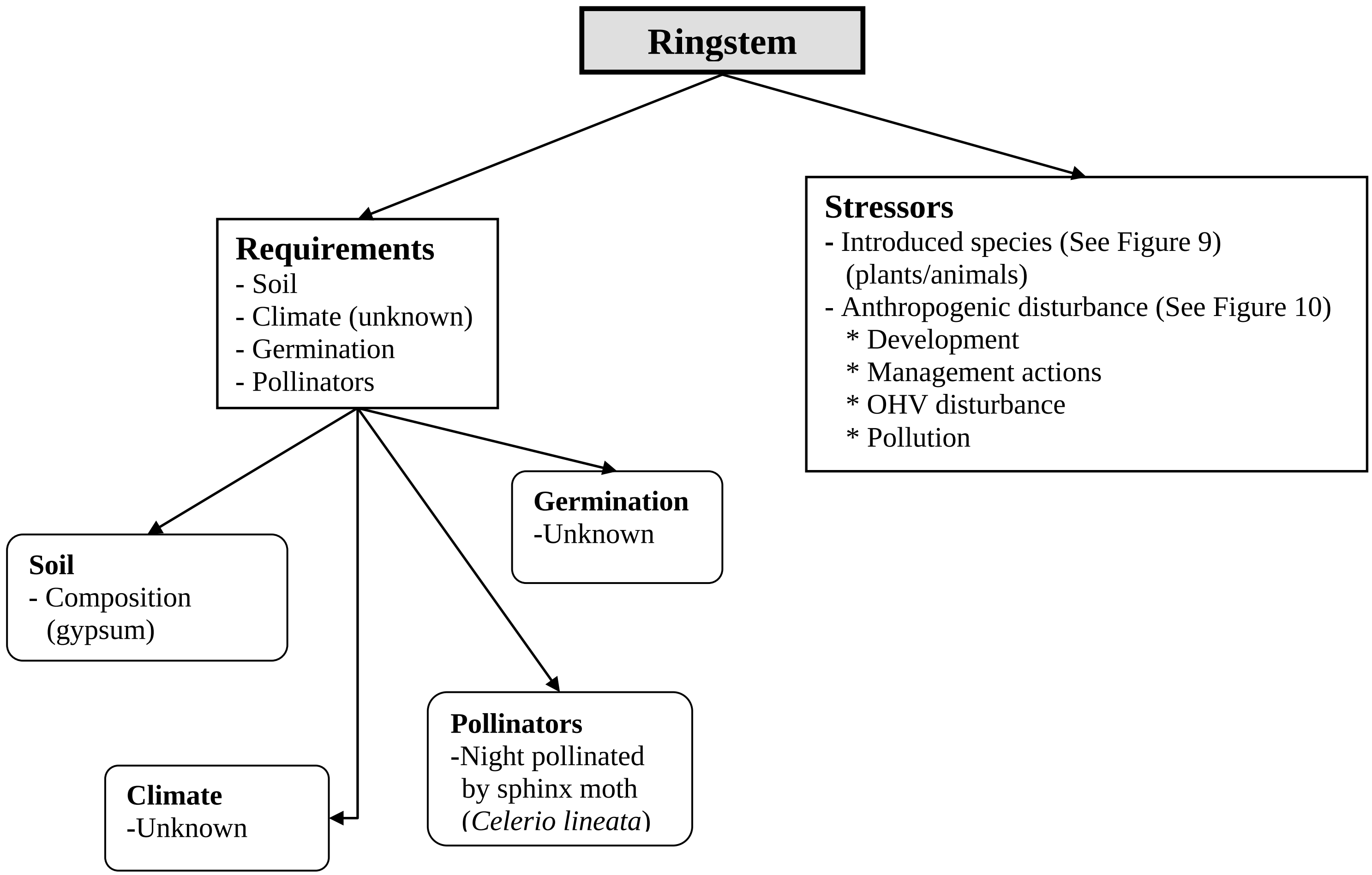


Figure 7. Conceptual model illustrating the requirements and stressors of ringstem.

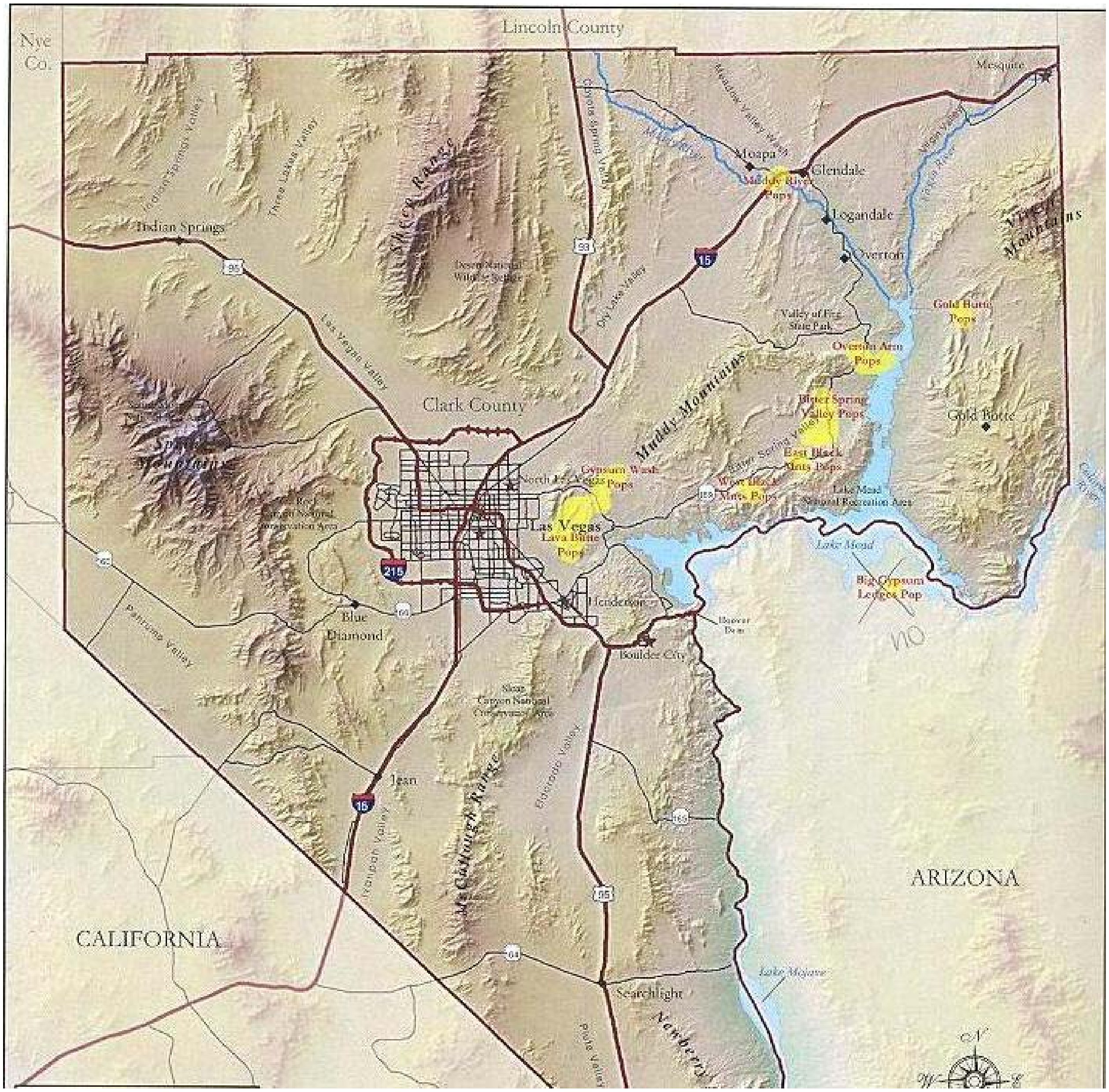


Figure 8. Reproduced from TNC 2007 delineating the known Clark County distribution of ringstem.

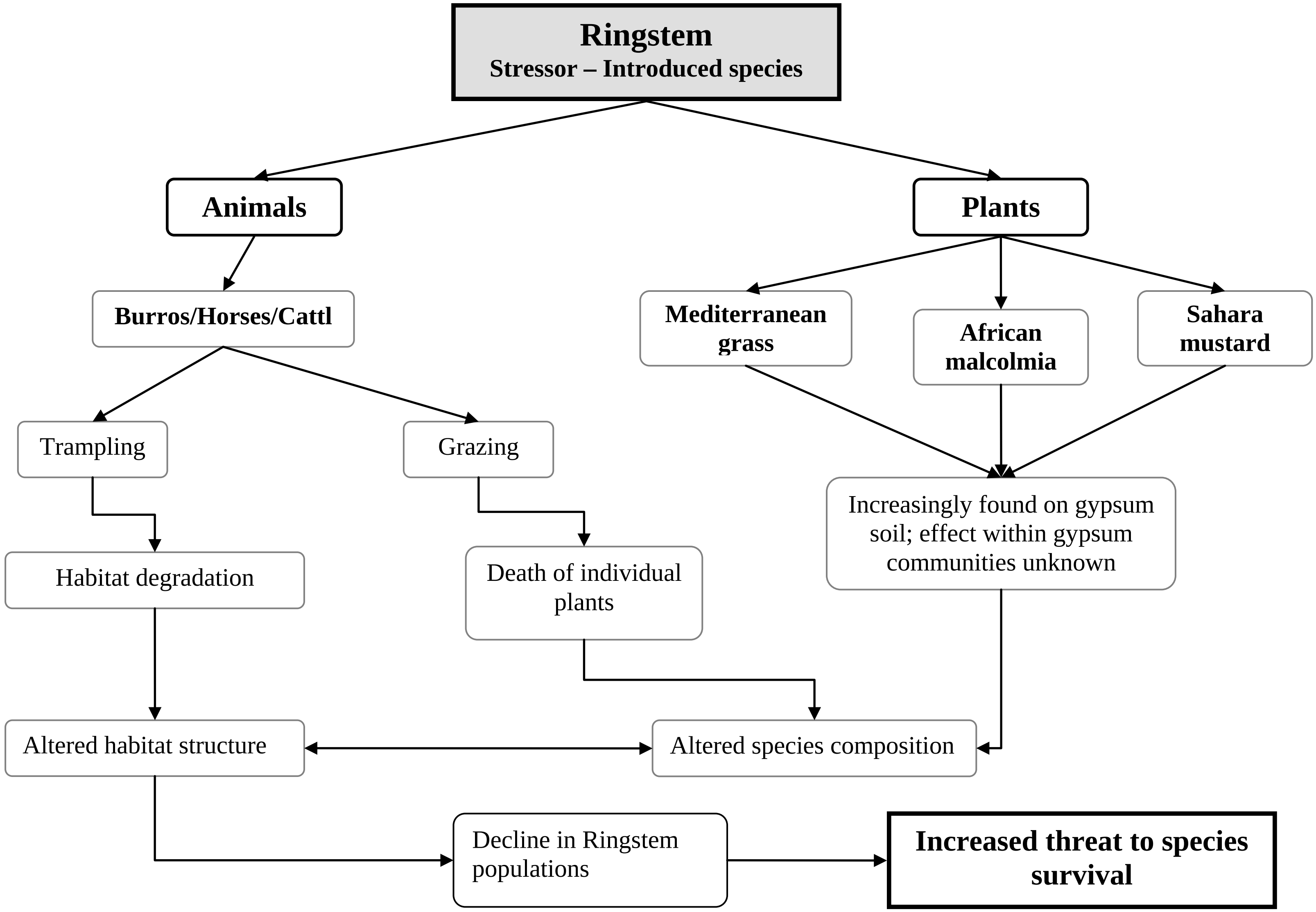


Figure 9. Conceptual model illustrating the effects of introduced species on ringstem.

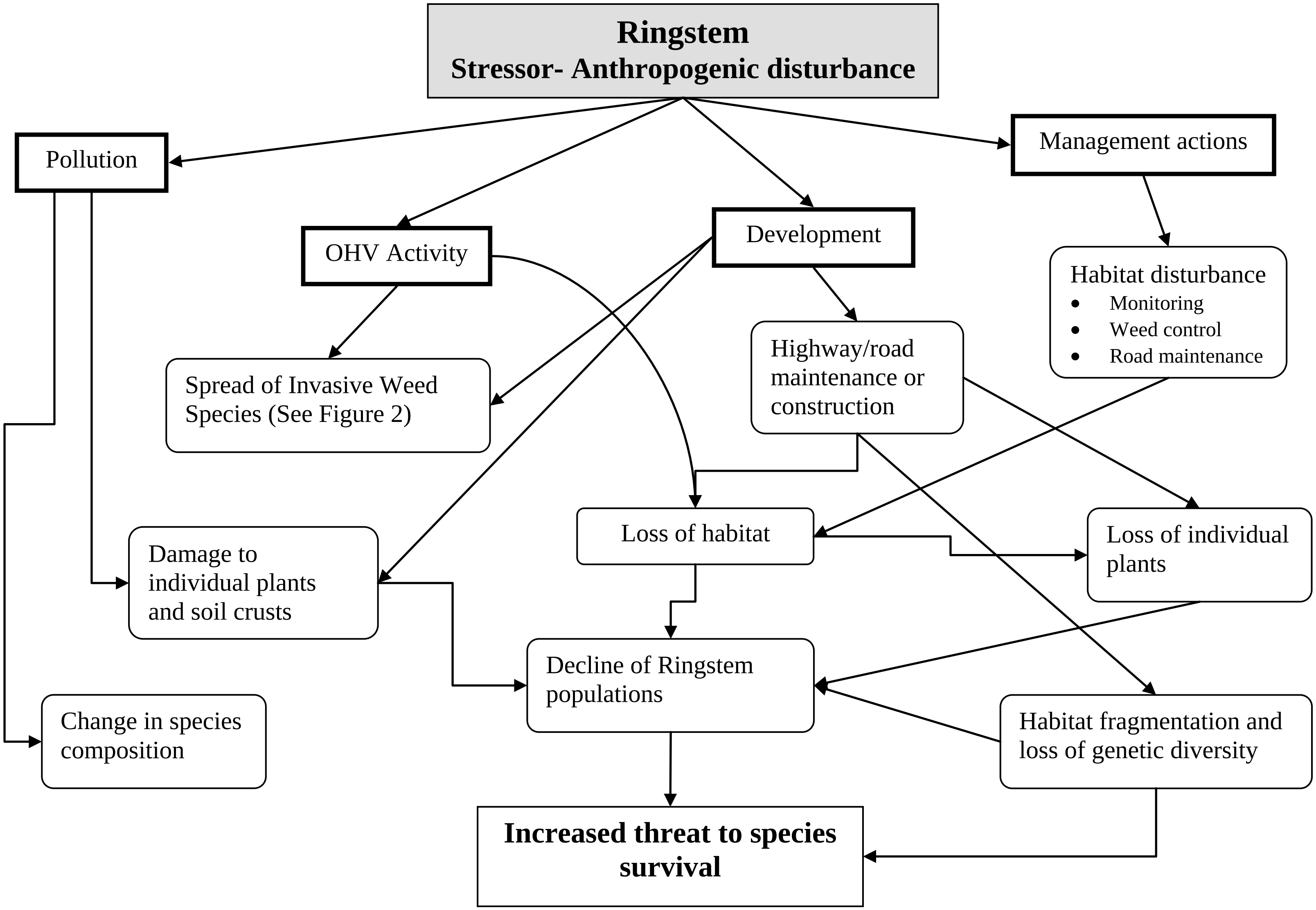


Figure 10. Conceptual model illustrating the effects of anthropogenic disturbance on ringstem.

Figure 11. Photos of three corner milkvetch. **A)** Threecorner milkvetch plant; **B)** Threecorner milkvetch flower; **C)** Threecorner milkvetch fruit.

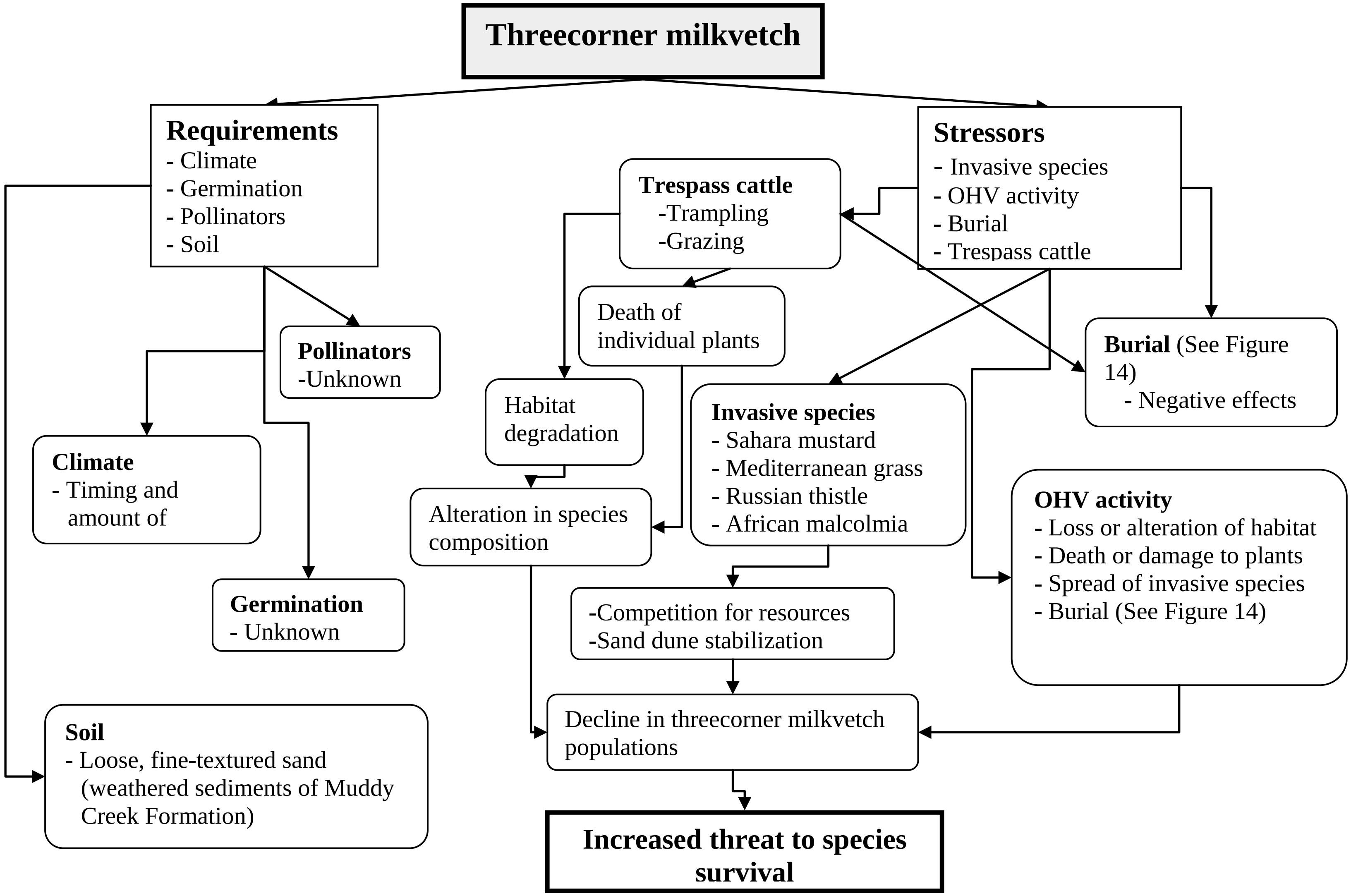


Figure 12. Conceptual model illustrating requirements and the effects of stressors on threecorner milkvetch.

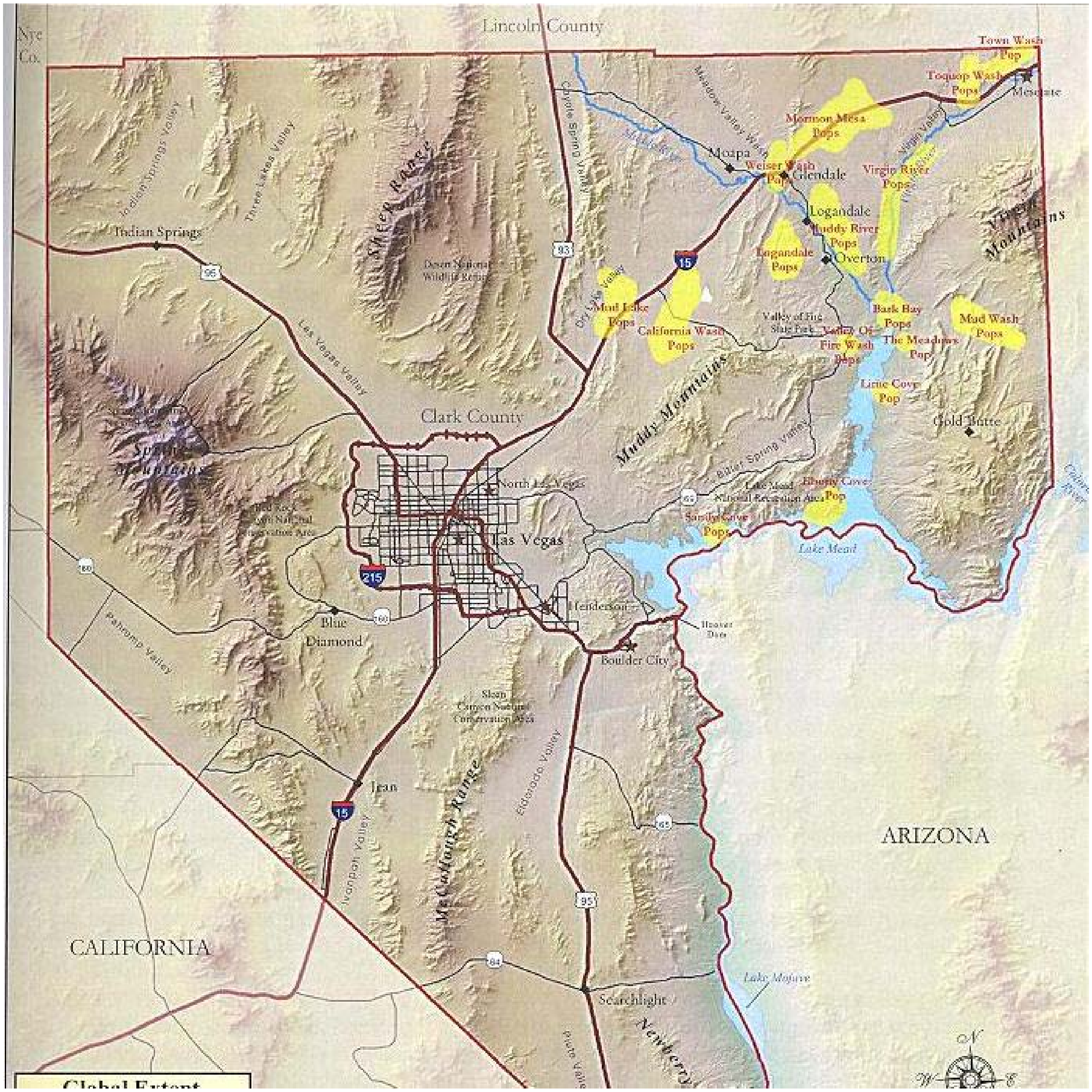


Figure 13. Reproduced from TNC (2007) delineating the known Clark County distribution of threecorner milkvetch.

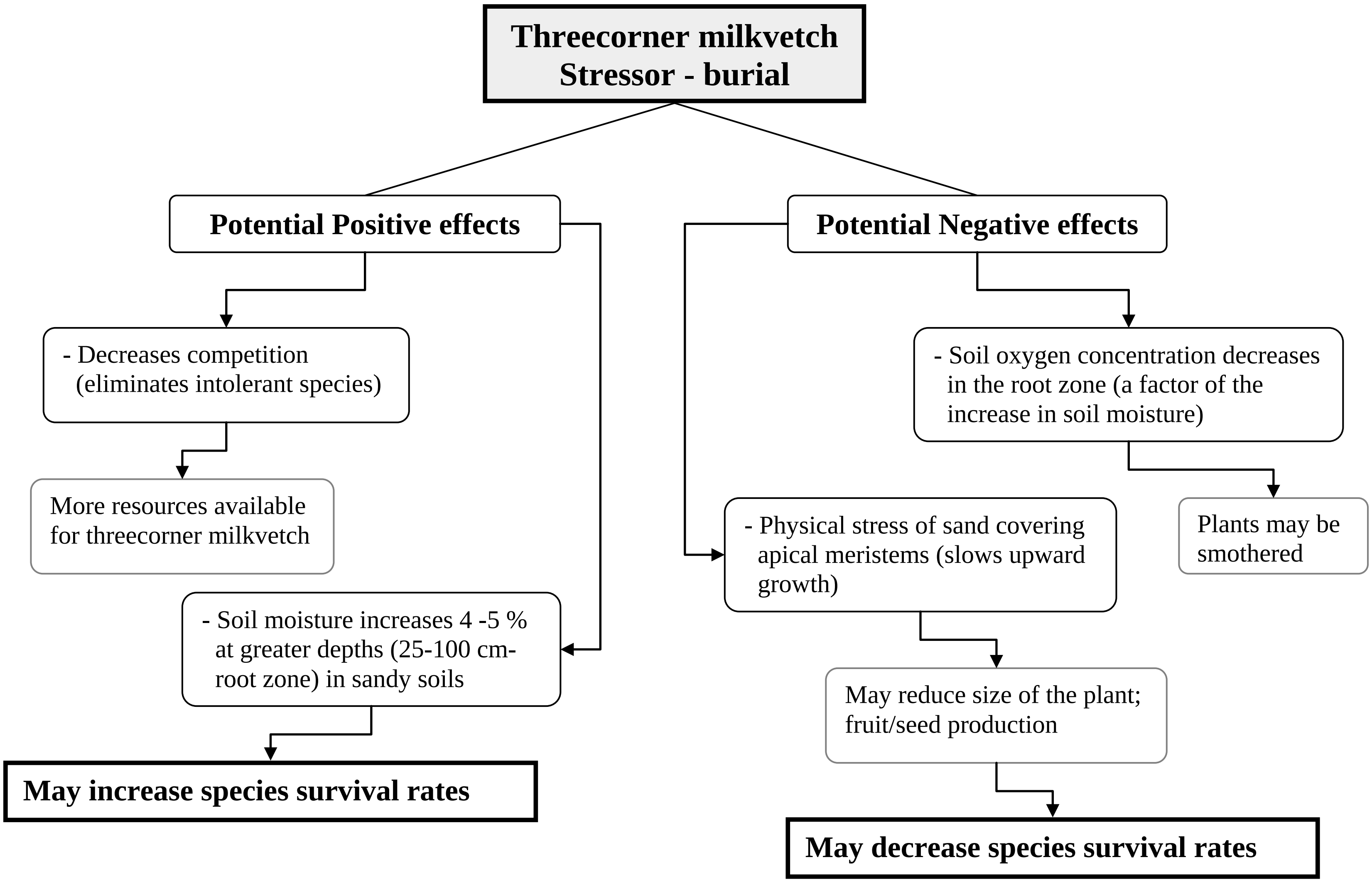


Figure 14. Conceptual model illustrating potential effects of burial by sand on threecorner milkvetch on Sandy Cove. Concepts based on research presented in the Canadian Journal of Botany 76: 713-738.

Figure 15. Photos of sticky buckwheat. **A)** *S*ticky buckwheat plant; **B)** *S*ticky buckwheat sticky stems; **C)** *S*ticky buckwheat flower.

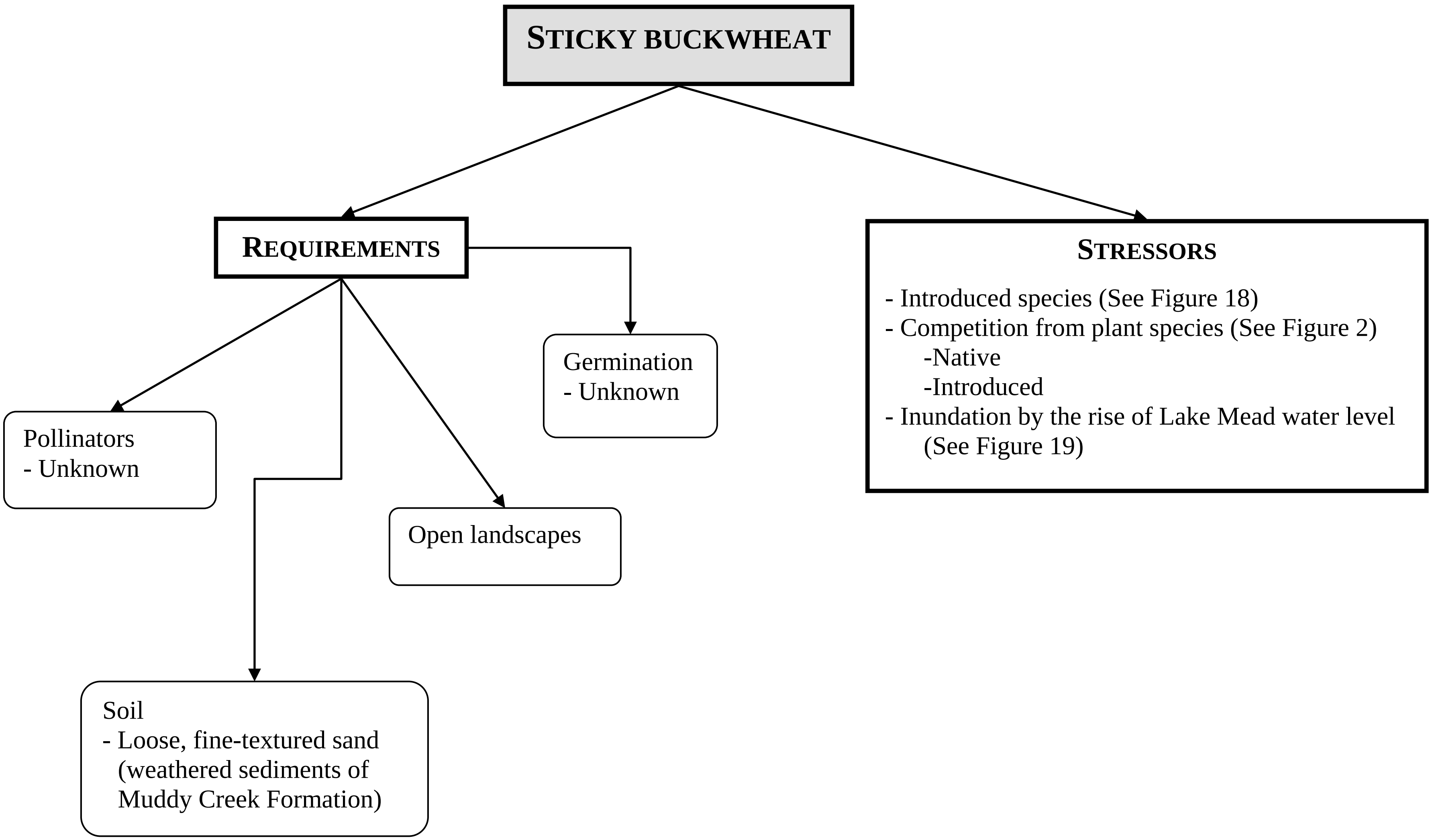


Figure 16. A conceptual model illustrating the requirements and stressors of sticky buckwheat.

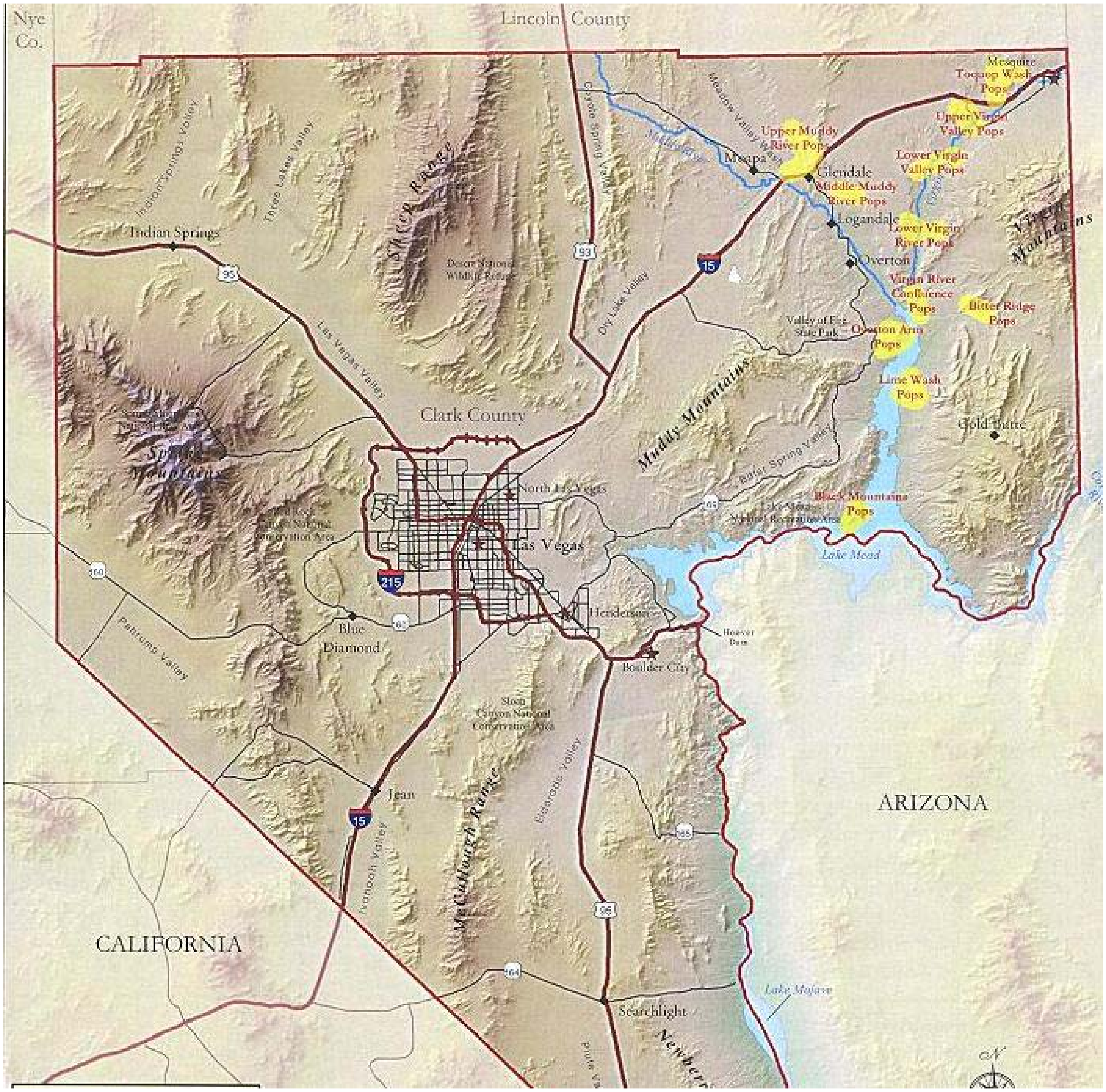


Figure 17. Reproduced from TNC 2007 delineating the known Clark County distribution of sticky buckwheat.

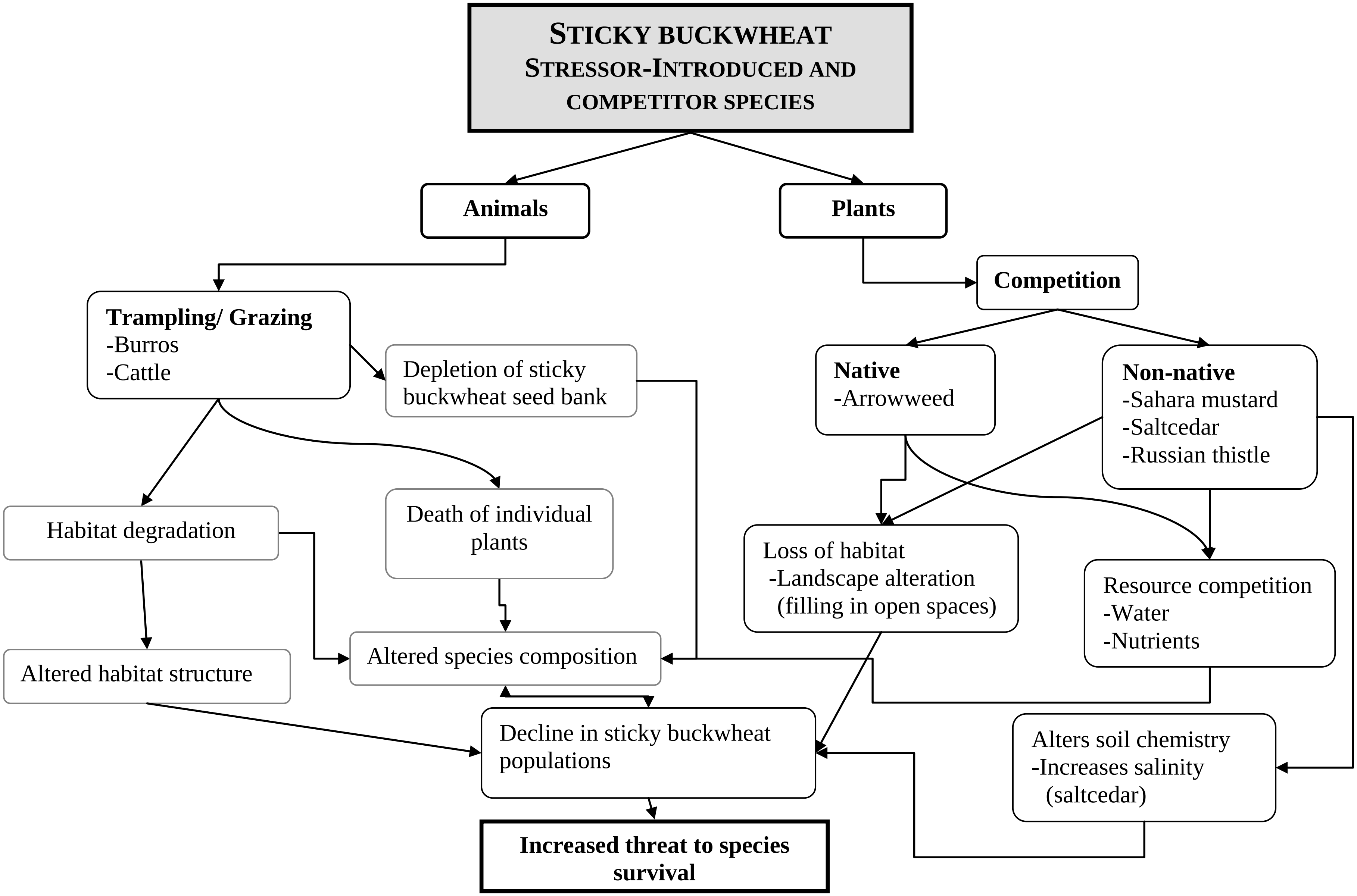


Figure 18. Conceptual model illustrating the effects of introduced species on sticky buckwheat.

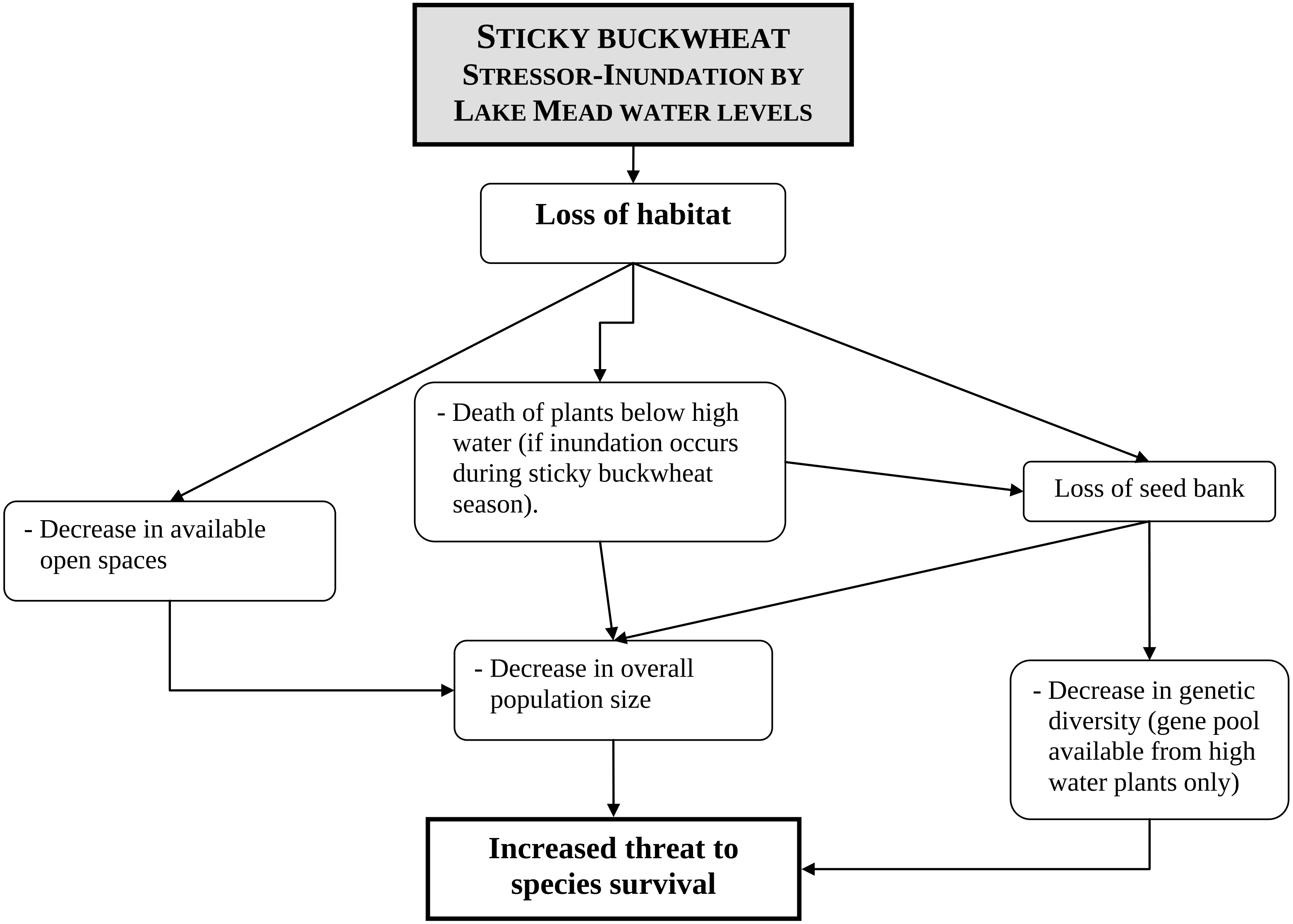


Figure 19. Conceptual model illustrating the effects of inundation by Lake Mead water levels on sticky buckwheat.


A) **B)**


C) **D)**


E) **F)**

Figure 20. Las Vegas bearpoppy monitoring sites; **A)** Blue Point Springs; **B)** Gale Hills; **C)** Road 100; **D)** Valley of Fire; **E)** Gold Butte; **F)** Sunrise Hills.

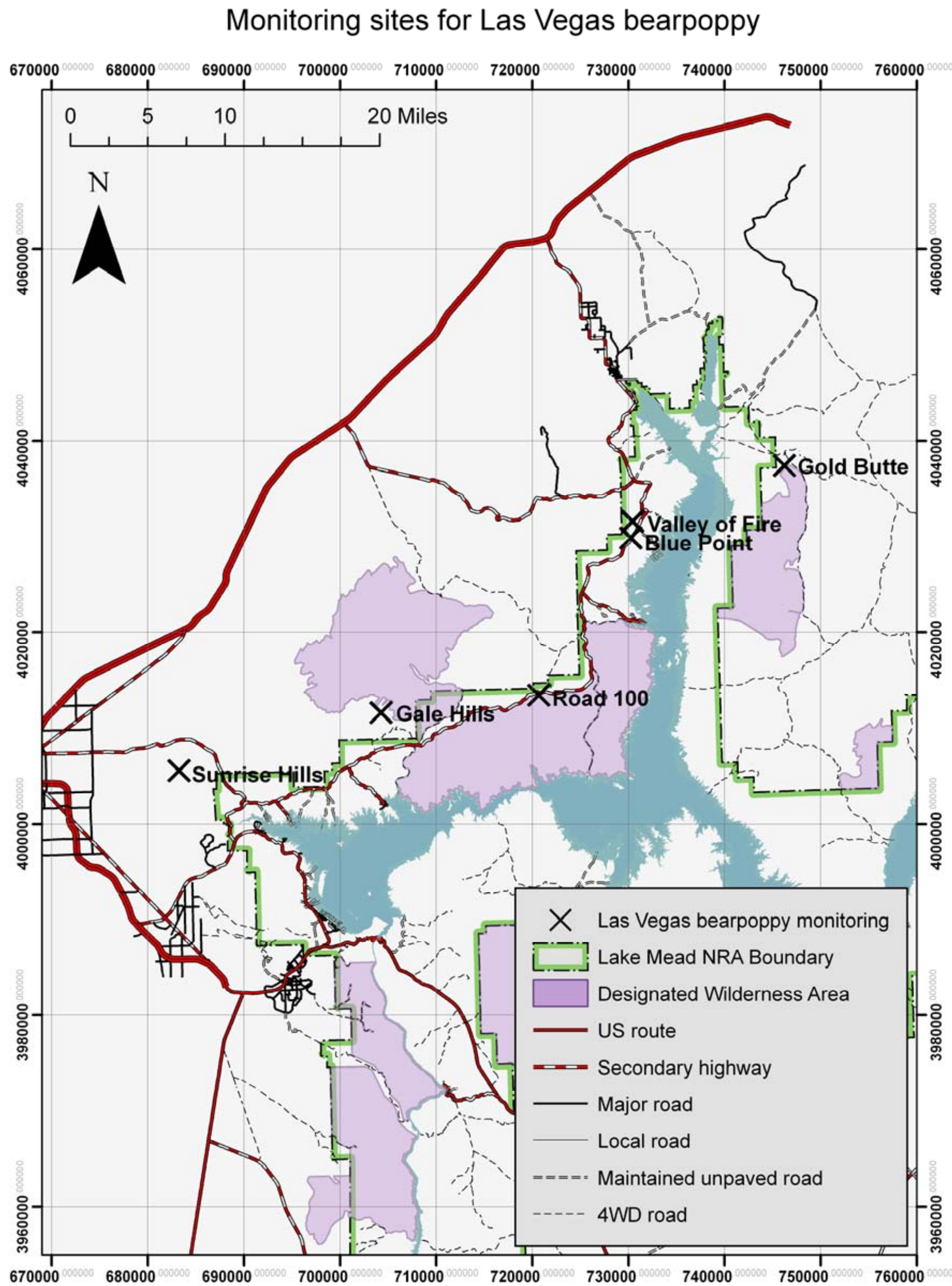


Figure 21. Locations of Las Vegas bearpoppy long-term monitoring sites. Established and initially sampled in 2008, and sampled again in 2009.

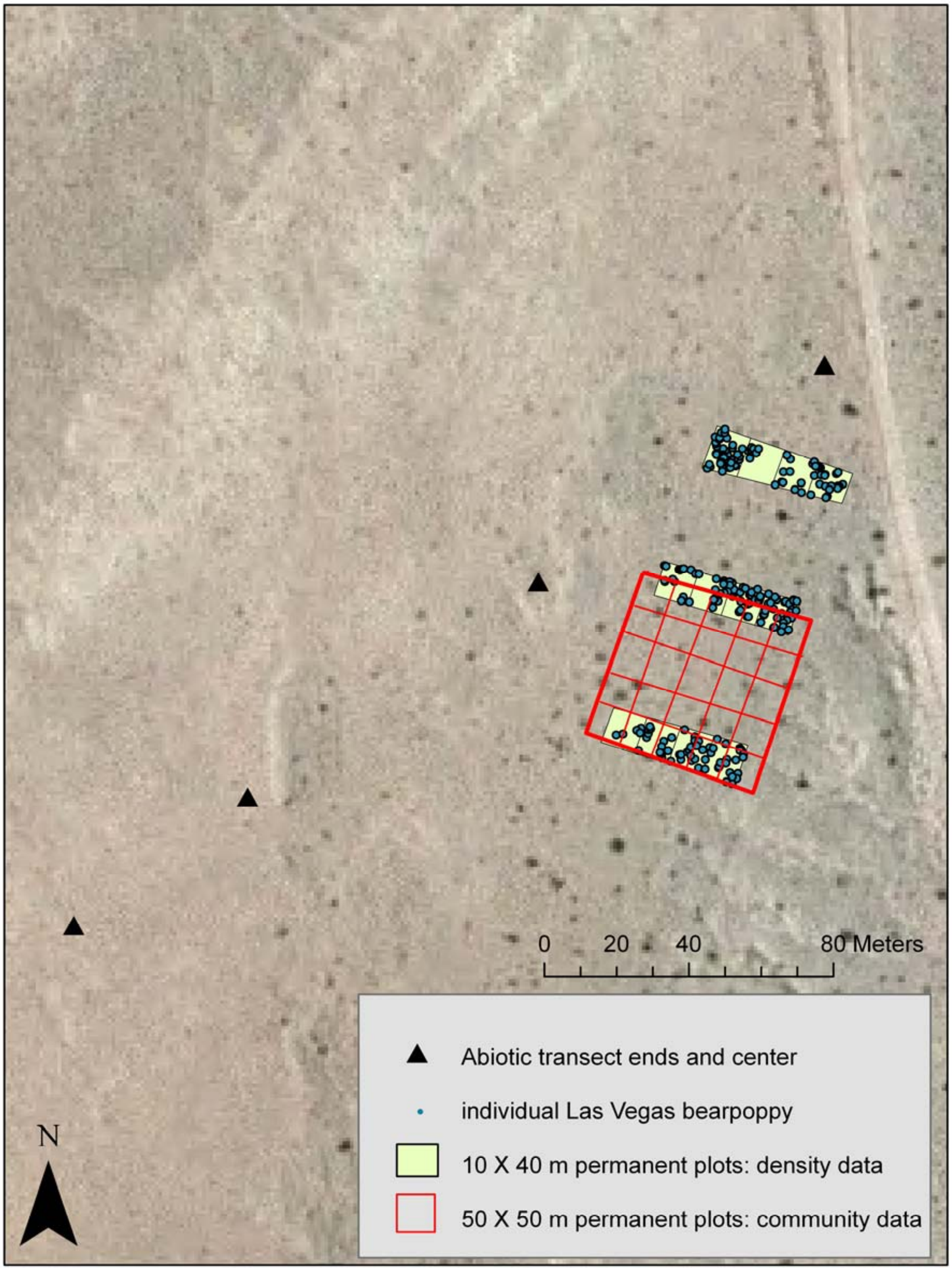


Figure 22. An overview of the three-tiered sampling of Las Vegas bearpoppy conducted at Valley of Fire.

A) 

B) 

C) 

Figure 23. Ringstem monitoring sites; **A)** Valley of Fire; **B)** Road 100; **C)** Sunrise Hills.

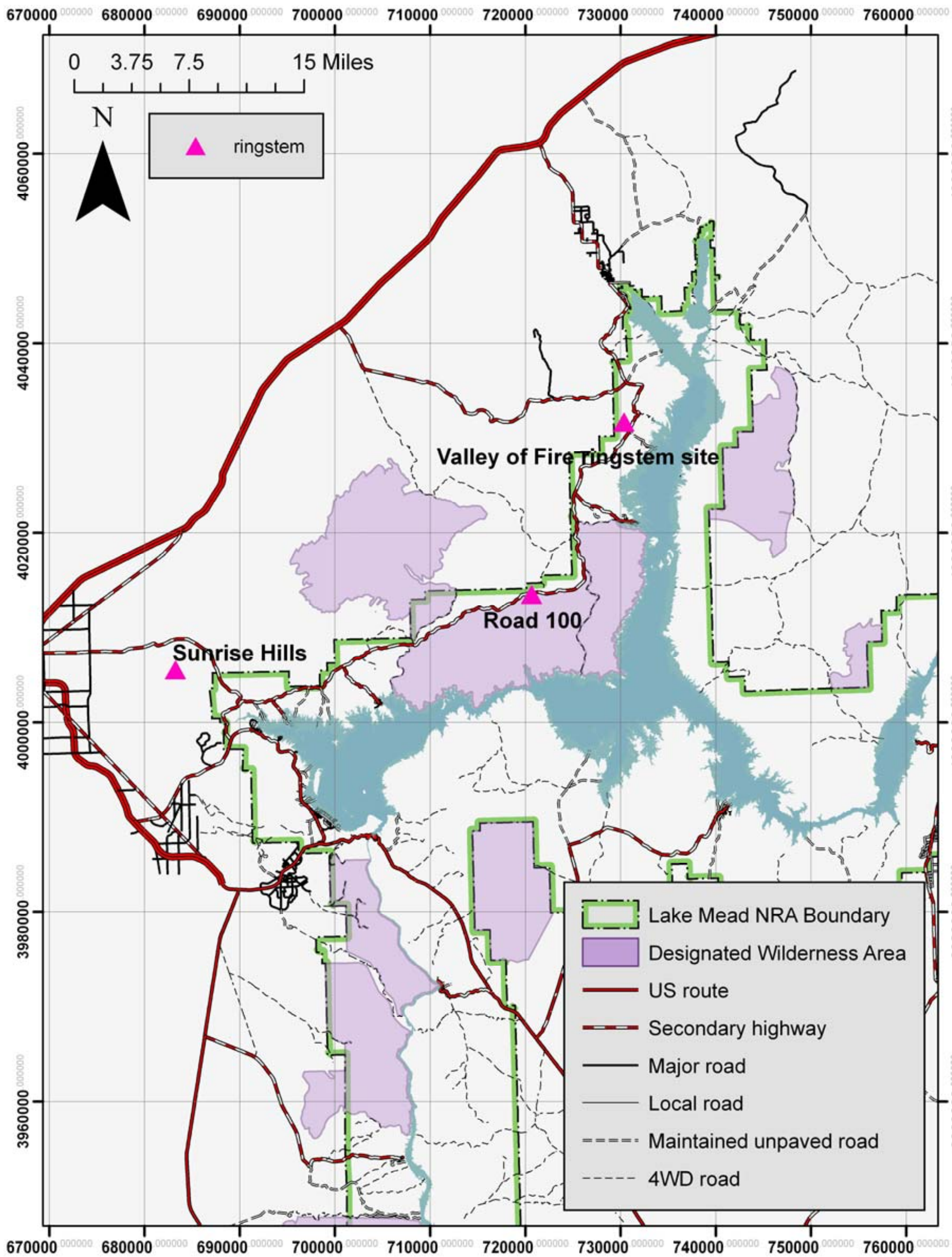


Figure 24. Overview of the three locations where ringstem monitoring frameworks were established in 2008 and sampled again in 2009.

Ringstem monitoring site:
Road 100

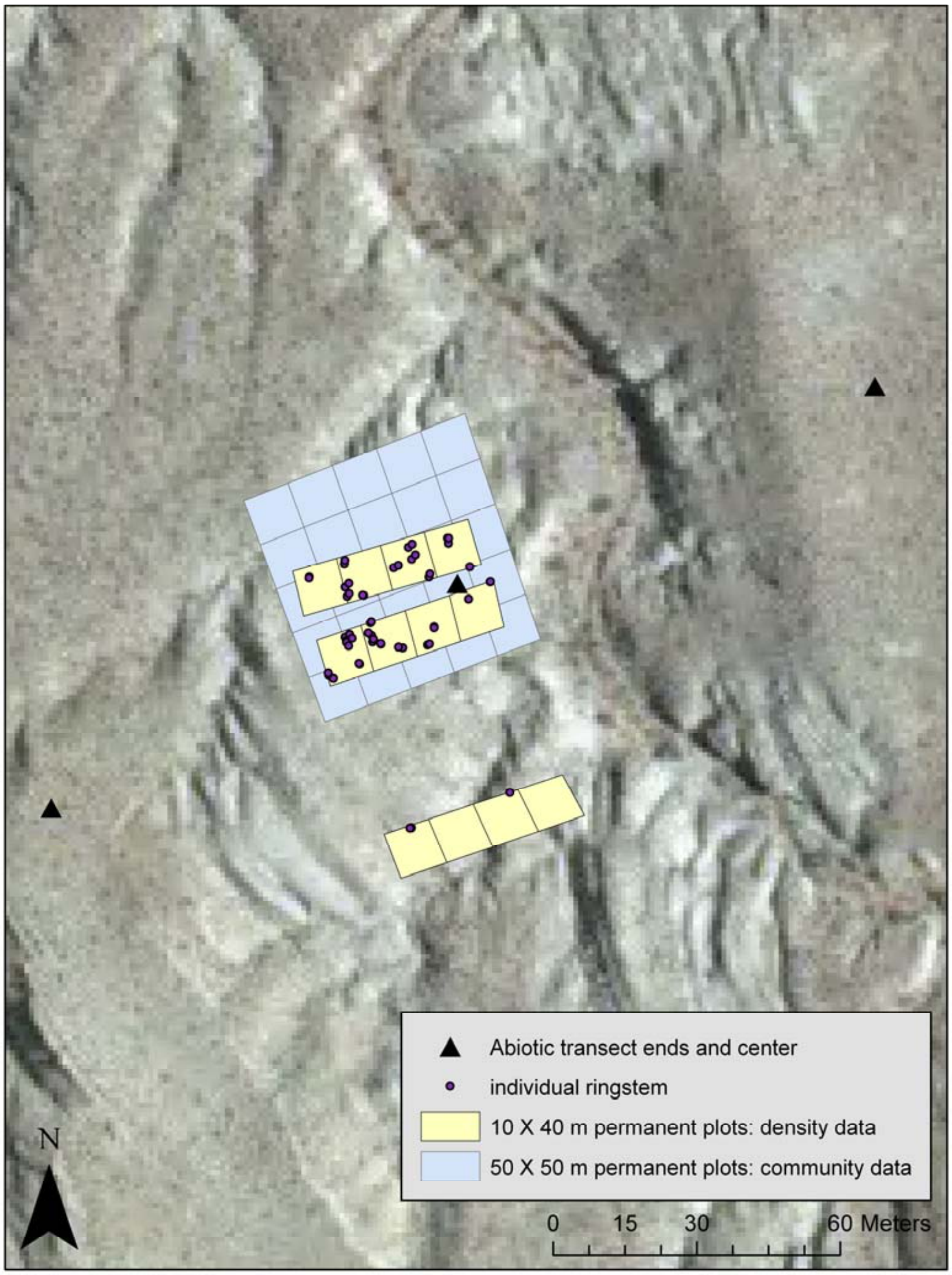


Figure 25. Schematic depiction of the three-tiered monitoring approach used to sample ringstem.

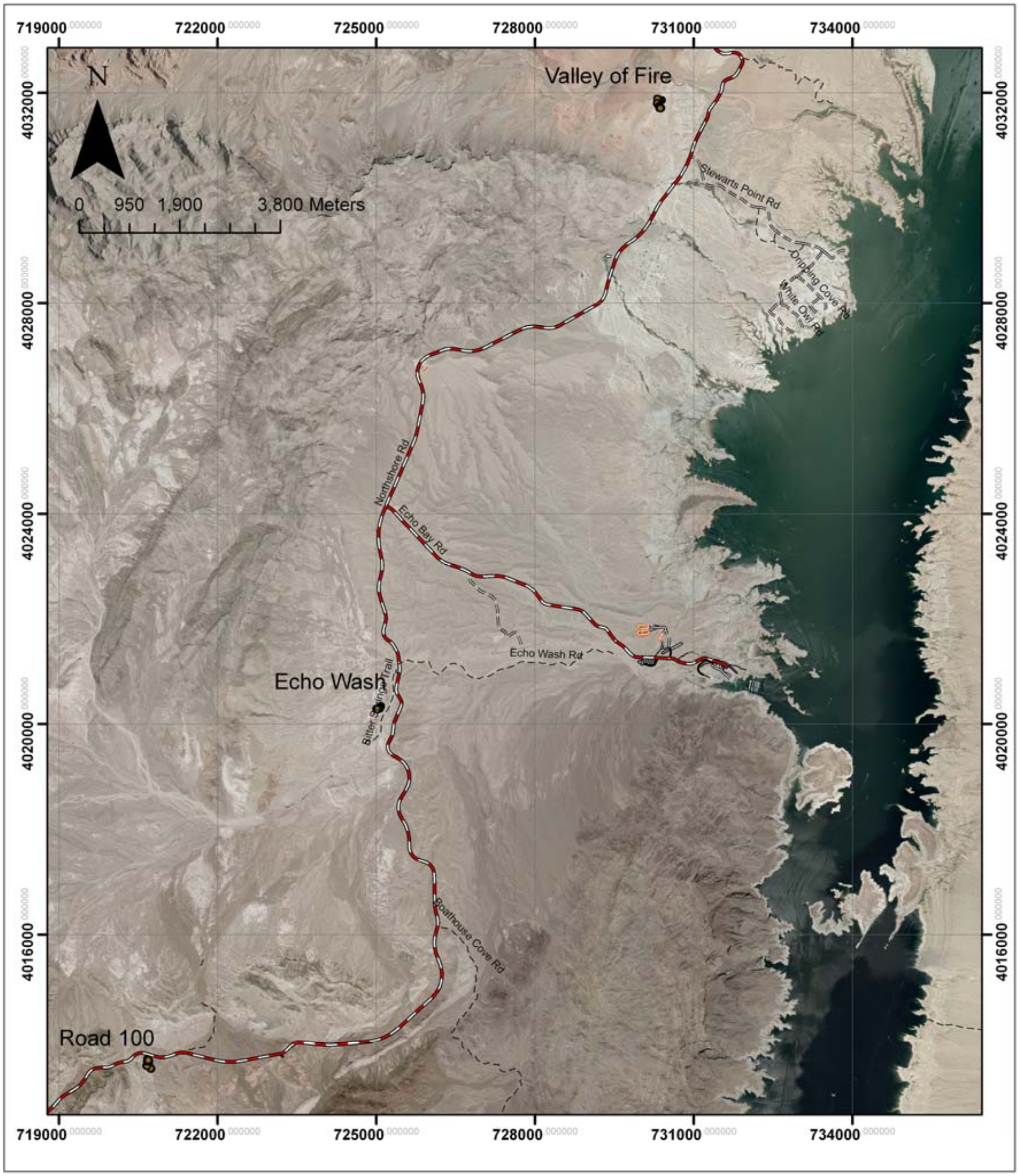
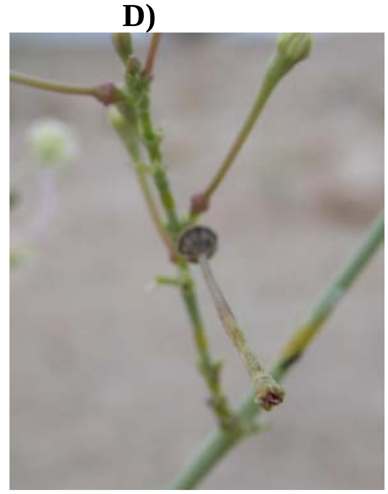


Figure 26. Locations of the three sites where ringstem phenology studies were conducted.


A) **B)**


C) **D)**

E) **F)**

Figure 27. Ringstem stages of development; **A)** Plant phenological stage -rosette; **B)** Floral phenological stage -1 Open, stamens emerge and anthers drop pollen, stamens are generally tightly twisted; **C)** Floral phenological stage -2 Pistil elongates; **D)** Floral phenological stage -3, stamens and pistil straighten and elongate; **E)** Floral phenological stage -4, corolla senesces, stamens dry and crinkled; **F)** Stage 5.

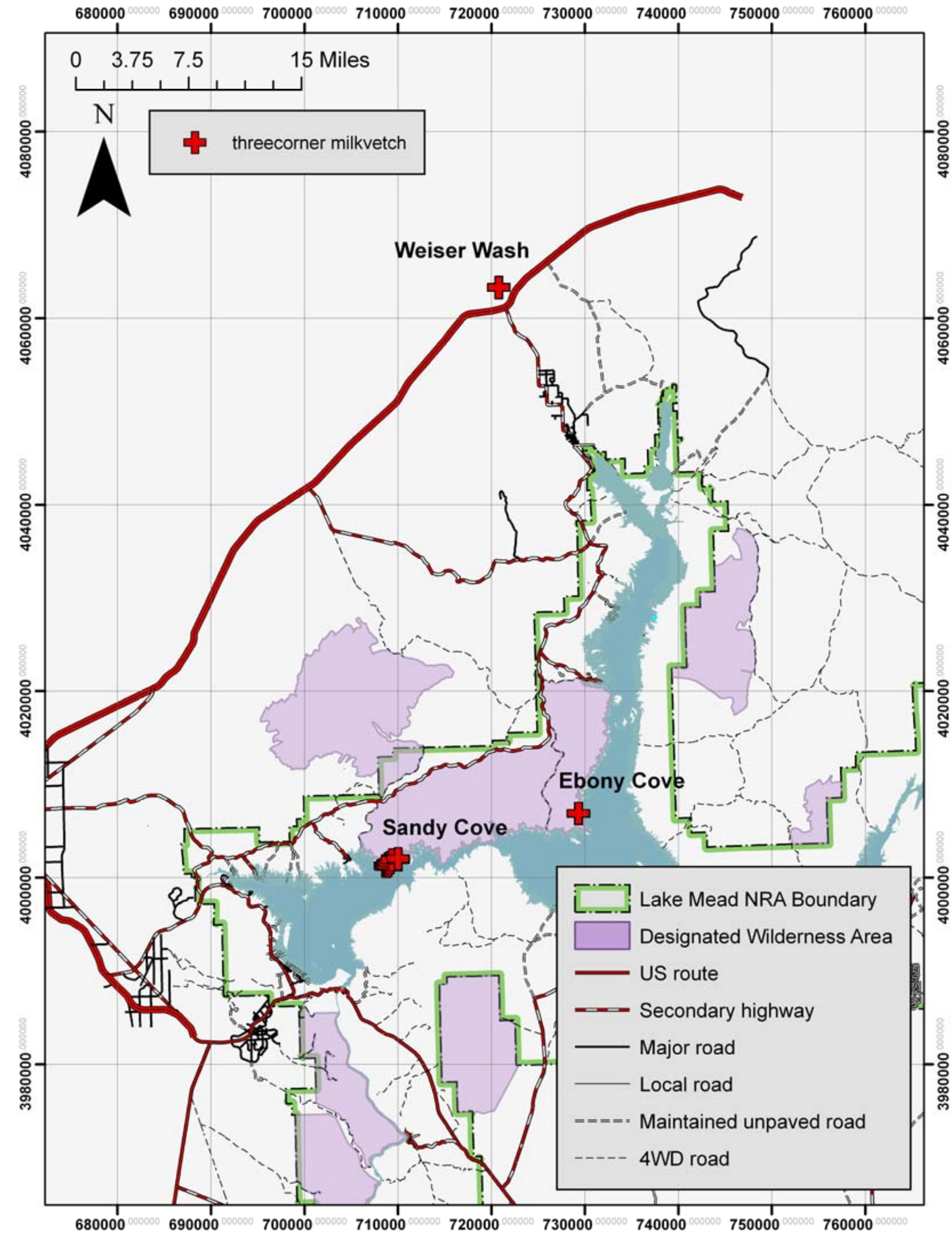


Figure 28. Overview of threecorner milkvetch monitoring sites.

A)
B)
C)


Figure 29. Threecorner milkvetch monitoring sites; **A)** Sandy Cove; **B)** Ebony Cove; **C)** Weiser Wash.

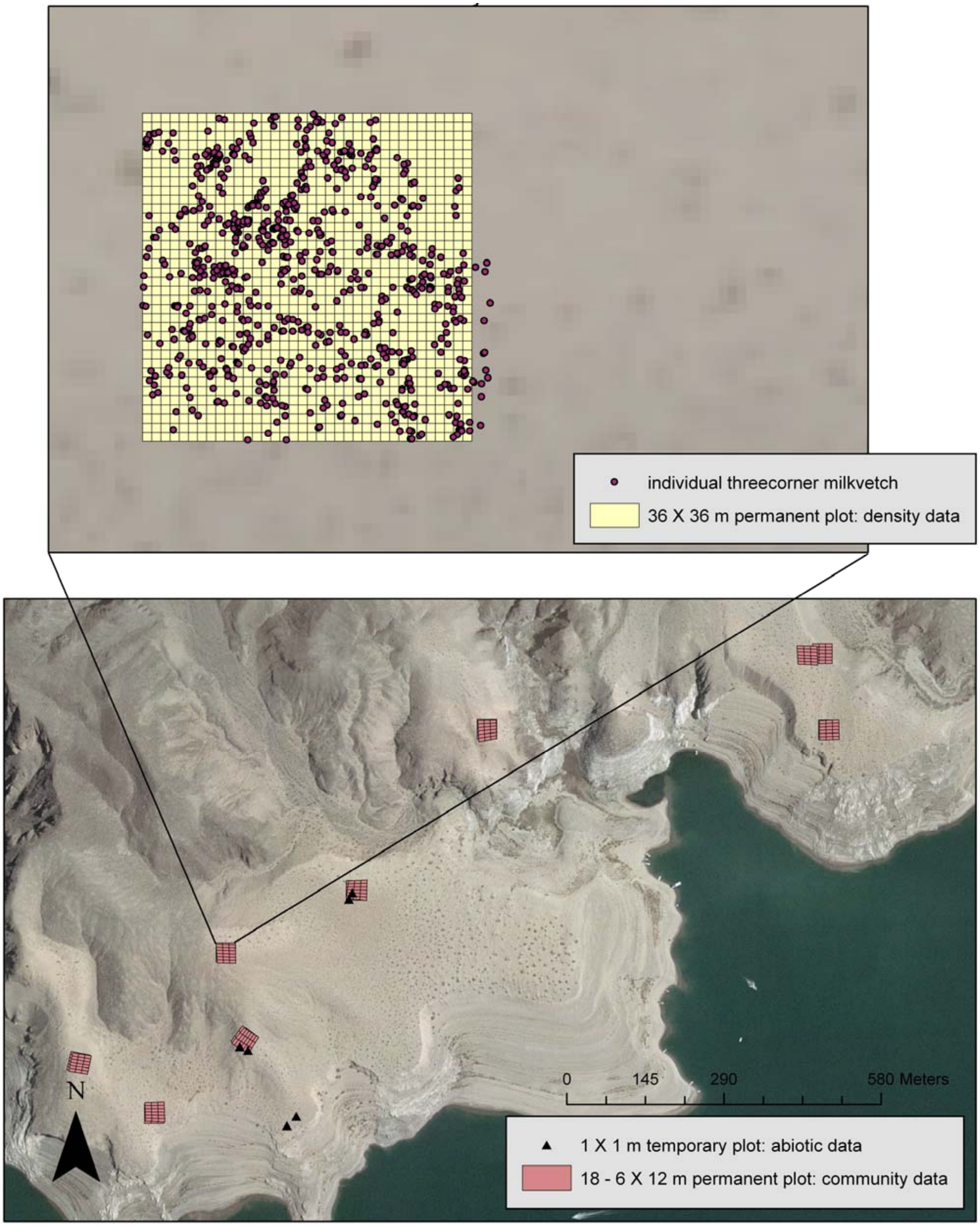


Figure 30. Schematic of the three-tiered sampling approach used at Sandy Cove.

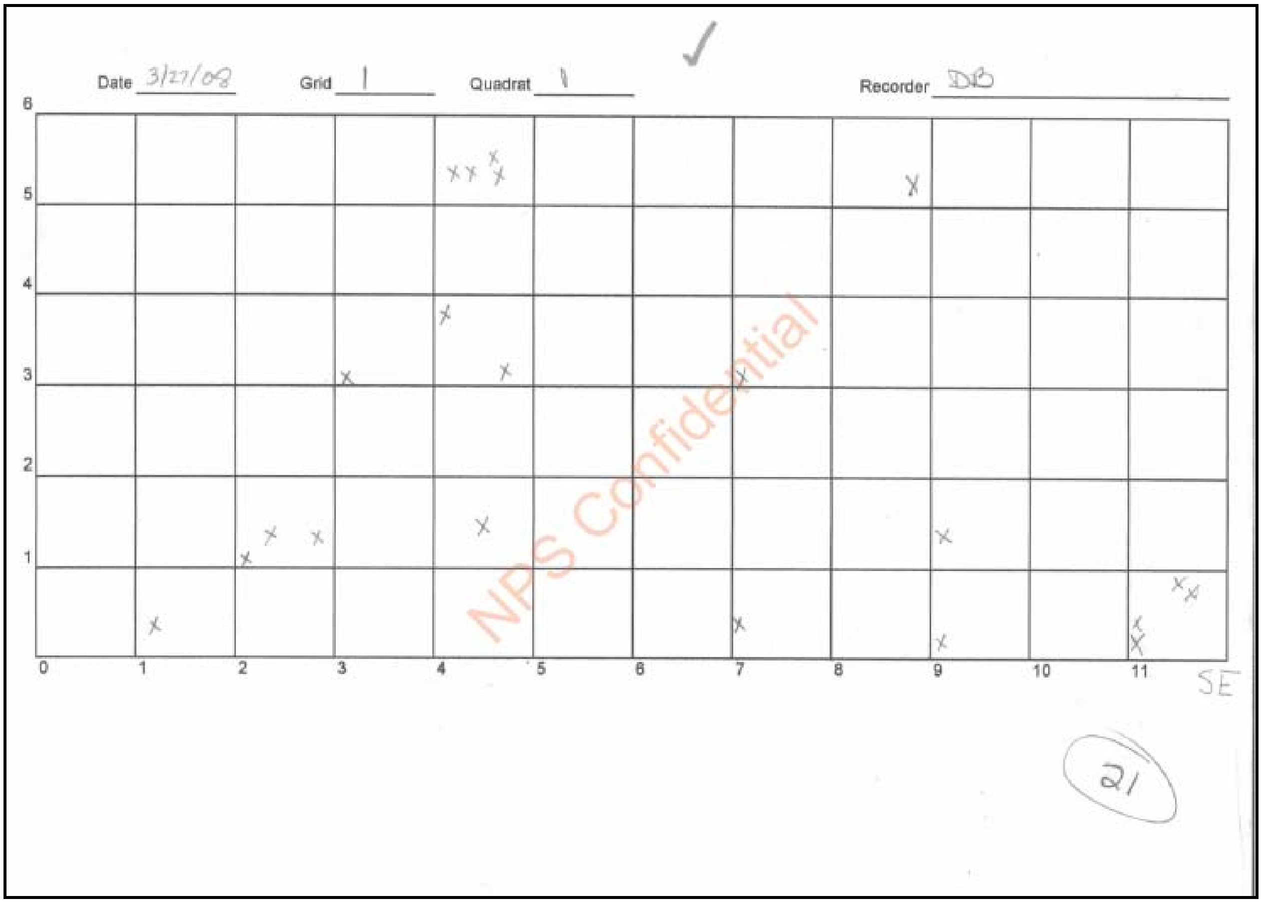


Figure 31. Actual data sheet used for mapping locations of threecorner milkvetch within 6 × 12m permanent plots. X represents the presence of a plant.

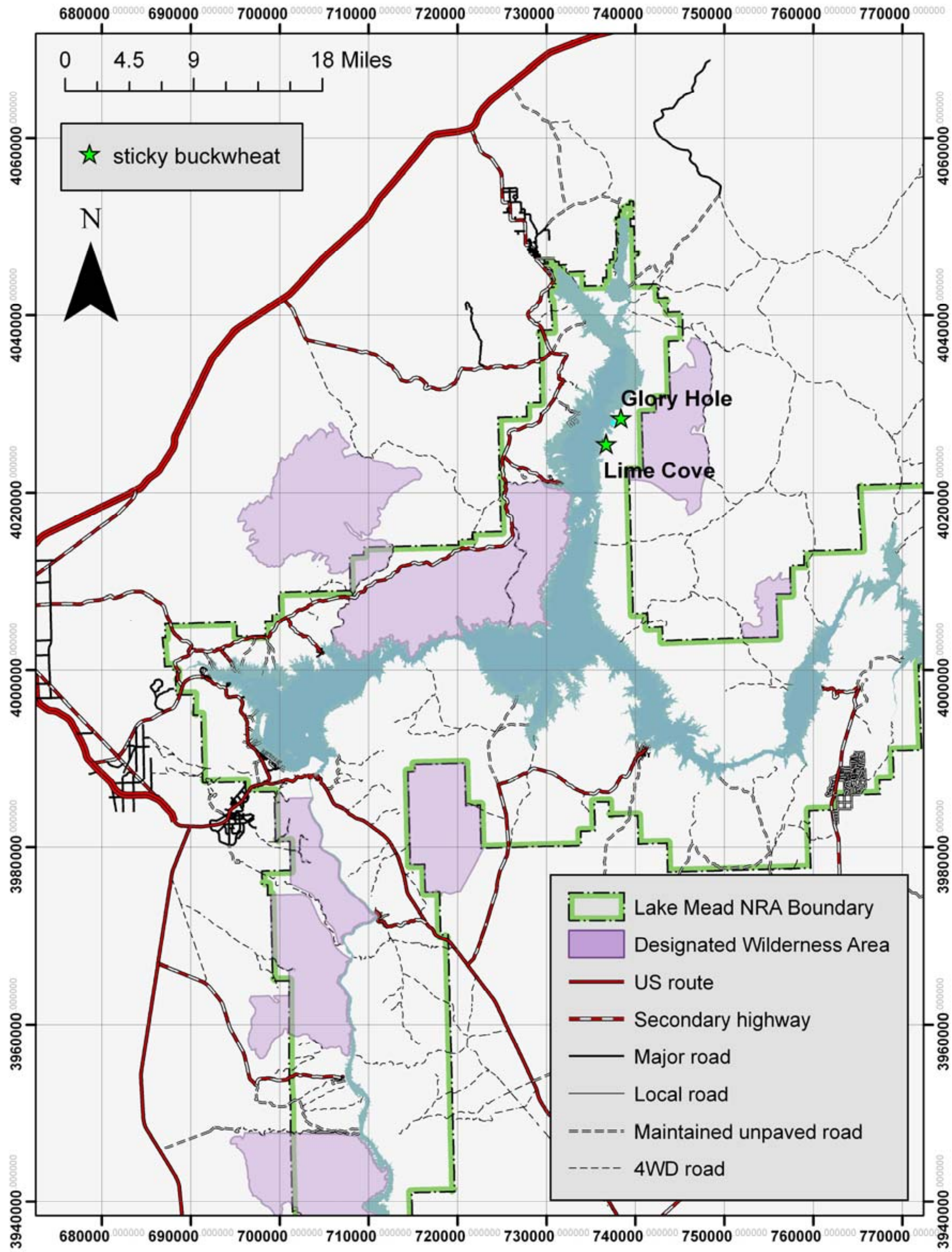
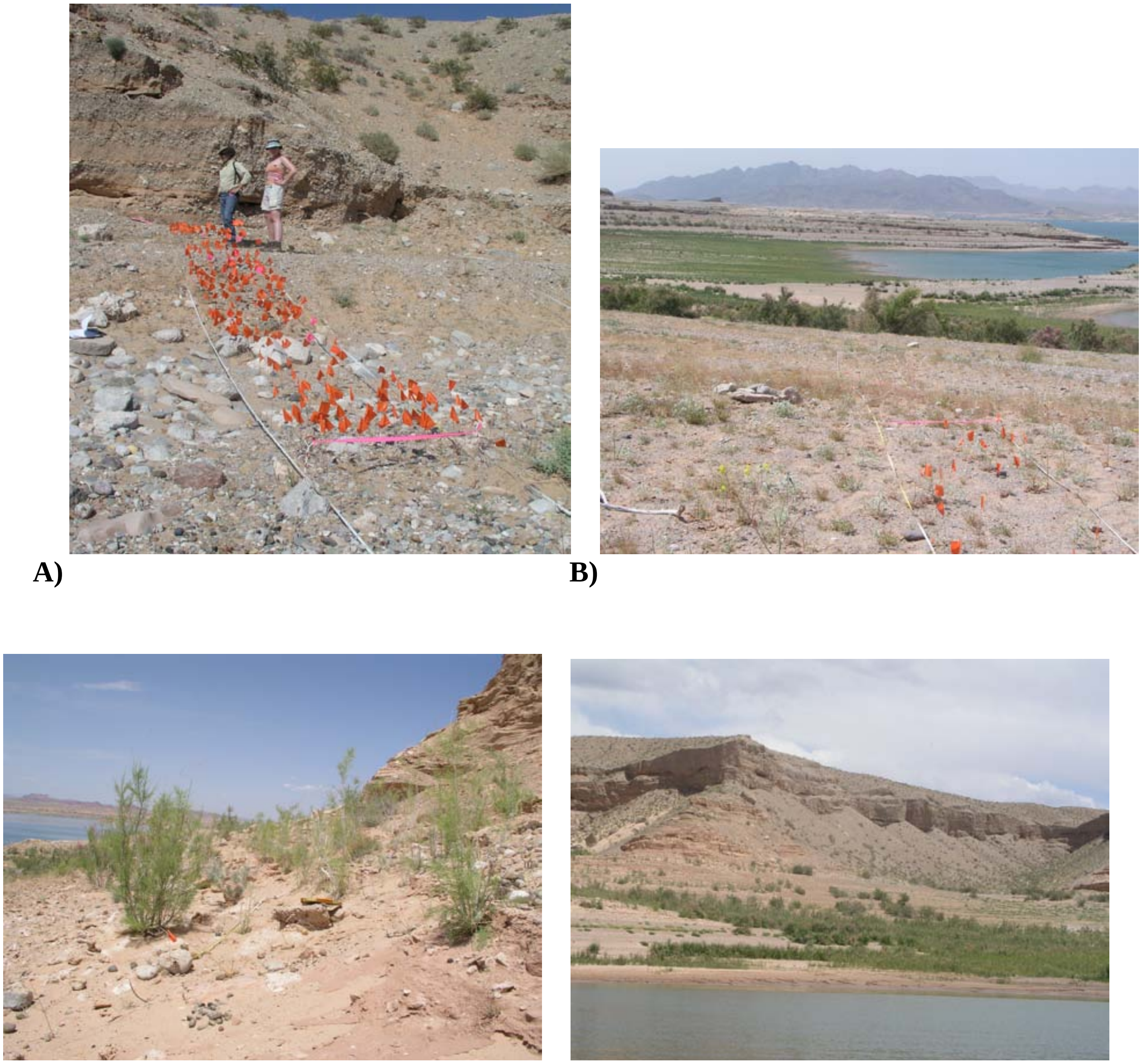


Figure 32. Overview of sticky buckwheat monitoring sites.



A) B) C) D)

Figure 33. Sticky buckwheat monitoring sites; **A)** Lime Cove quadrat; **B)** Lime Cove site; **C)** Glory Hole top corner of Macroplot; **D)** Glory Hole site.

Figure 34. Schematic of sticky buckwheat monitoring.

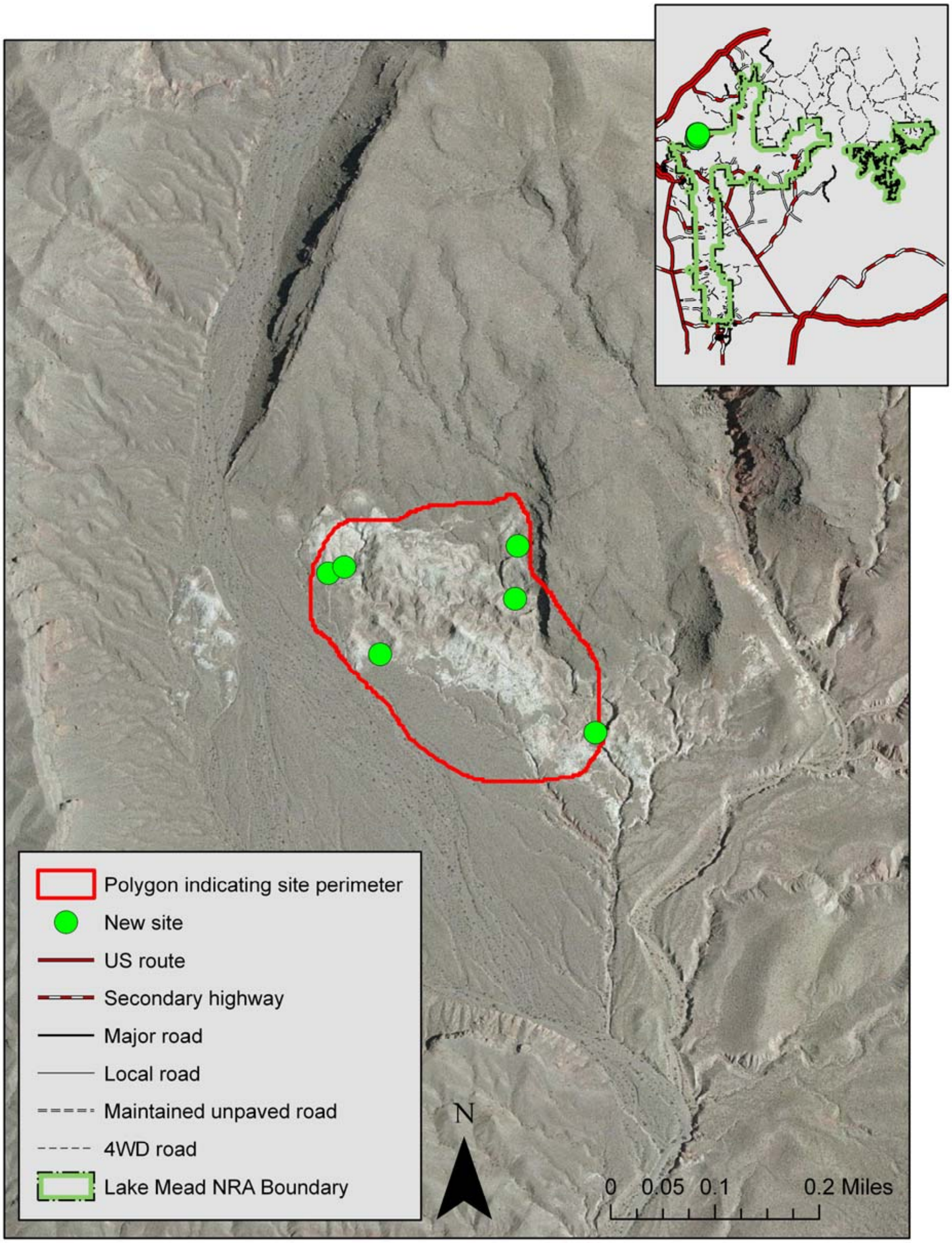


Figure 35. Location map of the new population of Las Vegas bearpoppy identified and documented during 2008 inventories.

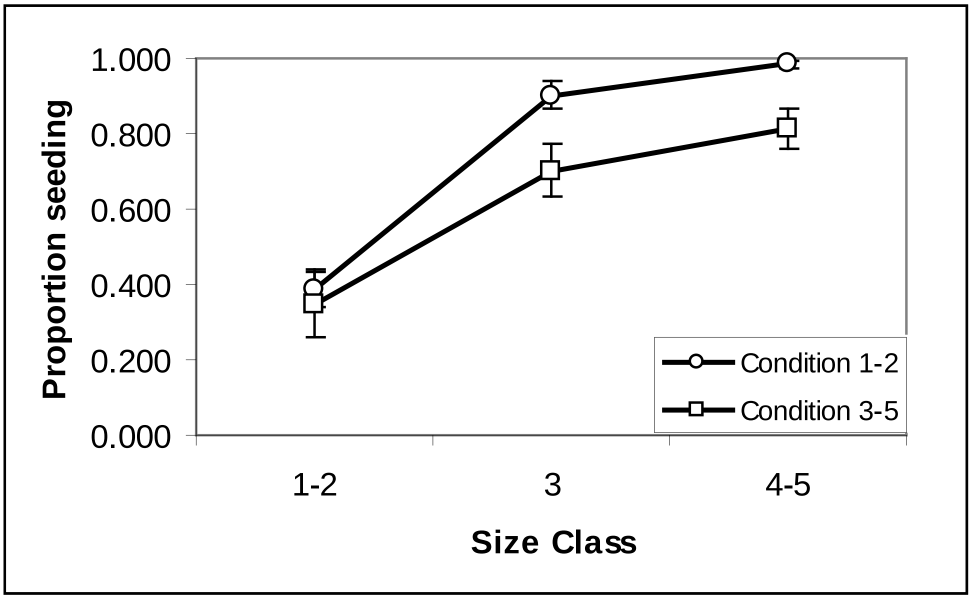


Figure 36. Mean (SE) proportion of plants seeding across age and size classes.

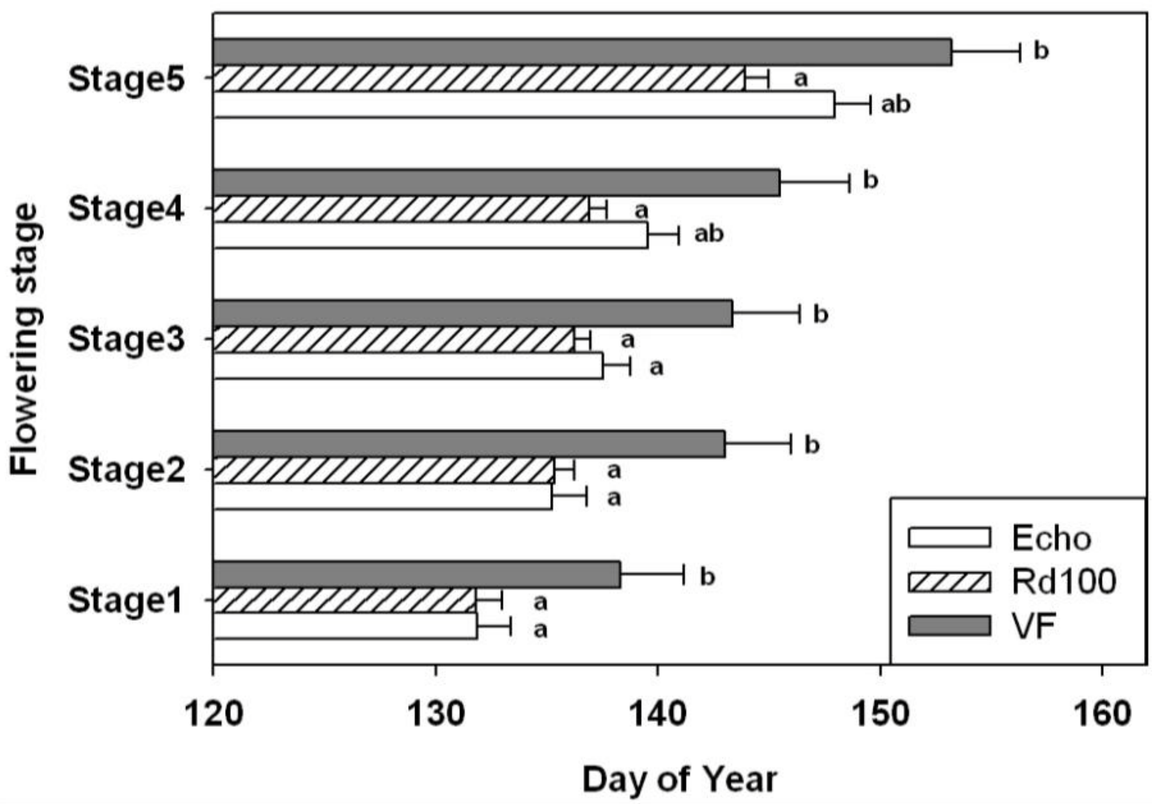


Figure 37. Day of year for ringstem to reach each flowering stage at each site (mean ± SE). Stages were: Stage 1 - open, stamens emerge and anthers drop pollen, stamens are generally tightly twisted; Stage 2 - pistil elongates; Stage 3 - stamens and pistil straighten and elongate; Stage 4 - corolla senesces, stamens dry and crinkled; and Stage 5. Within a stage, values with the same letter do not differ ($P > 0.05$). Sites were: Echo Wash (Echo), Road 100 (Rd100) and Valley of Fire (VF).

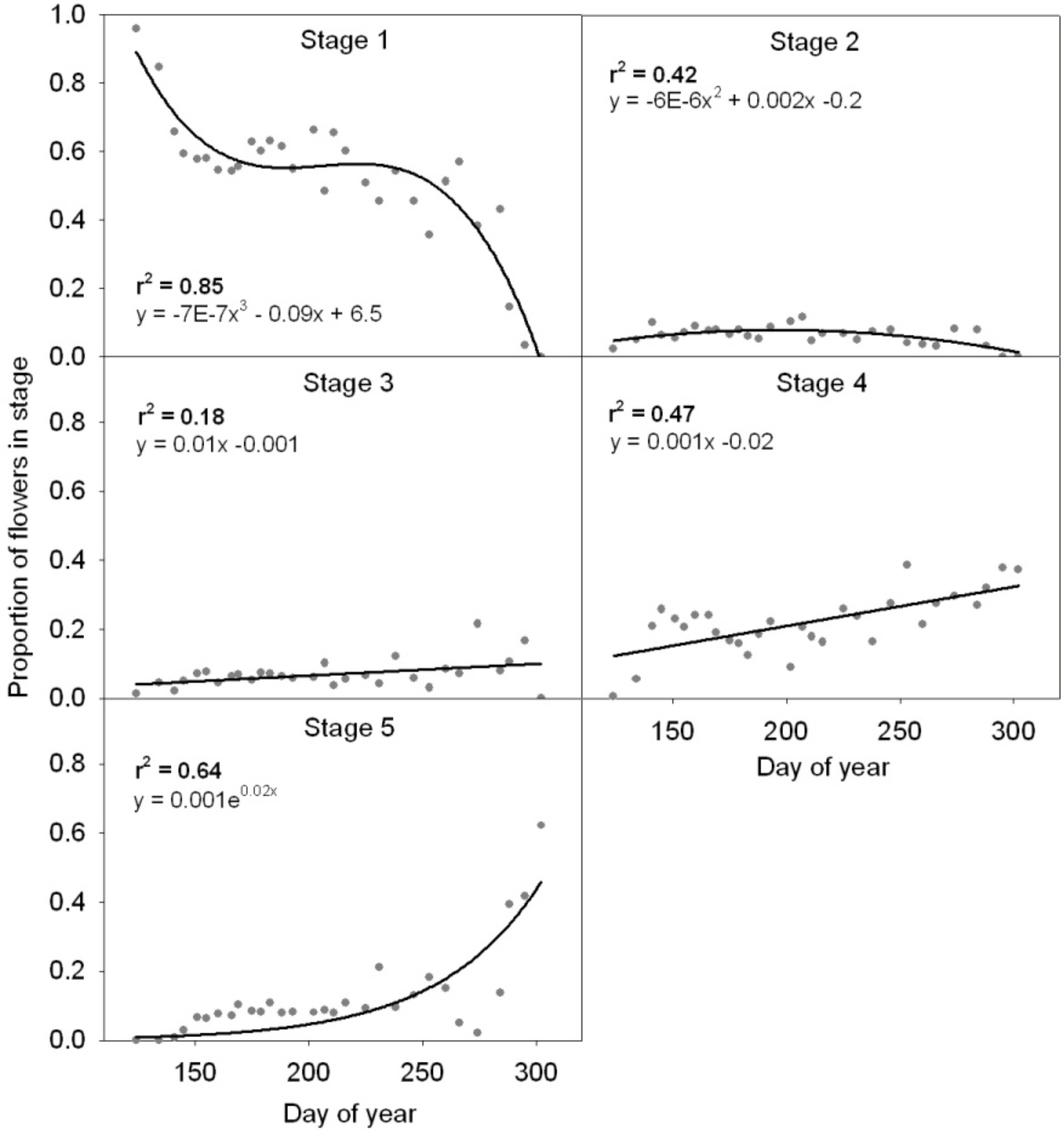


Figure 38. Proportion of ringstem flowers in each flowering stage (averaged across all sites) with best fit equations and associated r^2-values. Stages were: Stage 1 - open, stamens emerge and anthers drop pollen, stamens are generally tightly twisted; Stage 2 - pistil elongates; Stage 3 - stamens and pistil straighten and elongate; Stage 4 - corolla senesces, stamens dry and crinkled; and Stage 5.

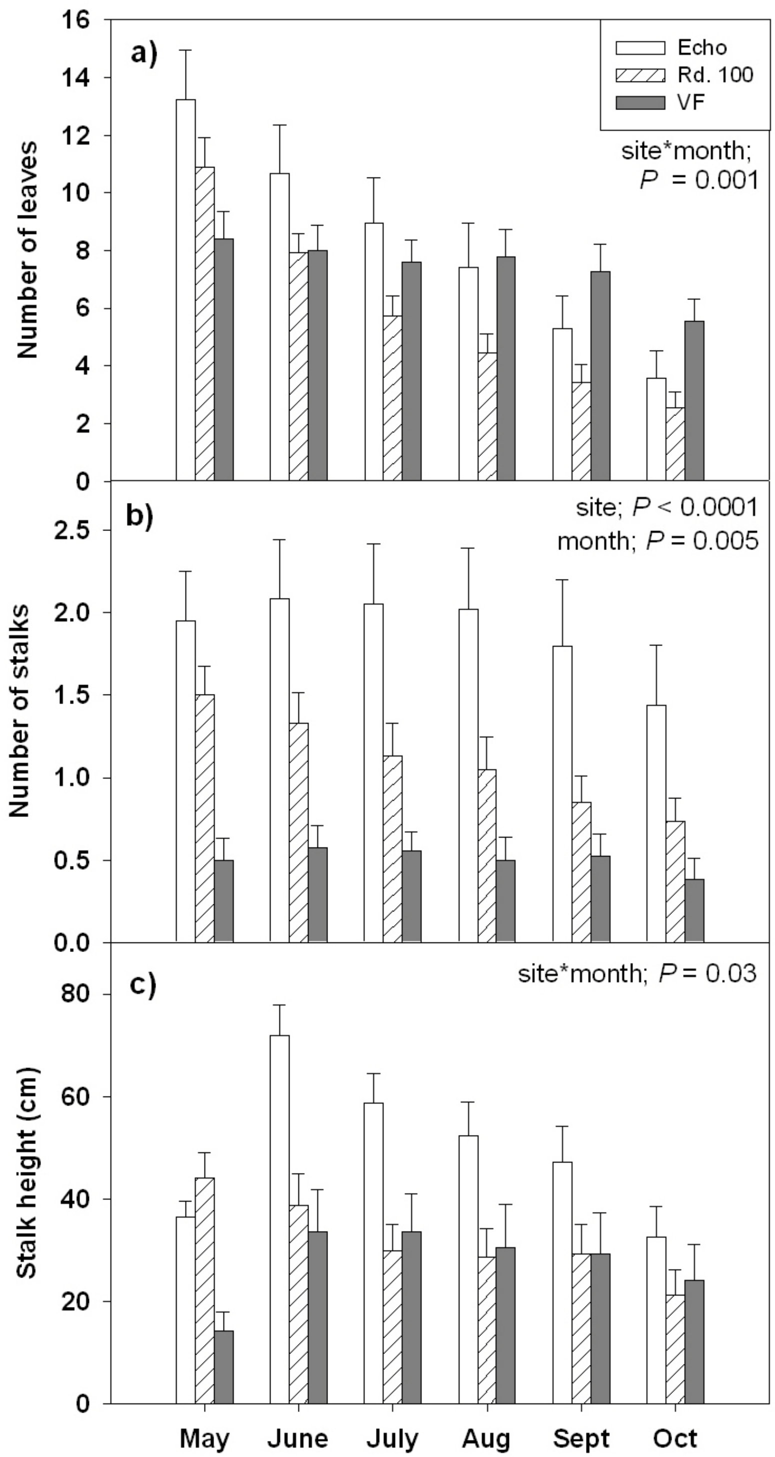


Figure 39. Relationships between sites and the number of ringstem leaves, stalks and height. **a)** Number of ringstem leaves, **b)** number of ringstem flowering stalks, and **c)** flowering stalk height per ringstem plant (mean ± 1 SE) for each month sampled during 2009. Significant main (site and month) and interactive effects with significance levels as determined by repeated measures analyses are noted on each panel. Sites were: Echo Wash (ECHO), Road 100 (Rd. 100) and Valley of Fire (VF).

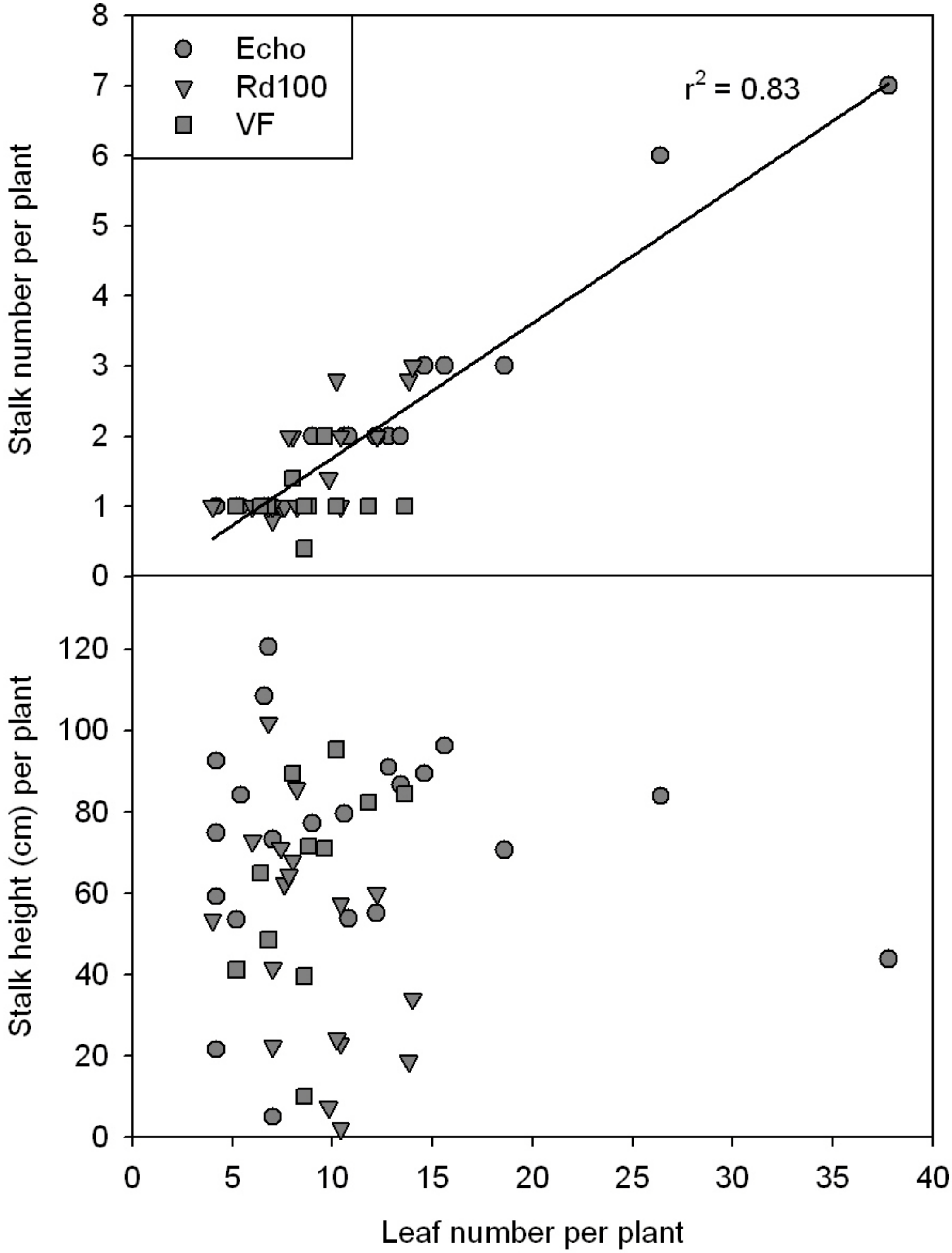


Figure 40. Relationship between ringstem mean leaf number and mean stalk number per plant (top) and mean number and mean stalk height (bottom) averaged for each flowering plant sampled. Data for each individual were averaged across day of year 151 – 169 to capture peak stalk and leaf production. Sites were: Echo Wash (ECHO), Road 100 (RD100) and Valley of Fire (VF).

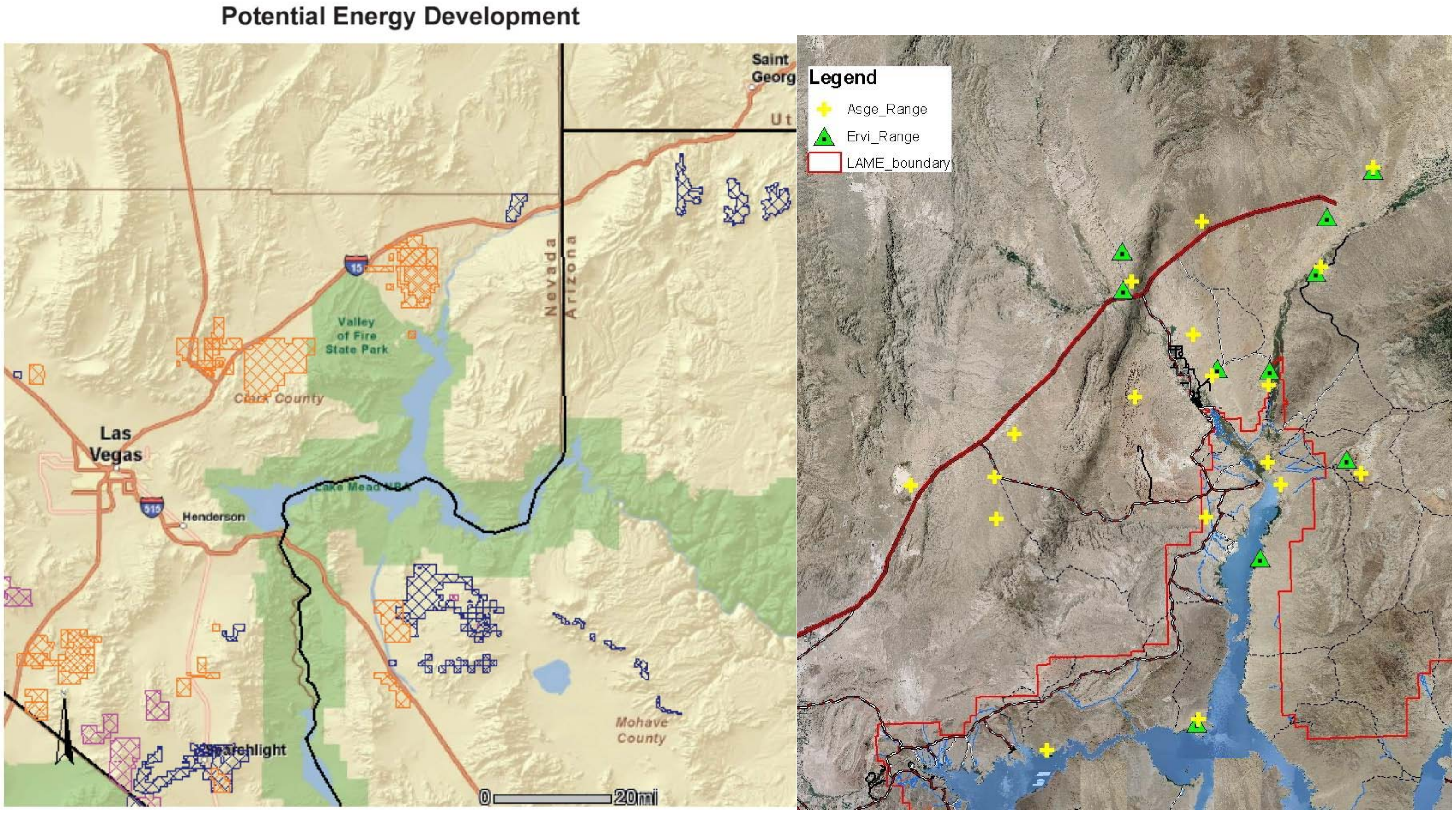


Figure 41. Threats of energy development on rare sand species. **A)** Map showing proposed areas for energy development in Clark County; **B)** map showing threecorner milkvetch and sticky buckwheat distributions.

TABLES

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Table 1. Las Vegas bearpoppy sites as described in Mistretta *et al.* (1996) that were re-evaluated in 2007-2008 for possible inclusion in random selection process for monitoring.
*Site # as listed in Mistretta *et al.*, 1996.
**Estimates reflected quick assessments of each area and did not represent an accurate estimate of the entire population size.

Site # *	General Area	Est. Plants_1996	Est. Plants_2007**	Land Manager
1	Rainbow Gardens	3,000	100-500	BLM
2	Rainbow Gardens	50,000	>1,000	BLM/State
14	Overton Arm West	>200,000	>1,000	NPS/State
19	Echo Wash	15,000	>1,000	BLM/NPS
35	Gold Butte	15,000	>1,000	BLM
42	Gold Butte	5,000	>1,000	BLM
54	Gale Hills	10,000	>1,000	BLM/Private
56	Gold Butte	30,000	>1,000	BLM
17	Pinto Valley North	900	>1,000	NPS
18	West End Wash	250	<100	NPS
21	Callville Wash	500	>1,000	NPS
61	Rainbow Gardens	600	<100	BLM
62	Rainbow Gardens	30,000	>1,000	BLM
63	Sunrise Hills	5,000	>1,000	BLM
64	Rainbow Gardens	20,000	<100	BLM
65	Sunrise Hills	300	<100	BLM
67	Rainbow Gardens	18,000	>1,000	BLM
68	Sunrise Hills	1,000	100-1,000	BLM
69	Rainbow Gardens	30,000	>1,000	?
78	West End Wash	1,000	>1,000	BLM/NPS
82	Bitter Springs	5,000	>1,000	BLM
83	Bitter Springs	10,000	>1,000	BLM/NPS
84	Bitter Springs	5,000	100-1,000	BLM
87	Gold Butte	1,000	<100	BLM
88	Gold Butte	20,000	>1,000	BLM
91	Pinto Valley North	2,000	>1,000	NPS
93	Government Wash	300	0	NPS
94	Valley of Fire	3,000	100-1,000	BLM/NPS/State
New	Gale Hills	-	>1,000	BLM

Table 2. Summaries of monthly precipitation (in mm) at Las Vegas bearpoppy monitoring sites in 2009. Modern rain gauge installation dates were: Gale Hills - December 2008; Sunrise Hills – January 2009; Blue Point, Road 100, and Valley of Fire - February 2009; the Gold Butte - May 2009. Values in italics were collected by an older version weather station. Months that do not include complete data are denoted by '*'. These months were not included during analyses.

2009	Blue Point (mm)	Gale Hills (mm)	Gold Butte (mm)	Road 100 (mm)	Sunrise Hills (mm)	Valley of Fire (mm)
January	-	2.4	-	*6.6*	1.6*	-
February	0*	33.8	-	*38.6*	27.4	0.0*
March	0.0	0.0	-	0.0	0.0	0.0
April	2.8	1.8	-	1.2	0.4	1.8
May	1.0	0.2	0.2*	1.0	0.0	0.0
June	0.0	0.0	1.8	0.0	0.0	0.0
July	0.6	0.2	0.4	5.2	0.8	0.6
August	1.0	2.2	0.2	0.8	0.4	0.6
September	0.0	0.0	0.2	0.0	0.0	0.0
October	0.0	0.0	1.0	0.6	0.0	0.0
November	0.0	0.4	0.4	0.0	0.4	0.0
December	18.0	15.0	16.0	21.0	11.8	14.4
Total	23.4	56.0	20.0	75.0	46.8	17.4

Table 3. Summaries of monthly precipitation (in mm) at ringstem monitoring sites in 2009. Weather stations were installed at Sunrise Hills in January and at Road 100 and Valley of Fire ANLE in February. Months that do not include completed data are denoted by '*'. Values in italics were collected by an older version weather station.

2009	Road 100 (mm)	Sunrise Hills (mm)	Valley of Fire ANLE (mm)
January	*6.604*	1.6*	-
February	*38.608*	27.4	0*
March	0.0	0.0	0.0
April	1.2	0.4	2.8
May	1.0	0.0	0.0
June	0.0	0.0	0.0
July	5.2	0.8	1.2
August	0.8	0.4	1.4
September	0.0	0.0	0.0
October	0.6	0.0	0.0
November	0.0	0.4	0.0
December	21.0	11.8	18.0
Total	75.0	46.8	23.4

Table 4. Summaries of monthly precipitation at threecorner milkvetch monitoring sites in 2009. Weather stations were installed at Ebony Cove in July, Sandy Cove in February and Weiser Wash in August 2009. Months that do not include completed data are denoted by '*'.

2009	Ebony Cove (mm)	Sandy Cove (mm)	Weiser Wash (mm)
January	-	-	-
February	-	0.8*	-
March	-	0.2	-
April	-	0.4	-
May	-	0	-
June	-	0	-
July	0*	0	-
August	1.2	0.8	0.6*
September	4.4	0	3.4
October	0	0	0
November	0	0	0.6
December	13.8	0	12
Total	19.4	2.2	16.6

Table 5. Summaries of monthly precipitation (in mm) at sticky buckwheat monitoring sites in 2009. Both weather stations were installed in February 2009. Months that do not include completed data are denoted by '*'.

2009	Glory Hole (mm)	Lime Cove (mm)
January	-	-
February	8.6*	7.8*
March	0	0.6
April	2.8	2.6
May	1.6	3.4
June	0	0.2
July	1.2	2.4
August	2	0.2
September	0.6	0.4
October	0	1.4
November	0.6	0.6
December	23.4	23.2
Total	40.8	42.8

Table 6. Perennial plant species commonly associated with gypsum habitat in this study.

Species	Common Name
Acacia greggii A. Gray	Catclaw acacia
Ambrosia dumosa (A. Gray) Payne	White bursage
Anulocaulis leiosolenus (Torr.) Standl. var. *leiosolenus*	Ringstem
Arctomecon californica Torr. & Frém.	Las Vegas bearpoppy
Atriplex confertifolia (Torr. & Frém.) S. Watson	Shadscale
Enceliopsis argophylla (D.C. Eaton) A. Nelson	Sunray
Ephedra torreyana S. Watson	Torrey's ephedra
Eriogonum inflatum Torr. & Frém	Desert trumpet
Lepidium fremontii S. Watson	Desert alyssum
Petalonyx parryi A. Gray	Parry's sandpaper plant
Phacelia palmeri Torr. Ex S. Watson	Palmer's phacelia
Psorothamnus fremontii (Torr. ex A. Gray) Barneby	Indigo bush
Stephanomeria pauciflora (Torr. A. Nelson)	Wire lettuce

Table 7. Plant species commonly associated with sand habitat in this study.

Species	Common Name	A/P
Abronia villosa S. Watson	Sand verbena	A
Ambrosia dumosa(A. Gray) Payne	White bursage	P
Astragalus geyeri A. Gray var. *triquetrus* M.E. Jones	Threecorner milkvetch	P
Astragalus sabulonum A. Gray	Gravel milkvetch	A/P
Camissonia brevipes(A. Gray) P.H. Raven	Suncups	A
Cryptantha angustifolia (Torr.) Greene	Narrowleaf cryptantha	A
Cryptantha pterocarya (Torr.) Greene	Wingnut cryptantha	A
Eriogonum viscidulum J.T. Howell	Sticky buckwheat	A
Larrea tridentata (DC.) Coville	Creosote bush	P
Lupinus shockleyi (S. Watson)	Desert lupine	A
Phacelia crenulata Torr. ex S. Watson	Notchleaf phacelia	A
Plantago ovate Forssk.	Woolly plantain	A
Psorothamnus fremontii (Torr. ex A. Gray) Barneby	Indigo bush	P
Schismus sp.	Mediterranean grass	A
Stephanomeria pauciflora (Torr.) A. Nelson	Wire lettuce	P
Streptanthella longirostris (S. Watson) Rydb.	Longbeak twistflower	A

Table 8. Summary of mean and bootstrapped 95% confidence limits (CL) of quadrat-level and whole-plot measurements at sites containing Las Vegas bearpoppy. Values are expressed as percent cover in the plot. Blue Point (BLPO), Gale Hills (GAHI), Gold Butte (GOBU), Road 100 (RD100), Sunrise Hills (SUHI), Valley of Fire (VFArca). Non-overlapping confidence intervals between years are denoted by '*'.

		2008		2009		sig diff
	site	Mean	95% CL	Mean	95% CL	between years
Total Cover	BLPO	10.29	8.57,12.26	7.71	6.68,8.74	
	GAHI	4.89	3.65,6.50	3.87	3.18,4.69	
	GOBU	3.50	2.91,4.25	4.80	4.10,5.61	
	RD100	8.36	6.04,11.54	6.39	4.88,8.39	
	SUHI	3.37	2.35,4.79	3.65	2.68,4.97	
	VFArca	14.73	12.43,17.6	11.64	10.36,12.93	
Annual cover	BLPO			0.87	0.68,1.08	
	GAHI			1.01	0.78,1.31	
	GOBU			1.16	0.94,1.40	
	RD100			2.25	1.69,2.92	
	SUHI			0.88	0.73,1.04	
	VFArca			1.69	1.43,1.97	
Perennial cover	BLPO	0.99	0.81,1.17	1.69	1.22,2.34	*
	GAHI	1.92	1.57,2.32	1.97	1.53,2.52	
	GOBU	1.40	1.23,1.58	1.88	1.67,2.11	*
	RD100	3.85	2.88,5.08	2.85	1.98,4.06	
	SUHI	0.88	0.73,1.03	1.72	1.15,2.55	*
	VFArca	2.35	1.93,2.82	2.73	2.31,3.25	
Shrub cover	BLPO	9.15	7.45,11.13	5.63	4.24,7.14	*
	GAHI	2.68	1.73,4.04	1.16	0.73,1.72	*
	GOBU	1.96	1.43,2.65	2.27	1.74,2.90	
	RD100	3.51	2.02,5.82	5.87	3.82,8.57	
	SUHI	2.30	1.40,3.58	1.55	0.88,2.52	
	VFArca	11.75	9.37,14.79	7.59	6.69,8.63	*
ARCA cover	BLPO	6.93	4.59,9.97	3.53	2.10,5.49	
	GAHI	3.22	1.89,5.16	0.66	0.25,1.32	*
	GOBU	3.00	2.20,3.96	1.28	0.75,1.96	*
	RD100	8.92	6.76,11.75	2.30	1.57,3.23	*
	SUHI	1.30	0.79,2.01	0.62	0.29,1.05	
	VFArca	12.62	8.56,17.71	6.99	4.12,11.18	

Table 9. Summary of mean and bootstrapped 95% confidence limits (CL) of quadrat-level and whole-plot measurements at sites containing Las Vegas bearpoppy. Diversity is back-transformed to Hill's number, richness is average number of species (for quadrat) or total number of species in the site (whole-plot). Blue Point (BLPO), Gale Hills (GAHI), Gold Butte (GOBU), Road 100 (RD100), Sunrise Hills (SUHI), Valley of Fire (VFArca). Non-overlapping confidence intervals between years are denoted by '*'.

		2008		2009		sig diff between years
	site	Mean	95% CL	Mean	95% CL	
Hill diversity	BLPO	3.93	3.41,4.46	5.96	5.27,6.76	*
	GAHI	3.46	3.07,3.90	4.99	4.41,5.62	*
	GOBU	4.57	4.03,5.12	7.15	6.27,8.02	*
	RD100	4.63	3.97,5.36	5.70	4.91,6.61	
	SUHI	2.62	2.23,3.03	3.43	2.92,3.98	
	VFArca	4.99	4.15,5.91	9.63	8.66,10.65	*
Richness	BLPO	5.84	5.30,6.44	7.70	6.82,8.61	*
	GAHI	4.48	3.96,5.02	5.55	4.86,6.28	
	GOBU	5.10	4.58,5.62	7.81	6.84,8.83	*
	RD100	6.01	5.12,7.04	6.80	5.71,8.10	
	SUHI	3.29	2.79,3.79	4.23	3.56,4.96	
	VFArca	8.96	8.14,9.84	13.03	11.98,14.09	*
Hill diversity (Annuals excluded)	BLPO	3.93	3.35,4.43	4.97	4.40,5.51	
	GAHI	3.46	3.03,3.86	4.29	3.75,4.81	
	GOBU	4.57	3.97,5.09	5.61	5.05,6.15	
	RD100	4.63	3.90,5.31	5.28	4.56,6.00	
	SUHI	2.62	2.16,2.99	2.92	2.47,3.30	
	VFArca	4.99	4.07,5.84	7.17	6.52,7.81	*
Richness (Annuals excluded)	BLPO	5.84	5.28,6.40	6.35	5.63,7.02	
	GAHI	4.48	3.93,4.98	4.78	4.12,5.42	
	GOBU	5.10	4.54,5.61	6.17	5.55,6.75	
	RD100	6.01	5.04,6.96	6.32	5.31,7.35	
	SUHI	3.29	2.68,3.75	3.58	2.98,4.06	
	VFArca	8.96	8.11,9.83	9.71	9.07,10.40	
Whole-plot diversity	BLPO	7.48		11.40		
	GAHI	8.63		14.45		
	GOBU	7.65		13.90		
	RD100	13.15		17.60		
	SUHI	4.53		6.71		
	VFArca	7.20		15.30		
Whole-plot richness	BLPO	16		24		
	GAHI	18		28		
	GOBU	10		21		
	RD100	17		28		
	SUHI	9		19		
	VFArca	18		28		

Whole-plot diversity	BLPO	6.48	8.01
(Annuals excluded)	GAHI	7.64	10.60
	GOBU	7.65	9.19
	RD100	12.47	14.57
	SUHI	4.53	4.95
	VFArca	6.75	10.27
Whole-plot richness	BLPO	15	15
(Annuals excluded)	GAHI	17	19
	GOBU	10	12
	RD100	16	18
	SUHI	9	9
	VFArca	17	16

Table 10. Total number of Las Vegas bearpoppy recorded at each monitoring site in 2008 & 2009.

	2008	**2009**
Blue Point	94	67
Road 100	77	68
Sunrise Hills	44	49
Valley of Fire (Las Vegas bearpoppy site)	237	206
Gold Butte	62	53
Gale Hills	70	37

Table 11. Spearman correlations (rho) and P-values for relationships between plant variables and climate variables by month. All correlations were based on six sites.

	Minimum Temp.		Maximum Temp.		Mean Temp.		IQR Temp.	
	rho	P-value	rho	P-value	rho	P-value	rho	P-value
May	-0.77	0.1028	0.31	0.5639	-0.03	1.0000	0.43	0.4194
June	-0.26	0.6583	0.26	0.6583	0.26	0.6583	-0.54	0.2972
July	-0.26	0.6583	0.31	0.5639	0.26	0.6583	0.20	0.7139
August	-0.26	0.6583	0.31	0.5639	0.26	0.6583	0.20	0.7139
September	-0.26	0.6583	0.26	0.6583	0.60	0.2417	0.14	0.8028
October	-0.09	0.9194	0.37	0.4972	0.37	0.4972	0.14	0.8028
November	0.43	0.4194	-0.77	0.1028	0.20	0.7139	0.20	0.7139

	Minimum VD		Maximum VD		Mean VD		IQR VD		Rainfall	
	rho	P-value	rho	P-value	rho	P-value	rho	P-value	rho	P-value
May	-0.14	0.8028	0.89	**0.0333**	0.49	0.3556	0.77	0.1028		
June	-0.26	0.6583	0.83	0.0583	0.54	0.2972	0.89	**0.0333**	-0.13	0.8047
July	0.09	0.9194	0.66	0.1750	0.54	0.2972	-0.37	0.4972	0.81	**0.0499**
August	-0.09	0.9194	0.83	0.0583	0.60	0.2417	0.89	**0.0333**	-0.06	0.9131
September	-0.09	0.9194	0.14	0.8028	0.60	0.2417	0.60	0.2417		
October	-0.14	0.8028	-0.37	0.4972	0.83	0.0583	0.71	0.1361	-0.03	0.9493
November	0.89	**0.0333**	-0.03	1.0000	0.83	0.0583	-0.54	0.2972		

Table 12. ANOVA results predicting presence of Las Vegas bearpoppy (log10-transformed +1) for species richness and log10+1 transformed diversity, relative proportion of perennial cover, relative proportion of shrub cover, and total cover. Model included quadrat as the subject effect and an unstructured covariance structure (determined by AICC). Proportion of annuals (propa) was treated alone because this variable was not measured the first year of the study (2008). The minimum adequate model was based on AICC. The high dimensionality and strong relationships among some variables make the AICC a more reliable estimator of the best model compared to using p-values.

		Full model		Reduced model	
Effect	df	FValue	P-value	FValue	P-value
Site	5,144	0.46	0.8090	0.60	0.6981
Year	1,144	0.00	0.9961	0.00	0.9668
Site*Year	5,144	0.88	0.4975	0.84	0.5212
arca_richness	1,144	2.21	0.1397		
arca_richness*Site	5,144	1.74	0.1286		
arca_richness*Year	1,144	1.59	0.2097		
arca_richn*Site*Year	5,144	0.75	0.5901		
log10diversity	1,144	0.86	0.3543	1.58	0.2111
log10diversity*Site	5,144	1.10	0.3622	0.19	0.9644
log10diversity*Year	1,144	3.37	0.0684	4.97	0.0273
log10diver*Site*Year	5,144	0.68	0.6421	1.43	0.2173
log10propp	1,144	0.30	0.5854	0.09	0.7680
log10propp*Site	5,144	0.61	0.6917	1.17	0.3286
log10propp*Year	1,144	0.54	0.4617	0.31	0.5771
log10propp*Site*Year	5,144	0.57	0.7199	1.01	0.4121
log10props	1,144	0.00	0.9438	0.00	0.9547
log10props*Site	5,144	0.54	0.7448	0.81	0.5447
log10props*Year	1,144	0.07	0.7899	0.02	0.8809
log10props*Site*Year	5,144	0.66	0.6556	0.80	0.5487
log10total	1,144	2.61	0.1081	1.59	0.2100
log10total*Site	5,144	2.57	0.0292	1.52	0.1875
log10total*Year	1,144	0.03	0.8646	1.92	0.1682
log10total*Site*Year	5,144	1.16	0.3296	1.88	0.1017

Site	5,137	3.95	0.0022
log10propa	1,137	9.73	0.0022
log10propa*Site	5,137	1.59	0.1665

Table 13. Slopes, slope SE, and P-values for testing slope significance relative to zero for Las Vegas bearpoppy. Estimates were derived from the model in Table 12 for each continuous predictor variable individually to avoid misleading coefficient signs or magnitudes. Blue Point (BLPO), Gale Hills (GAHI), Gold Butte (GOBU), Road 100 (RD100), Sunrise Hills (SUHI), Valley of Fire (VFArca).

Variable	Site Year	Slope	SE	DF	tValue	P (slope=0)
biodiversity	BLPO 2008	0.475	0.497	144	0.96	0.3402
biodiversity	BLPO 2009	1.760	0.520	144	3.38	**0.0009**
biodiversity	GAHI 2008	0.346	0.561	144	0.62	0.5384
biodiversity	GAHI 2009	1.206	0.541	144	2.23	**0.0274**
biodiversity	GOBU 2008	-0.459	0.542	144	-0.85	0.3986
biodiversity	GOBU 2009	1.211	0.511	144	2.37	**0.0192**
biodiversity	RD100 2008	0.190	0.465	144	0.41	0.6826
biodiversity	RD100 2009	0.641	0.461	144	1.39	0.1670
biodiversity	SUHI 2008	0.539	0.490	144	1.10	0.2737
biodiversity	SUHI 2009	0.213	0.447	144	0.48	0.6340
biodiversity	VFARCA 2008	0.469	0.355	144	1.32	0.1882
biodiversity	VFARCA 2009	1.882	0.587	144	3.21	**0.0017**
proportion annuals	BLPO 2009	-2.650	1.816	137	-1.46	0.1468
proportion annuals	GAHI 2009	-2.248	1.314	137	-1.71	0.0894
proportion annuals	GOBU 2009	-3.231	1.159	137	-2.79	**0.0060**
proportion annuals	RD100 2009	-0.042	0.903	137	-0.05	0.9629
proportion annuals	SUHI 2009	-0.167	1.046	137	-0.16	0.8735
proportion annuals	VFARCA 2009	-4.034	2.731	137	-1.48	0.1419
proportion perennials	BLPO 2008	3.888	2.297	144	1.69	0.0927
proportion perennials	BLPO 2009	-3.354	0.773	144	-4.34	**0.0000**
proportion perennials	GAHI 2008	0.267	0.875	144	0.30	0.7609
proportion perennials	GAHI 2009	-0.499	1.449	144	-0.34	0.7309
proportion perennials	GOBU 2008	0.318	1.017	144	0.31	0.7550
proportion perennials	GOBU 2009	-1.078	0.849	144	-1.27	0.2063
proportion perennials	RD100 2008	0.517	0.690	144	0.75	0.4546
proportion perennials	RD100 2009	0.215	0.972	144	0.22	0.8256
proportion perennials	SUHI 2008	0.728	0.716	144	1.02	0.3114
proportion perennials	SUHI 2009	-0.291	0.811	144	-0.36	0.7204
proportion perennials	VFARCA 2008	2.554	1.317	144	1.94	0.0543
proportion perennials	VFARCA 2009	-1.686	1.565	144	-1.08	0.2831
proportion shrubs	BLPO 2008	-1.163	3.720	144	-0.31	0.7550
proportion shrubs	BLPO 2009	-1.657	0.475	144	-3.49	**0.0006**
proportion shrubs	GAHI 2008	0.317	0.785	144	0.40	0.6871
proportion shrubs	GAHI 2009	-0.816	0.330	144	-2.47	**0.0147**
proportion shrubs	GOBU 2008	-1.599	0.934	144	-1.71	0.0893
proportion shrubs	GOBU 2009	-1.608	0.717	144	-2.24	**0.0263**
proportion shrubs	RD100 2008	-0.068	0.605	144	-0.11	0.9103
proportion shrubs	RD100 2009	-0.436	0.250	144	-1.74	0.0832
proportion shrubs	SUHI 2008	-0.509	0.683	144	-0.75	0.4574
proportion shrubs	SUHI 2009	-0.355	0.288	144	-1.23	0.2195
proportion shrubs	VFARCA 2008	-3.052	1.648	144	-1.85	0.0660
proportion shrubs	VFARCA 2009	-2.378	0.630	144	-3.78	**0.0002**

Table 13. cont'd.

Variable	Site Year	Slope	SE	DF	tValue	P (slope=0)
richness	BLPO 2008	0.055	0.041	144	1.35	0.1795
richness	BLPO 2009	0.090	0.029	144	3.15	**0.0020**
richness	GAHI 2008	-0.022	0.044	144	-0.50	0.6181
richness	GAHI 2009	0.070	0.033	144	2.09	**0.0382**
richness	GOBU 2008	-0.028	0.047	144	-0.59	0.5549
richness	GOBU 2009	0.056	0.025	144	2.28	**0.0239**
richness	RD100 2008	-0.001	0.026	144	-0.03	0.9759
richness	RD100 2009	0.019	0.020	144	0.93	0.3524
richness	SUHI 2008	0.012	0.052	144	0.23	0.8169
richness	SUHI 2009	0.021	0.037	144	0.57	0.5699
richness	VFARCA 2008	0.014	0.027	144	0.52	0.6023
richness	VFARCA 2009	0.070	0.024	144	2.90	**0.0043**
total cover	BLPO 2008	-0.016	0.327	144	-0.05	0.9603
total cover	BLPO 2009	0.443	0.506	144	0.88	0.3825
total cover	GAHI 2008	-0.608	0.223	144	-2.73	**0.0071**
total cover	GAHI 2009	0.318	0.394	144	0.81	0.4210
total cover	GOBU 2008	0.010	0.357	144	0.03	0.9778
total cover	GOBU 2009	0.947	0.457	144	2.07	**0.0400**
total cover	RD100 2008	0.107	0.197	144	0.54	0.5873
total cover	RD100 2009	0.213	0.275	144	0.77	0.4402
total cover	SUHI 2008	-0.142	0.211	144	-0.67	0.5027
total cover	SUHI 2009	0.007	0.256	144	0.03	0.9771
total cover	VFARCA 2008	-0.537	0.326	144	-1.65	0.1014
total cover	VFARCA 2009	0.434	0.581	144	0.75	0.4563

Table 14. Generalized linear model results for size and condition of plants as well as their site of origin relative to success in Las Vegas bearpoppy seeding. Size class was first treated in a separate model because a larger number of date and sites were available compared to those for condition. The minimum adequate model was chosen by using the AICC.

Full model						Minimum adequate model			
Year	Effect	NumDF	DenDF	FValue	ProbF	NumDF	DenDF	FValue	ProbF
2008	Site	2	17	0.0	0.9993	2	21	18.5	**0.0000**
2008	sizeclass	2	17	25.2	0.0000	2	21	37.8	**0.0000**
2008	Site*sizeclass	4	17	0.8	0.5354				
2009	Site	5	26	1.3	0.3049	5	36	3.4	**0.0123**
2009	sizeclass	2	26	0.0	0.9991	2	36	47.2	**0.0000**
2009	Site*sizeclass	10	26	0.1	0.9997				

Minimum adequate model					
Year	Effect	NumDF	DenDF	FValue	ProbF
2009	Site	5	66	2.0	0.0903
2009	Condition	1	66	15.1	0.0002
2009	sizeclass	2	66	35.9	0.0000
2009	Condition*sizeclass	2	66	4.3	**0.0169**

Table 15. Estimated proportion Las Vegas bearpoppy seeding from first model in Table 14 for terms in the minimum adequate model. Letters denote significant differences within effects and years (α =0.05). Blue Point (BLPO), Gale Hills (GAHI), Gold Butte (GOBU), Road 100 (RD100), Sunrise Hills (SUHI), Valley of Fire (VFArca).

Year	Effect	Site	Size class	Mean	SE	
2008	Site	BLPO		0.793	0.056	b
2008	Site	GAHI		0.498	0.086	a
2008	Site	VFArca		0.915	0.023	c
2008	Size class		1-2	0.267	0.036	a
2008	Size class		3	0.841	0.041	b
2008	Size class		4-5	0.955	0.027	b
2009	Site	BLPO		0.889	0.033	b
2009	Site	GAHI		0.765	0.080	ab
2009	Site	GOBU		0.729	0.073	ab
2009	Site	RD100		0.556	0.072	a
2009	Site	SUHI		0.775	0.081	ab
2009	Site	VFArca		0.755	0.035	b
2009	Size class		1-2	0.365	0.042	a
2009	Size class		3	0.819	0.037	b
2009	Size class		4-5	0.921	0.021	c

Table 16. Estimated proportion seeding from second model in Table 14 for terms in the minimum adequate model. Letters denote significant differences within effects and years (α =0.05). Blue Point (BLPO), Gale Hills (GAHI), Gold Butte (GOBU), Road 100 (RD100), Sunrise Hills (SUHI), Valley of Fire (VFArca).

2009	Site	GOBU			0.748	0.074	
2009	Site	RD100			0.680	0.069	
2009	Site	SUHI			0.798	0.075	
2009	Site	VFArca			0.744	0.044	
2009	Condition		1-2		0.876	0.032	b
2009	Condition		3-4		0.638	0.050	a
2009	Size class			1-2	0.368	0.050	a
2009	Size class			3	0.823	0.039	b
2009	Size class			4-5	0.942	0.022	c
2009	Condition*Size class		1-2	1-2	0.389	0.049	a
2009	Condition*Size class		1-2	3	0.902	0.035	c
2009	Condition*Size class		1-2	4-5	0.984	0.012	d
2009	Condition*Size class		3-4	1-2	0.346	0.086	a
2009	Condition*Size class		3-4	3	0.702	0.068	b
2009	Condition*Size class		3-4	4-5	0.814	0.051	bc

Table 17. Total number of ringstem recorded at each monitoring site in 2008 and 2009.

	2008	**2009**
Road 100	26	28
Sunrise Hills	31	49
Valley of Fire (ringstem site)	32	38

Table 18. Summary of mean and bootstrapped 95% confidence limits (CL) of quadrat-level and whole-plot measurements at sites containing ringstem. Cover values are expressed as percent cover in the plot. Diversity is back-transformed to Hill's number; richness is average number of species (for quadrat) or total number of species in the site (whole-plot). Site names are denoted as: Road 100 (RD100), Sunrise Hills (SUHI), and Valley of Fire ringstem site (VFAnle). Non-overlapping confidence intervals between years are denoted by '*'.

		2008		2009		Sig.
	Site	Mean	95% CL	Mean	95% CL	diff
Total Cover	RD100	8.38	6.02,11.61	6.39	4.89,8.44	
	SUHI	3.27	2.26,4.67	3.65	2.66,5.02	
	VFAnle	5.84	4.81,7.21	4.84	4.34,5.35	
Annual cover	RD100	0.03	0,0.08	0.27	0.09,0.51	*
	SUHI	0.00	0,0	0.30	0.15,0.48	*
	VFAnle	0.00	0,0	0.14	0.07,0.23	*
Perennial cover	RD100	3.83	2.84,5.06	2.94	2.40,3.59	
	SUHI	0.86	0.70,1.01	0.91	0.72,1.09	
	VFAnle	1.65	1.16,2.40	1.78	1.52,2.08	
Shrub cover	RD100	3.51	2.01,5.82	2.79	1.81,4.21	
	SUHI	2.18	1.28,3.50	2.22	1.46,3.38	
	VFAnle	3.61	2.92,4.56	2.78	2.45,3.14	
ANLE cover	RD100	1.66	0.99,2.54	1.68	1.13,2.35	
	SUHI	0.84	0.45,1.40	0.67	0.30,1.19	
	VFAnle	0.69	0.34,1.15	1.17	0.72,1.83	
Hill diversity	RD100	4.66	4.00,5.38	5.70	4.88,6.61	
	SUHI	2.60	2.20,3.00	3.43	2.91,3.99	
	VFAnle	4.76	4.05,5.48	6.96	6.13,7.82	*
Richness	RD100	6.05	5.16,7.06	6.80	5.68,8.09	
	SUHI	3.24	2.73,3.76	4.23	3.55,4.94	
	VFAnle	6.32	5.74,6.93	7.71	6.88,8.57	
Hill diversity (Annuals excluded)	RD100	4.59	3.93,5.32	5.25	4.58,6.01	
	SUHI	2.60	2.22,3.01	2.92	2.53,3.33	
	VFAnle	4.76	4.06,5.48	6.69	5.96,7.46	*
Richness (Annuals excluded)	RD100	5.95	5.03,6.98	6.28	5.34,7.35	
	SUHI	3.24	2.74,3.75	3.58	3.07,4.11	
	VFAnle	6.32	5.74,6.95	7.42	6.70,8.20	
Whole-plot diversity	RD100	13.26		17.50		
	SUHI	4.52		6.71		
	VFAnle	7.69		13.35		
Whole-plot richness	RD100	18.00		27.00		
	SUHI	9.00		19.00		
	VFAnle	17.00		23.00		
Whole-plot diversity (Annuals excluded)	RD100	13.04		14.83		
	SUHI	4.52		4.95		
	VFAnle	7.69		12.13		
Whole-plot richness (Annuals excluded)	RD100	16.00		18.00		
	SUHI	9.00		9.00		
	VFAnle	17.00		20.00		

Table 19. Proportional representation for each life form as a function of total cover for ringstem. These were the values used for deriving ranks for comparison with the climate data to avoid confounding total cover with individual categories' representation. Site names are denoted as: Road 100 (RD100), Sunrise Hills (SUHI), and Valley of Fire ringstem site (VFAnle).

	a		p		s	
site	2008	2009	2008	2009	2008	2009
RD100	0.01	0.05	0.52	0.49	0.42	0.43
SUHI	0	0.09	0.35	0.29	0.58	0.58
VFAnle	0	0.03	0.30	0.37	0.66	0.58

Table 20. Listing of congruent order by site for ringstem variables and climate variables by month. Numbers denote months (e.g., 5=May) in 2009. Dates analyzed include months 2-9 for all variables except rainfall, which included only months 5-8.

Plant variable	**Environment**
Proportion annuals	Min temp (5,7,8)
Proportion perennials, Total cover, ANLE cover	IQR temp (3,6)
	Max vd (7)
	IQR vd (4,5)
	Rainfall (7)
Proportion shrubs	Min temp (3,4,6,9)
	Mean temp (3,5,8)
	Max vd (3)
Diversity, Richness	IQR temp (4,5,8)
	Min vd (2)
	Max vd (2,4,5,6,8)
	Mean vd (2,3,4)
	IQR vd (2,6,8)

Table 21. ANOVA results predicting presence of ringstem (log_{10}-transformed +1) for species richness and log_{10}+1 transformed diversity, relative proportion of perennial cover, relative proportion of shrub cover, and total cover. Model included quadrat as the subject effect and a compound symmetry covariance structure (determined by AICC). Proportion of annuals was treated alone because this variable was not reliably measured the first year of the study (2008). The minimum adequate model was based on AICC.

	Full model			Reduced model		
Effect	df	FValue	P-value	df	FValue	P-value
Site	2,72	0.11	0.8936	2,72	0.31	0.7318
Year	1,35	1.46	0.2356	1,41	4.18	0.0474
Site*Year	2,35	0.58	0.5650	2,41	1.22	0.3056
Richness	1,35	0.80	0.3771			
Richness*Site	2,35	0.25	0.7786			
Richness*Year	1,35	0.44	0.5107			
Richness*Site*Year	2,35	0.08	0.9256			
Diversity	1,35	0.01	0.9113	1,41	2.88	0.0970
Diversity*Site	2,35	0.52	0.5970	2,41	1.51	0.2326
Diversity*Year	1,35	0.43	0.5186	1,41	5.27	0.0269
Diversity*Site*Year	2,35	0.13	0.8777	2,41	0.69	0.5074
Diversity2	1,35	5.64	0.0232	1,41	5.33	0.0260
Diversity2*Site	2,35	1.03	0.3686	2,41	1.28	0.2902
Diversity2*Year	1,35	1.57	0.2192	1,41	0.62	0.4372
Diversity2*Site*Year	2,35	0.80	0.4593	2,41	0.57	0.5700
Prop_Perennials	1,35	0.80	0.3769	1,41	0.21	0.6523
Prop_Perennials*Site	2,35	0.54	0.5859	2,41	0.13	0.8763
Prop_Perennials*Year	1,35	0.16	0.6885	1,41	0.31	0.5810
Prop_Perennials*Site*Year	2,35	0.28	0.7545	2,41	0.20	0.8224
Prop_Shrubs	1,35	0.46	0.5032	1,41	0.10	0.7511
Prop_Shrubs*Site	2,35	0.08	0.9202	2,41	0.07	0.9294
Prop_Shrubs*Year	1,35	1.25	0.2707	1,41	1.51	0.2256
Prop_Shrubs*Site*Year	2,35	0.77	0.4717	2,41	0.65	0.5273
Total Cover	1,35	0.18	0.6751	1,41	0.14	0.7090
Total Cover*Site	2,35	0.29	0.7495	2,41	0.15	0.8589
Total Cover*Year	1,35	0.11	0.7396	1,41	0.27	0.6041
Total Cover*Site*Year	2,35	0.01	0.9898	2,41	0.58	0.5667

Effect	df	FValue	P-value
Site	2,69	3.46	0.0370
Prop_Annuals	1,69	0.03	0.8549
Prop_Annuals*Site	2,69	0.56	0.5750

Table 22. Slopes, slope SE, and P-values for testing slope significance relative to zero for ringstem. Estimates were derived from the model in Table 21 for each continuous predictor variable individually to avoid misleading coefficient signs or magnitudes. The exception to this is the quadratic term for Hill diversity, which was fit with the linear Hill diversity term present. Site names are denoted as: Road 100 (RD100), Sunrise Hills (SUHI), and Valley of Fire ringstem site (VFAnle).

Variable	Year	Site	Slope	SE	DF	tValue	P (slope=0)
Hill diversity- linear	2008	RD100	-0.020	0.345	59	-0.06	0.9533
Hill diversity- linear	2009	RD100	0.823	0.489	59	1.68	0.0978
Hill diversity- linear	2008	SUHI	-0.177	1.022	59	-0.17	0.8631
Hill diversity- linear	2009	SUHI	0.068	0.458	59	0.15	0.8827
Hill diversity- linear	2008	VFAnle	0.075	0.337	59	0.22	0.8251
Hill diversity- linear	2009	VFAnle	1.323	0.677	59	1.95	0.0554
Hill diversity- quadratic	2008	RD100	-2.050	1.512	59	-1.36	0.1803
Hill diversity- quadratic	2009	RD100	-4.007	2.026	59	-1.98	0.0526
Hill diversity- quadratic	2008	SUHI	-0.435	2.269	59	-0.19	0.8487
Hill diversity- quadratic	2009	SUHI	-0.231	1.560	59	-0.15	0.8828
Hill diversity- quadratic	2008	VFAnle	-2.678	1.551	59	-1.73	0.0895
Hill diversity- quadratic	2009	VFAnle	-3.692	2.311	59	-1.60	0.1155
Proportion annuals	2009	RD100	-1.605	1.565	69	-1.03	0.3087
Proportion annuals	2009	SUHI	0.363	1.162	69	0.31	0.7556
Proportion annuals	2009	VFAnle	0.603	2.883	69	0.21	0.8350
Proportion perennials	2008	RD100	0.978	0.516	65	1.89	0.0628
Proportion perennials	2009	RD100	0.670	0.705	65	0.95	0.3453
Proportion perennials	2008	SUHI	0.931	0.432	65	2.15	**0.0349**
Proportion perennials	2009	SUHI	0.223	0.605	65	0.37	0.7141
Proportion perennials	2008	VFAnle	-0.528	0.661	65	-0.80	0.4275
Proportion perennials	2009	VFAnle	-1.007	1.226	65	-0.82	0.4146
Proportion shrubs	2008	RD100	-0.856	0.472	65	-1.81	0.0743
Proportion shrubs	2009	RD100	-0.572	0.650	65	-0.88	0.3819
Proportion shrubs	2008	SUHI	-0.910	0.425	65	-2.14	**0.0359**
Proportion shrubs	2009	SUHI	0.120	0.574	65	0.21	0.8354
Proportion shrubs	2008	VFAnle	0.686	0.670	65	1.02	0.3098
Proportion shrubs	2009	VFAnle	1.624	1.328	65	1.22	0.2257
Richness	2008	RD100	0.000	0.020	65	0.01	0.9907
Richness	2009	RD100	0.002	0.015	65	0.14	0.8876
Richness	2008	SUHI	-0.018	0.035	65	-0.52	0.6030
Richness	2009	SUHI	0.021	0.024	65	0.85	0.3968
Richness	2008	VFAnle	-0.019	0.027	65	-0.70	0.4885
Richness	2009	VFAnle	0.005	0.020	65	0.27	0.7907
Total cover	2008	RD100	-0.085	0.158	65	-0.54	0.5903
Total cover	2009	RD100	-0.070	0.196	65	-0.36	0.7210
Total cover	2008	SUHI	-0.082	0.151	65	-0.55	0.5862
Total cover	2009	SUHI	0.091	0.169	65	0.54	0.5936
Total cover	2008	VFAnle	-0.287	0.195	65	-1.47	0.1460
Total cover	2009	VFAnle	0.100	0.393	65	0.25	0.7997

Table 23. Least squares means and SE for proportions ringstem bolting for two size classes (measured by number of stems) of plants for three sites and two years. No plants larger than ten stems were present at the Valley of Fire ringstem site either year. There was a significant difference between years at Sunrise Hills but not at Road 100, and there was a significant effect of the number of stems in both sites. Site names are denoted as: Road 100 (RD100), Sunrise Hills (SUHI), and Valley of Fire ringstem site (VFAnle).

Site	Year	Bolting 0-10 stems	SE	Bolting >11 stems	SE
RD100	2008	0.76	0.10	1.00	0.00
RD100	2009	0.72	0.11	1.00	0.00
SUHI	2008	0.08	0.06	0.57	0.19
SUHI	2009	0.29	0.07	0.89	0.10
VFAnle	2008	0.34	0.08		
VFAnle	2009	0.24	0.07		

Table 24. Least squares means and SE for proportions of ringstem bolting for two size classes (measured by number of leaves) of plants for three sites in 2009. There was a significant difference between the two size classes (number of leaves) at Sunrise Hills and at the Valley of Fire ringstem site, but not at Road 100. Site names are denoted as: Road 100 (RD100), Sunrise Hills (SUHI), and Valley of Fire ringstem site (VFAnle).

Site	Bolting 0-10 leaves	SE	Bolting >11 leaves	SE
RD100	0.79	0.07	0.89	0.07
SUHI	0.32	0.06	0.56	0.09
VFAnle	0.19	0.05	0.50	0.14

Table 25. Summary of mean and bootstrapped 95% confidence limits (CL) for the numbers of ringstem leaves and stems at each site in each year they were measured. These are intended as a reference for Tables 23-24. Site names are denoted as: Road 100 (RD100), Sunrise Hills (SUHI), and Valley of Fire ringstem site (VFAnle).

		2008		2009	
	Site	Mean	95% CL	Mean	95% CL
Leaves	RD100			8.07	6.75,9.60
	SUHI			7.77	6.19,9.87
	VFAnle			6.75	5.75,8.02
Stems	RD100	5.28	3.40,7.77	7.40	5.49,9.76
	SUHI	2.53	1.36,4.39	2.79	1.77,4.24
	VFAnle	1.01	0.53,1.66	1.40	0.93,1.97

Table 26. Total number of threecorner milkvetch individuals encountered at Sandy Cove in 2008 and 2009.

	2008	**2009**
Sandy Cove	3968	2027

Table 27. Shown are summaries of mean and bootstrapped 95% confidence interval of quadrat-level measurements at sites containing threecorner milkvetch. Diversity is back-transformed to Hill's number, richness is average number of species, and all other values are expressed as percent cover in the plot. Top panel includes summary values, then second life forms, and the third information on nativity categories (a-annual; p-perennial; s-shrub; n-native; w-non-native). Sites are denoted as Sandy Cove (SACO), Ebony Cove (EBCO) and Weiser Wash (WEWA).

	Total cover	95% CI		Richness	95% CI		Diversity	95% CI	
2008 SACO	23.51	20.68	26.45	12.97	11.89	14.06	5.48	4.99	6.01
2009 EBCO	21.76	19.85	23.86	20.41	18.80	21.98	10.03	8.96	11.18
2009 SACO	16.81	14.63	19.07	12.42	11.06	13.81	6.28	5.63	6.95
2009 WEWA	24.80	23.20	26.55	19.65	18.92	20.40	10.06	9.03	11.19

	a	95% CI		p	95% CI		s	95% CI	
2008 SACO	5.72	5.06	6.42	0.32	0.23	0.42	15.92	13.75	18.26
2009 EBCO	9.77	8.86	10.67	0.02	0.00	0.06	11.67	10.32	13.21
2009 SACO	5.88	5.22	6.59	0.23	0.17	0.31	9.74	8.22	11.45
2009 WEWA	9.31	8.63	10.12	2.59	2.35	2.84	11.89	10.20	13.78

	n	95% CI		w	95% CI	
2008 SACO	21.68	19.09	24.48	0.96	0.81	1.13
2009 EBCO	19.90	18.11	21.79	1.37	1.16	1.59
2009 SACO	15.28	13.35	17.40	1.08	0.93	1.25
2009 WEWA	18.76	17.06	20.62	4.90	4.27	5.67

Table 28. Shown are whole-site richness and diversity at each threecorner milkvetch site by year. Sites are denoted as Sandy Cove (SACO), Ebony Cove (EBCO) and Weiser Wash (WEWA).

	Richness	Diversity
2008 SACO	60	9.54
2009 EBCO	42	13.63
2009 SACO	55	11.61
2009 WEWA	49	12.90

Table 29. Shown are the top five species by cover for each threecorner milkvetch site. Values are the sum of mid-points (of cover) for each quadrat by site and year. The grand total is the total sum of mid-points for each site and year. The percentage of relative cover represented by the most common, the two most common, and the five most common species is provided in the 'Top1', 'Top2', and 'Top5' rows. Species abbreviations are as follows, Ambdum-*Ambrosia dumosa*, Kraere-*Krameria erecta*, Lartri-*Larrea tridentata*, Psofre-*Psorothamnus fremontii*, Pecpla-*Pectocarya platycarpa*, Plaova-*Plantago ovata*, and Strlon-*Streptanthella longirostris.* Sites are denoted as Sandy Cove (SACO), Ebony Cove (EBCO) and Weiser Wash (WEWA).

2008 SACO		2009 EBCO		2009 SACO		2009 WEWA	
Ambdum	1541	Ambdum	324	Ambdum	1072	Ambdum	322
Kraere	112	Lartri	79	Kraere	83	Ephedra	67
Lartri	1072	Pecpla	23	Lartri	747	Kraere	39
Psofre	279	Psofre	29	Plaova	101	Lartri	42
Schismus	102	Schismus	43	Strlon	86	Schismus	142
Grand Total	4117		815		3027		914
Top1	37%		40%		35%		35%
Top2	63%		49%		60%		51%
Top5	75%		61%		69%		67%

Table 30. Total number of sticky buckwheat individuals recorded during monitoring in 2008 & 2009.

	2008	**2009**
Lime Cove	4708	7043
Glory Hole	126	491

Table 31. Shown are summaries of mean and bootstrapped 95% confidence interval of quadrat-level and whole-plot measurements at sites containing sticky buckwheat. Diversity is back-transformed to Hill's number, richness is average number of species, and all other values are expressed as percent cover in the plot. Top panel includes summary values, the second life forms, the third information on nativity categories, and fourth whole-plot values (a-annual; p-perennial; s-shrub; n-native; w-non-native). Monitoring sites are denoted as Glory Hole (GLHO) and Lime Cove (LICO).

	Total cover	95% CI		Richness	95% CI		Hill diversity	95% CI	
2008 GLHO	22.11	18.88	25.93	8.53	7.63	9.46	4.62	3.99	5.34
2008 LICO	24.68	21.62	28.15	10.47	9.93	11.03	5.07	4.65	5.54
2009 GLHO	26.01	23.18	29.22	10.74	9.49	11.96	3.79	3.16	4.53
2009 LICO	24.26	20.56	28.59	11.54	10.91	12.19	4.56	4.02	5.14

	a	95% CI		p	95% CI		s	95% CI	
2008 GLHO	16.60	14.04	19.47	0.05	0.02	0.09	2.82	1.66	4.41
2008 LICO	22.81	20.02	25.98	0.03	0.01	0.07	0.35	0.09	0.83
2009 GLHO	19.57	17.15	22.20	0.05	0.02	0.11	2.19	1.03	3.83
2009 LICO	22.11	18.57	26.12	0.01	0.00	0.02	0.36	0.10	0.90

	n	95% CI		w	95% CI	
2008 GLHO	4.23	3.10	5.47	14.08	10.61	18.34
2008 LICO	11.32	9.69	13.19	11.42	8.92	14.18
2009 GLHO	4.75	3.45	6.27	17.91	14.57	21.63
2009 LICO	8.36	6.82	10.19	13.44	10.38	17.16

Table 32. The values provided are the sum of cover midpoints across all quadrats for each sticky buckwheat site and year. The 'Top1', 'Top2', and 'Top5' rows indicate the percent of total cover represented by the most common, two most common, and five most common species, respectively. Species abbreviations are as follows, Cryang-*Cryptantha angustifolia*, Salsola-d-dead litter from *Salsola* sp., Tamram-*Tamarix* sp., Cambre-*Camissonia brevipes*, and Erivis-*Eriogonum viscidulum*. Monitoring sites are denoted as Glory Hole (GLHO) and Lime Cove (LICO).

2008 GLHO		2008 LICO		2009 GLHO		2009 LICO	
Cryang	78	Cambre	177	Cryang	57	Cryang	65
Salsola	537	Erivis	329	Erivis	76	Erivis	348
Salsola-d	80	Salsola	123	Salsola	115	Salsola	126
Schismus	307	Schismus	716	Schismus	963	Schismus	895
Tamram	374	Tamram	114	Tamram	367	Tamram	119
Grand Total	1727		1872		1932		1877
Top1	31%		38%		50%		48%
Top2	53%		56%		69%		66%
Top5	80%		78%		82%		83%

Table 33. Estimated intercepts and slopes predicting presence of sticky buckwheat (log10-transformed +1) for species richness (ervi_richness), log10+1 transformed diversity (diversity), percent cover of annuals within plot (annual), percent cover of perennials within plot (perennial), percent cover of shrubs within plot (scovmid), percent cover of native plant species within plot (native), percent cover of non-native plant species within plot (w (non-native), and percent cover of litter (lcovmid) by year and site. The model included transect as a random effect and a two-dimensional exponential geometrically anisotropic spatial covariance structure (determined by AICC). The table provided is the minimum adequate model based on AICC. Monitoring sites are denoted as Glory Hole (GLHO) and Lime Cove (LICO).

Year Site	Effect	Estimate	StdErr	DF	tValue	Probt
2008GLHO	Intercept	-0.45	0.67	9	-0.66	0.5241
2008GLHO	diversity	0.54	0.22	55	2.49	**0.0160**
2008GLHO	perennial	0.02	0.41	55	0.04	0.9673
2008GLHO	annual	0.33	0.15	55	2.28	**0.0263**
2008GLHO	w (non-native)	-0.49	0.12	55	-4.13	**0.0001**
2008GLHO	scovmid	0.22	0.35	55	0.64	0.5254
2009LICO	Intercept	-0.07	0.34	9	-0.20	0.8480
2009LICO	diversity	0.71	0.22	50	3.18	**0.0025**
2009LICO	perennial	-0.61	0.58	50	-1.07	0.2916
2009LICO	native	1.67	0.14	50	12.03	**0.0000**
2009LICO	scovmid	-0.16	0.14	50	-1.16	0.2521
2008LICO	Intercept	-0.94	0.97	9	-0.98	0.3548
2008LICO	ervi_richness	0.10	0.04	55	2.52	**0.0147**
2008LICO	diversity	1.09	0.64	55	1.71	0.0928
2008LICO	perennial	-1.45	0.80	55	-1.80	0.0772
2008LICO	native	1.18	0.32	55	3.69	**0.0005**
2008LICO	scovmid	-0.51	0.35	55	-1.43	0.1571
2009GLHO	Intercept	0.64	0.45	9	1.42	0.1903
2009GLHO	diversity	0.48	0.24	54	1.97	0.0540
2009GLHO	perennial	1.90	0.44	54	4.35	**0.0001**
2009GLHO	w (non-native)	-0.41	0.18	54	-2.32	**0.0242**
2009GLHO	shrub	0.36	0.12	54	2.93	**0.0050**
2009GLHO	scovmid	-0.08	0.19	54	-0.44	0.6646
2009GLHO	lcovmid	-0.49	0.18	54	-2.80	**0.0070**

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LITERATURE CITED

Abella, S.R., J.E. Spencer, J. Hoines, C. Nazarchyk. 2008. Assessing an exotic plant surveying program in the Mojave Desert, Clark County, NV, USA. Environmental Monitoring Assessment. DOI 10.1007/s10661-008-0263-0. 10 Pp.

Bangle, D.N. 2005a. Report on Arctomecon californica (Las Vegas bearpoppy) Monitoring, Lake Mead National Recreation Area. For Vegetation Monitoring Program: rare plants, plant poaching and weed management programs (project number 2003-NPS-363-P2004-07. Unpublished report to Clark County. 30 Pp.

Bangle, D.N. 2005b. Report on surveys and mapping of Anulocaulis leiosolenus (ringstem) and other select plants of concern within Lake Mead National Recreation Area during 2004 and 2005. For Vegetation Monitoring Program: rare plants, plant poaching and weed management programs (project number 2003-NPS-363-P2004-07). Unpublished report to Clark County. 25 Pp.

Bangle, D.N. 2005c. Report on Astragalus geyeri var. triquetrus (threecorner milkvetch) Monitoring (2000-2005) within Lake Mead National Recreation Area. For Vegetation Monitoring Program: rare plants, plant poaching and weed management programs (project number 2003-NPS-363-P2004-07). Unpublished report to Clark County. 24 Pp.

Bangle, D.N. and J. Craig. Control methods of the invasive plant Brassica tournefortii (Sahara mustard) in the Mojave Desert. In prep.

Drohan, P.J., Merkler, D.J., How do we find a true gypsophile? Geoderma (2009), doi:10.1016/j.geoderma.2009.01.008.

Douglas, N.A. 2007. Molecular phylogenetic studies in Nyctaginaceae: Patterns of diversification in arid North America. Dissertation at Duke University, Durham, North Carolina.

Flora of North America Editorial Committee, eds. 1997. Magnoliophyta: Magnoliidae and Hamamelidae. Flora of North America North of Mexico. Volume 3. 616 Pp.

Flora of North America Editorial Committee, eds. 2003. Magnoliophyta: Caryophyllidae, part 1. Flora of North America North of Mexico. Volume 4: 584 Pp.

Howell, J.T. 1942. New western plants. Leaflets of Western Botany 3:138-142.

Jost, L. 2006. Entropy and diversity. Oikos 113(2):363-375.

Knight, T. 1992. Status report on four rare plant species located on Lake Mead National Recreation Area, Nevada and Arizona. Unpublished report to National Park Service, Lake Mead National Recreation Area, Boulder City, NV. (34 pp.)

McClellan, Y., and W.J. Boecklen. 1993. Plant mediation of ant-herbivore associations: the role of sticky rings formed by Boerhavia spicata. Coenoses 8:15-20.

Megill, Laura. 2007. Seed fates of arctomecon californica. Masters thesis at University of Nevada, Las Vegas, Nevada. 93 Pp.

Meyer, S.E. 1987. Life history of Arctomecon californica (Papaveraceae), a Mojave Desert endemic perennial herb. Centro Regional para Estudios de Zonas Aridas y Semiaridas del Colegio de Postgraduados, Chapingo, Mexico. 25 Pp & 6 Figures.

Meyer, S.E. and T. Forbis. 2006. Population viability analysis (PVA) for Arctomecon californica (Papaveraceae), an eastern Mojave Desert gypsophile perennial herb. Abstract for the 2006 Botanical Society of America meetings. 2 Pp.

Mistretta, O., R. Pant, T.S. Ross, J.M. Porter, and J.D. Morefield. 1996. Current knowledge and conservation status of Arctomecon californica Torrey and Frémont (Papaveraceae), the Las Vegas bearpoppy. Nevada Natural Heritage Program, U.S. Fish and Wildlife Service, Carson City, Nevada. 103 Pp. with appendices.

Morefield, J. 2001. Rare Plant Fact Sheet. Nevada Natural Heritage Program. Pp. 1.

The National Park Service. 2002. The Lake Mead National Recreation Area Lake Management Plan and Final Environmental Impact Statement. Lake Mead National Recreation Area, Boulder City, Nevada.

The Nature Conservancy. 2007. A Conservation Management Strategy for nine low elevation rare plants in Clark County, Nevada. Nevada Field Office Reno, NV. TNC 2007.

Niles, W.E., P.J. Leary, J.S. Holland, and F.H. Landau. 1999. Survey of special status plants in the eastern Mojave Desert 1999. University of Nevada, Las Vegas, prepared for U.S. Bureau of Land Management, Las Vegas, Nevada. 90 Pp.

Niles, W.E., J.S. Holland, P.J. Leary, and F.H. Landau. 1995. Survey of the special status plants in the Eastern Mojave Desert. University of Nevada, Las Vegas, submitted to the Bureau of Land Management, Las Vegas, Nevada. 71 Pp.

Niles, W.E., P.J. Leary, J.S. Holland, and F.H. Landau. 1995. Occurrence and distribution of Astragalus geyeri var. triquetrus (three-corner milkvetch) and Eriogonum viscidulum (sticky buckwheat) in Lake Mead National Recreation Area and adjacent regions of Nevada and Arizona. Prepared for the Lake Mead National Recreation Area, National Park Service, Boulder City, Nevada. 74 pp.

O'Hara, R.B. and D.J. Kotze. 2010. Do not log-transform count data. Methods in Ecology and Evolution in press.

Philippi, T., B. Collins, S. Guisti and P.M. Dixon. 2001. A multistage approach to population monitoring for rare plant populations. Natural Areas Journal 21(1):111-116.

Powell, E. 1999. Report on 1998 surveys for Arctomecon californica, Las Vegas bearpoppy, in Lake Mead National Recreation Area. National Park Service, Lake Mead National Recreation Area, Boulder City, Nevada. 6 Pp.

Powell, E. 1999. Report on Las Vegas bearpoppy (Arctomecon californica) monitoring. National Park Service, Lake Mead National Recreation Area, Boulder City, Nevada. 6 Pp.

R Development Core Team. 2009. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

[RECON] Regional Environmental Consultants, Inc. 2000. Final Clark County Nevada Multiple Species Habitat Conservation Plan and Environmental Impact Statement. Prepared for Clark County Administrative Services. 550 Pp. and appendices.

Reveal, J.L. 1978. Status report for Eriogonum viscidulum. University of Maryland, College Park, Maryland. Pp 6.

Reveal, J.L. 2003. Taxonomic Eriogonoideae (Polygonaceae) of North America north of Mexico: ERIOGONUM Michaux.

SAS Institute. 2002-2003. SAS v 9.1. Cary, NC.

Song, L. C., Jr. 2001. Preliminary report: bear poppy germination studies. Available from: U.S. Fish and Wildlife Service, 1340 Financial Blvd, Ste. 234, Reno Nevada 89502. 1pp.

Spellenberg, R. 1993. Taxonomy of Anulocaulis (Nyctagnaceae). SIDA Contributions to Botany 15:373-389.

Sutter, R., S. Kokos, and D. Bangle. 2009. “Improving the Implementation of Ecological Monitoring and Adaptive Management in the Clark County Multiple Species Habitat Conservation Plan” Final Report for Contract 2005-TNC-574F-P between Clark County and The Nature Conservancy. 27 Pp. with appendix.

Tepedino, V.J. and L.L. Hickerson. 1996. The reproductive ecology of Arctomecon californica. USDA Bee Biology & Systematics Lab, Logan, Utah. 19 Pp.

Walker, L.R., L. Megill, D. Johnson. 2007. Final report: Seed banks of Arctomecon californica (Las Vegas bearpoppy) in the upper Las Vegas Wash. 37 Pp.

APPENDIX 1.

Monitoring methods and protocols for *Arctomecon californica* (Las Vegas bearpoppy) in gypsum habitat within Clark County, Nevada

Monitoring period for Las Vegas bearpoppy: May

BACKGROUND AND OBJECTIVES

National Park Service (NPS) Management Policies direct managers at Lake Mead National Recreation Area (LMNRA) to survey for, protect, and manage state and locally listed species and other native species that are of special concern to the parks in order to maintain the species' natural distribution and abundance (NPS 2002). An additional concern of park managers is maintaining ecosystem health and stability by protecting habitat that supports high biodiversity areas including rare plant sites thus allowing natural processes to occur (i.e. energy flow through the system, natural fluctuations in species abundance). The Clark County Multiple Species Habitat Conservation Plan (MSHCP) lists specific goals for the management of rare plant species as outlined in the Low Elevation Rare Plant Conservation Management Strategy (TNC 2007). The key purposes of the MSHCP are to achieve a balance between 1) long-term conservation and recovery of the diversity of natural habitats and native species of plants and animals, 2) the orderly and beneficial use of land in order to promote the economy, health, well-being, custom and culture of Clark County residents (TNC 2007), as well as, having no net unmitigated loss or fragmentation of habitat in intensively managed areas and maintain stable or increasing plant populations.

Arctomecon californica (Las Vegas bearpoppy) is an endemic rare plant found on gypsum soils within southern Nevada and adjacent portions of Arizona. The Las Vegas bearpoppy is currently listed by the State of Nevada as critically endangered and is on the Nevada Natural Heritage Programs Sensitive List (ranks G3 S3-defined as very rare and local throughout its range). It is listed as a covered species under the MSHCP. The Las Vegas bearpoppy has been documented from 108 populations in east-central Clark County, Nevada, and from eight sites in the Lake Mead and lower Grand Canyon areas of northwestern Mohave County, Arizona. The species' distribution ranges from south of the Temple Bar area of Lake Mead to near the southern base of the Virgin Mountains, and from lower Grand Canyon to Las Vegas Valley. According to the last major review of this species conducted by Mistretta et al.

(1996) the currently known global population of *Arctomecon californica* consisted of at least 830,000 plants restricted to less than 39,500 acres of publicly and privately owned land divided among 99 populations – 91 in east-central Clark County and eight in adjacent northwestern Mohave County.

Las Vegas bearpoppy is restricted to dry soils with high gypsum content, and is entirely dependent on incident precipitation. This dependence on fluctuations in regional rainfall patterns results in wide yearly population fluctuations (Mistretta et al. 1996). Las Vegas bearpoppy appears to remain present on some sites over many years while disappearing and reappearing on other sites. Powell (1999) suggested that the sites on which Las Vegas bearpoppy plants remain active over long periods of time may be more important for the survival of pollinators or other associated species than the sites on which Las Vegas bearpoppy plants are ephemeral.

Many of the fragmented populations within the urban areas of Las Vegas Valley have likely been extirpated in recent years. At the time of the Nevada Natural Heritage Program report in 1996 only 48 (44%) of the Nevada populations of bearpoppy were relatively unimpacted and were considered secure from future development or encroachment (Mistretta et al. 1996). These 48 populations, however, comprised a large majority of the known habitat and numbers of plants. This statistic stresses the importance for a new monitoring approach for Las Vegas bearpoppy habitat and populations within Clark County. The monitoring strategy should include measuring any loss or fragmentation of the remaining Las Vegas bearpoppy populations and habitat.

Prior monitoring for Las Vegas bearpoppy at LMNRA was conducted along eight transects spread throughout poppy habitat. This study increased our knowledge about the population structure and demography of the Las Vegas bearpoppy. The major threats to the eight transect sites monitored during the project were from trampling by feral burros and wild horses particularly within the Northshore area and by off-road vehicles on the Bureau of Land Management (BLM) lands. The removal of burros in LMNRA by the NPS has been ongoing and aggressive. In the 2005 surveys, most of the LMNRA transect sites showed evidence of old disturbance (i.e. motorcycle tracks, burro, horse, and foot prints) but little new disturbance. This may be attributed to the previous burro removals within LMNRA as well as other management actions to reduce off-road vehicles.

Although valuable information was gathered from this long-term study, it did not provide a statistically valid method for monitoring population density and habitat characteristics of Las Vegas bearpoppy and its habitat. A new monitoring plan is necessary to evaluate changes within and across populations and monitor progress towards our goal of no unmitigated loss or fragmentation of habitat plus maintaining stable or increasing populations.

Las Vegas bearpoppy occurs on gypsum substrate with a substantial cryptogamic crust component. This soil type and the biological crusts that occur on these soil types are considered sensitive and easily damaged. Monitoring in such delicate habitat poses a problem for resource managers in that monitoring methods may cause a significant amount of damage, which may be detrimental to the habitat dynamics and the plants found within this habitat. Minimizing habitat disturbance is an integral part of the current monitoring protocol. The monitoring methods were designed to minimize the impact of the habitat by utilizing drainage channels and wildlife trails to collect data.

This monitoring project is intended to be long term, but implementing the work will be dependent on land managers funding and personnel availability for the project.

MONITORING OBJECTIVES:

1. Determine if the current density of Las Vegas bearpoppy at monitored populations occurring on BLM and NPS lands within Clark County remains within 30% of the first measurement over the next 10 years.
2. Determine the abiotic factors that influence the density of Las Vegas bearpoppy monitored populations occurring on BLM and NPS lands within Clark County and over the next 10 years.
3. Determine if native plant community biodiversity and density at monitored Las Vegas bearpoppy populations occurring on BLM and NPS lands within Clark County remain within 30% of the first measurement over the next 10 years.

SAMPLING OBJECTIVE:

1. We want to be 90% sure of detecting a 30% change in the confidence interval of Las Vegas bearpoppy and are willing to accept a 10% chance that a change did not take place (in good rainfall years).

MANAGEMENT OBJECTIVE:

1. If change is > 30%, we will attempt to determine the cause.

- Stochastic event – such as change in climate or soil chemistry- No management action has been determined
- Threat induced event – remove threat (invasive species, OHV access, trespass cattle/burros/horses)

PILOT YEAR STUDY

Monitoring protocols were developed and plans implemented in 2006 to determine an appropriate experimental design for monitoring Las Vegas bearpoppy. After evaluating the pilot year data (descriptive statistics, power analysis and sample size calculations), it was determined that a modified sampling design was necessary to decrease variability among sampling units and increase power. We determined that increasing the number of study sites, decreasing the number of plots per site, and changing plot size would provide a better representation of overall status and trends of the species throughout its range, while still providing valuable data at the population level.

SAMPLING DESIGN

Randomization in positioning sampling units as well as good interspersion of sampling units throughout the monitored populations of target species must be employed for monitoring studies. Throughout this monitoring project, populations are defined as they are in the Clark County Rare Plant Conservation Management Plan (TNC 2007), in groups by geographic area. We will refer to smaller Las Vegas bearpoppy population patches within the larger population areas as sub-populations.

The following populations will be monitored throughout this project and include several of the known populations of Las Vegas bearpoppy (as described above) that occur in Clark County on NPS and BLM lands as follows; Bitter Spring Valley, Gale Hills, Gold Butte, Sunrise Valley, and Valley of Fire. The Government Wash population appeared to be dormant as no live or dead poppies could be located during modern surveys and thus was not included in this project. The White Hills and Middle Point populations were not included due to the limited size or extreme topography of the sub-populations. Sub-populations were selected using a stratified random approach within each population in an attempt to ensure that the entire area is represented by the data.

A three-tiered approach to monitoring was employed to address the three different components listed in the management objectives and include; trends in density of Las Vegas bearpoppy populations over time, spatial analysis of target species, measuring abiotic factors that may influence the target population and biodiversity within the target habitat, and collecting community plant ecology data.

To address the trends in density of Las Vegas bearpoppy we placed a permanent transect at each selected sub-population (100 meters long). Transect lengths were consistent across all sites. All sub-populations selected for monitoring are equally weighted by plot number and size. Three permanent rare plant plots were placed along the 100 m transect in a restricted random sampling manner. For example, a 10 x 40m plot was placed within the first 33 meters, another in the second 33 meters and another in the last 34 meters. Within the rare plant plots, all Las Vegas bearpoppy will be counted and data collected will include, size class, plant condition, and phenology at time of survey. Individual poppy plants will not be mapped using GIS technology, but spatial data will be gathered by drawing a map of their locations in each plot, thereby eliminating additional disturbance to the habitat.

Community ecology data will also be collected at each sub-population every 5 years and/or in years of above average rainfall. One large permanent plot (50 x 50m), divided into smaller quadrats (10 x 10m), was randomly placed along the 100m transect to include at least one rare plant plot. Researchers will record all plant species within the plot, number of each rare plant species within the plot, foliar cover for all species, and notation of disturbance or invasive plant species presence. Dead perennials will be combined and recorded separately from live plants. Dead plants of select species (annual or perennial) may be recorded separately if the researcher sees value in doing so (i.e. another rare plant).

To measure abiotic factors we will place separate 1 x 1m temporary plots in areas of Las Vegas bearpoppy high density, low density, and zero density. The plots will be placed so that they fall in and out of the habitat supporting the poppy sub-population and will include at least one 10 x 40m plot. Select abiotic data will be collected (in the same re-located plots) once in the beginning of the project and then periodically for comparison of climate change effects or other changes that may alter abiotic factors. Abiotic factors will include soil property analyses (chemistry, particle size, pH, total elements, and soil moisture). Additional abiotic factors will be collected at the site but not within each plot including, ambient temperature, relative humidity, and rainfall.

Inventories for *Arctomecon californica* included in project 2005-NPS-535-P will occur each year. The inventories will include surveys of historical, currently known, and an additional 20% in areas containing no known historical or currently known occurrences of this species. When a target species is located, polygons will be mapped to include the population. An estimate of number of individuals, associated plant species, threats and unusual disturbances will be recorded.

FIELD METHODS

At each site, disturbance trails (burro trails, off road vehicle tracks, and small drainages), which are common in this habitat, will be utilized as much as possible to set up plots and collect data. Vegetation is sparse in this habitat, which makes using disturbance trails for gathering data possible in most cases. The transect start and end points will be permanently marked, as well as the corners of all plots (except 1 x 1m) with an 8 inch spike and engraved washer. Meter tapes will be used the first year only in order to delineate the plots. In consecutive years, a range finder and pin flags will be used to mark each 10m interval, which will eliminate the need to walk tapes across the habitat. Cardboard cutouts representing percentages of each quadrat will be used as visual aids to more accurately estimate percent cover. GPS coordinates will be recorded at all plot corners. Data will be recorded on data sheets (Figs. 1-3) and transferred to electronic databases or Arcmap after completion of the field season.

Occasionally, researchers may need to collect a plant within a plot for identification. The specimen would be identified soon after collection and then processed as a voucher specimen and subsequently stored in the Lake Mead Study Collection Herbarium or at the Wes E. Niles Herbarium on the campus of the University of Nevada Las Vegas.

Upon completion of monitoring each year, researchers will enter data into the appropriate database and compile notes from all researchers involved in data collection.

DATA STORAGE, ANALYSIS, AND REPORTING

Consultations with a statistician resulted in a description of statistical analyses that will be performed on the monitoring data. Consultations with LMNRA data managers resulted in a database in which to store and access all monitoring data. Annual reports and presentations will be prepared upon request. Report formats will follow guidelines of each agency or organization requesting a written report.

Personnel requirements and training

One lead field researcher will be responsible for completing monitoring each year including, scheduling and preparing for data collection, training assistants, gathering all necessary equipment needed for monitoring, transportation to each site, making sure data is collected properly and is input in to the database, and ensure that voucher specimens are processed. The lead researcher must meet the following requirements:

- Strong familiarity with local flora both native and invasive species
- Experience conducting plant surveys
- Familiarity with gypsum and biological crust habitats
- Rare plant knowledge
- Ability to hike for considerable distances and up and down uneven terrain
- Ability to tolerate high ambient temperatures during field work
- Experience driving on 4-wheel drive roads

Assistant researcher(s) will be responsible for helping lead researcher in above described duties plus have the ability to hike for considerable distances and up and down uneven terrain, tolerate high ambient temperatures, and quickly learn several plant species commonly found in study area.

Operational requirements

Data collection at each monitoring site should be complete within 2 days unless unexpected problems occur (bad weather, damaged equipment, illness, access issues, etc.). Equipment needed to successfully complete monitoring for Las Vegas bearpoppy include: one four wheel drive vehicle, one or two GPS units, NPS park radio, binoculars, camera, compass, meter tapes, pin flags, pins with pre-measured string, cardboard cutouts, PVC pipe frame (1 x 1m), implements for abiotic sampling, data sheets, pen and pencil, sharpie, field notebook, plant press, and pruners. In the first year of monitoring additional equipment will be necessary to delineate plots including: eight inch spikes and washers.

REFERENCES

Bangle, D. 2005. Report on *Arctomecon californica* (Las Vegas bearpoppy) monitoring Lake Mead National Recreation Area (2005). Unpublished report to Clark County Multiple Species Habitat Conservation Plan from the National Park Service, Lake Mead National Recreation Area. Boulder City, NV. 30 pages.

The Nature Conservancy (TNC). 2007. A Conservation Management Strategy for Nine Low Elevation Rare Plants in Clark County, Nevada. TNC, Nevada Field Office Reno, Nevada. 390 pages.

Lake Mead National Recreation Area, National Park Service (NPS). 2002. Lake Management Plan. 455 pages.

Mistretta, O., P. Rashmi, T. S. Ross, and M. J. Porter. 1995. Current knowledge and conservation status of *Arctomecon californica* Torrey & Fremont (Papaveraceae), the California bearpoppy. Status report prepared for Nevada Natural Heritage Program, Department of Conservation and Natural resources and U.S. Fish and Wildlife Service. 36 pages and 3 Appendices.

Powell, E. 1999. Report on Las Vegas bearpoppy (*Arctomecon californica*) monitoring. Unpublished report submitted to the National Park Service, LMNRA (19 pages).

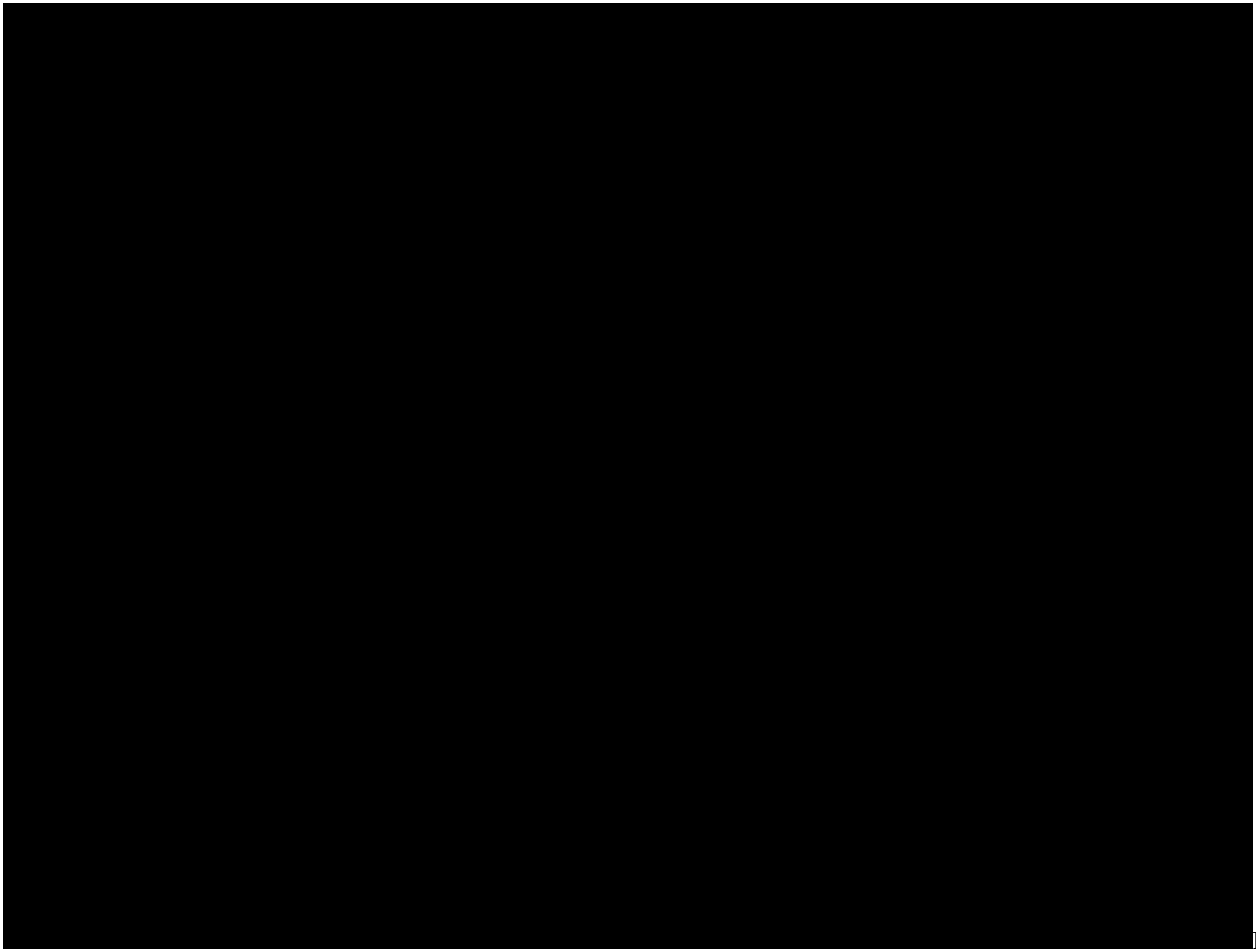


Figure 1. Grid map used for spatially representing *Arctomecon californica* within rare plant plots.

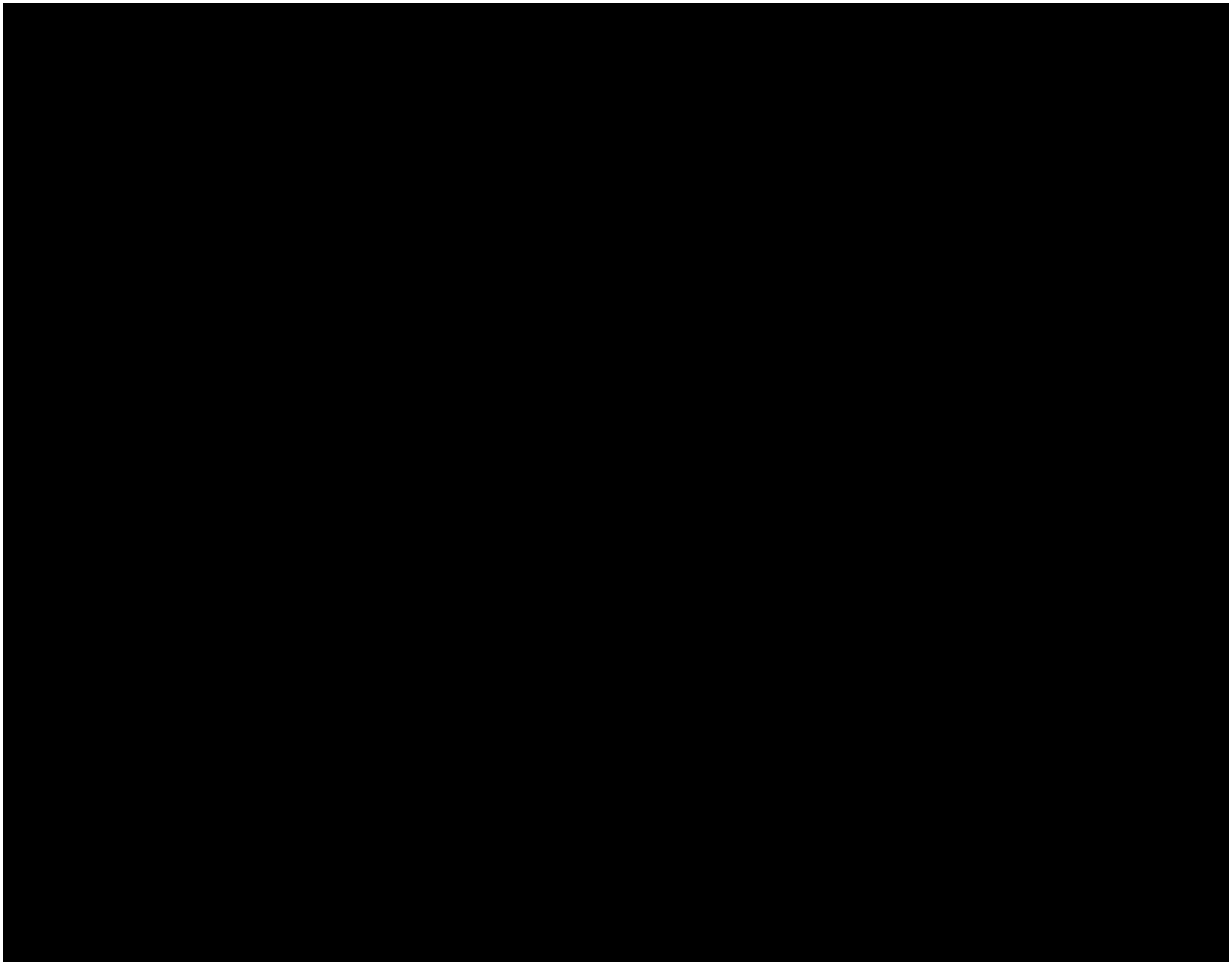


Figure 2. Community ecology grid map for *Arctomecon californica* monitoring.

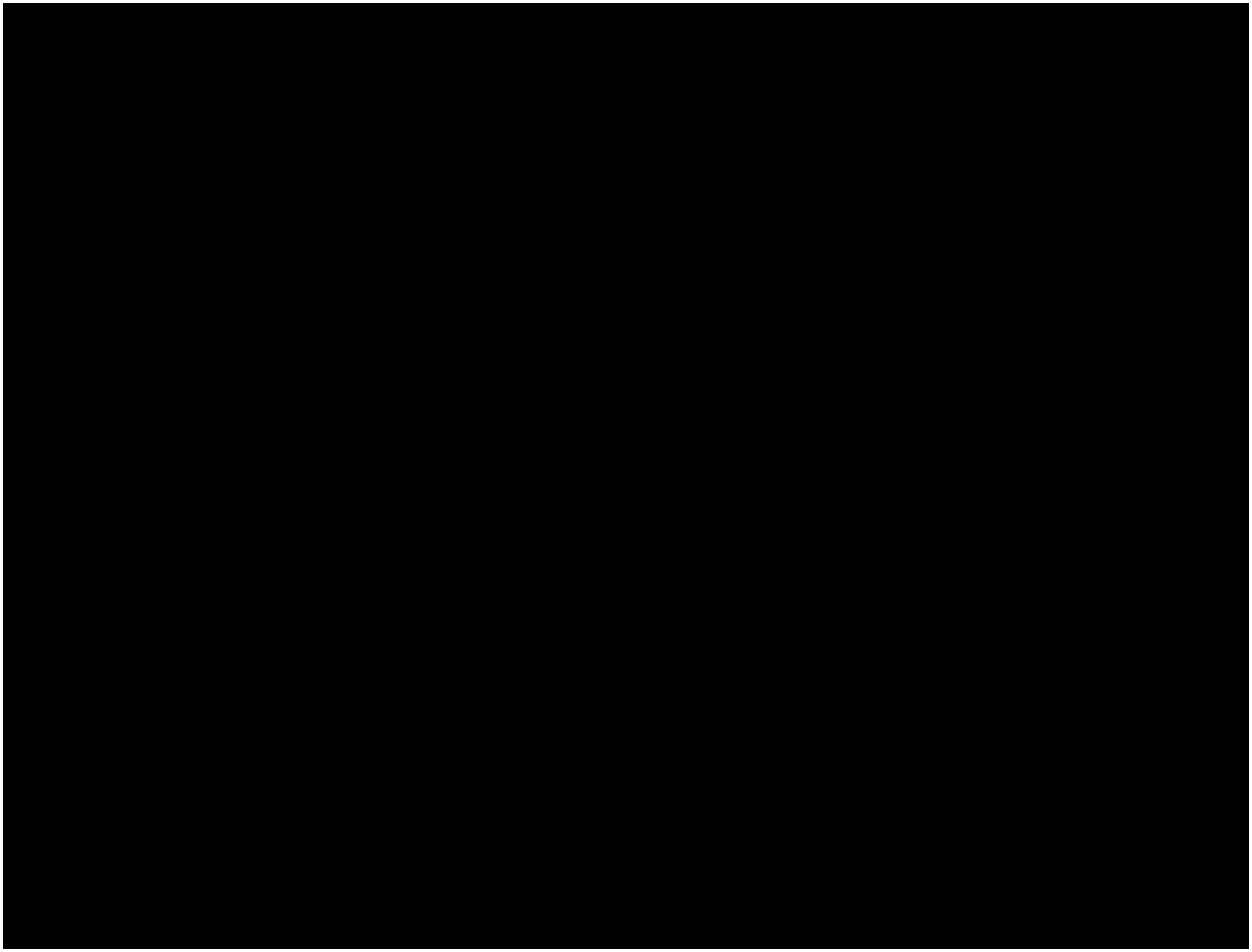


Figure 3. Data sheet used in *Arctomecon californica* monitoring.

APPENDIX 2.

Monitoring methods and protocols for *Anulocaulis leiosolenus* var. *leiosolenus* (ringstem) in gypsum habitat within Clark County, Nevada
Monitoring period for ringstem: May-June

BACKGROUND AND OBJECTIVES

National Park Service Management (NPS) Policies direct managers at Lake Mead National Recreation Area (LMNRA) to survey for, protect, and manage state and locally listed species and other native species that are of special concern to the parks in order to maintain the species' natural distribution and abundance (NPS 2002). An additional concern of park managers is maintaining ecosystem health and stability by protecting habitat that supports high biodiversity areas including rare plant sites thus allowing natural processes to occur (i.e. energy flow through the system, natural fluctuations in species abundance). The Clark County Multiple Species Habitat Conservation Plan (MSHCP) lists specific goals for the management of rare plant species as outlined in the Low Elevation Rare Plant Conservation Management Strategy (TNC 2007). The key purposes of the MSHCP are to achieve a balance between 1) long-term conservation and recovery of the diversity of natural habitats and native species of plants and animals, 2) the orderly and beneficial use of land in order to promote the economy, health, well-being, custom and culture of Clark County residents (TNC 2007), as well as, having no net unmitigated loss or fragmentation of habitat in intensively managed areas and maintain stable or increasing plant populations.

Anulocaulis leiosolenus var. *leiosolenus* (ringstem) is listed as a covered species under the (MSHCP) and as a watch species on the Nevada Natural Heritage Programs Sensitive List (ranks G4, T3, S2-defined as imperiled in the state because of rarity due to very restricted range, very few populations or other factors making it vulnerable). Ringstem is found within LMNRA in Clark County, Nevada and Mohave County, Arizona. There are four recognized varieties of *A. leiosolenus*, which in addition to *A. l. leiosolenus*, includes: *A. l.* var. *gypsogenus*, *A. l.* var. *lasianthus*, and *A. l.* var. *howardii*. The following description of distribution was provided by Norman Douglas (personal communication 2005), a Ph.D. student at Duke University working on phylogenetics of the family. The distribution of *A. l. leiosolenus* is disjunct across its range and little is known about the ecology or biology of this species. In Arizona, *A. l. leiosolenus* has been recorded from the Big Gyp Hills within LMNRA, the Grand Canyon (bottom of Bright Angel Trail) and from Camp Verde (located 86 miles north of Phoenix). The New Mexico populations of *A. l. leiosolenus* are found along the southern portion of the Rio Grande down into Texas near El Paso and Ciudad Juarez, Mexico.

Surveys for *A. l. leiosolenus* were conducted in 2004-2005 and focused on gypsum soil habitats in the areas of Stewarts Point, Valley of Fire, Echo Wash, and Pinto Valley (old Road 99 and old Road 100) within LMNRA, and on Bureau of Land Management (BLM) lands at Rainbow Gardens, with approximately 6,500 plants recorded at that time. Routine monitoring has not occurred prior to the current proposed monitoring protocol. NPS and Public Lands Institute (PLI) personnel acknowledge the need to implement a monitoring plan for ringstem beginning with the 2008 field season. Annual monitoring of this species will provide baseline information on the status and threats of ringstem. Little information exists about the ecology or biology of this species and any information gathered during annual monitoring will aid managers in protecting ringstem as well as, benefit researchers in any future studies on this species. An additional concern is that there does not appear to be a logical hypothesis that explains the disjunct distribution of ringstem across its range. The taxonomy, too, remains questionable suggesting that the variety that occurs in our area may be genetically distinct from other populations, which may warrant increased protection within LMNRA and perhaps the state of Nevada.

Ringstem occurs on gypsum substrates with a substantial cryptogamic crust component. This soil type and the biological crusts that occur on these soil types are considered sensitive and easily damaged. Monitoring in such delicate habitat poses a problem for resource managers in that monitoring methods may cause a significant amount of damage, which may be detrimental to the habitat dynamics and the plants found within this delicate habitat. The monitoring methods were designed to minimize the impact of the habitat by utilizing drainage channels and wildlife trails to collect data.

This monitoring project is intended to be long term, but implementing the work will be dependent on land managers funding and personnel availability for the project.

MONITORING OBJECTIVES:

1. Determine if the current density of ringstem remains within 30% of the first measurement at monitored populations occurring on BLM and NPS lands within Clark County over the next 10 years.
2. Determine the abiotic factors that might influence the density of ringstem and the biodiversity within the habitat at monitored populations occurring on BLM and NPS lands within Clark County and over the next 10 years.
3. Determine if native plant community biodiversity and density remain within 30% of the first measurement at monitored ringstem populations occurring on BLM and NPS lands within Clark County over the next 10 years.

SAMPLING OBJECTIVE:

1. We want to be 90% sure of detecting a 30% change in the confidence interval in good rainfall years and are willing to accept a 10% chance that a change did not take place.

MANAGEMENT OBJECTIVE:

1. If change is > 30%, we will attempt to determine the cause.
    - Stochastic event – such as change in climate or soil chemistry- No management action has been determined
    - Threat induced event – remove threat (invasive species, OHV access, trespass cattle/burros/horses)

SAMPLING DESIGN

Randomization in positioning sampling units as well as good interspersion of sampling units throughout the monitored populations of target species must be employed for monitoring studies. Throughout this monitoring project, populations are defined as they are in the Clark County Rare Plant Conservation Management Strategy (2007), in groups by geographic area. We will refer to smaller ringstem population patches within the larger population areas as sub-populations.

The following populations include all known populations (as described above) of ringstem recorded in Clark County on NPS, BLM, and private lands as follows; Muddy River, Gold Butte, Overton Arm, Bitter Spring Valley, East Black Mountains, Lava Butte, and Gypsum

Wash populations. The Muddy River, Gypsum Wash and West Black Mountains populations occur on private land or in difficult to access areas and will not be included in this project. Sub-populations will be randomly selected within each population to ensure that the range of this species is represented by the data.

A three-tiered approach to monitoring will be employed to address the three different components listed in the management objectives and include; trends in density of ringstem populations over time, collecting community plant ecology data, and measuring abiotic factors that may influence the target population and biodiversity within the habitat.

To address the trends in density of ringstem we will place one 100m transect at each selected sub-population. All sub-populations selected for monitoring will be equally weighted by plot number and size. Three permanent plots will be placed along each transect in a restricted random sampling manner. For example, a 10 x 40m plot will be placed within the first 33 meters, another in the second 33 meters and another in the last 34 meters. Individual ringstem data collected will include, number of leaves, number of stalks (past and present years), condition, and status of current year's phenology. Individual ringstem plants will not be mapped using GIS technology, but spatial data will be gathered by drawing a map of their locations in each plot, thereby eliminating additional disturbance to the habitat. The four corners of each plot will be marked with a GPS unit.

Community ecology data will be collected at each sub-population every five years and/or in years of above average rainfall. One large permanent plot (50 x 50m), divided into smaller quadrats (10 x 10m), will be placed randomly along the 100m transect and will include at least one ringstem plot. Researchers will record all plant species, number of ringstem individuals, and foliar cover for all species within each quadrat. Any disturbance or invasive plant species presence outside the plots will be noted. Dead perennials will be combined and recorded separately from live plants. Dead plants of select species (annual or perennial) may be recorded separately if the researcher sees value in doing so (i.e. another rare plant).

To measure abiotic factors we will place separate 1 x 1m temporary plots in areas of high ringstem density, low density, and zero density. The plots will be placed so that they fall in and out of the habitat supporting the ringstem sub-population and will include at least one 10 x 40m plot. Select abiotic data will be collected (in the same re-located plots) once in the beginning of the project and then periodically for comparison of climate change effects or other influences that may alter abiotic factors. Abiotic factors will include soil property analyses (chemistry, particle size, pH, total elements, and soil moisture). Additional abiotic factors will be collected at the site but not along a gradient including, ambient temperature, relative humidity, and rainfall.

Inventories for *Anulocaulis leiosolenus* var. *leiosolenus* included in project 2005-NPS-535-P will occur each year. The inventories will include surveys of historic locations and an additional 20% in areas containing no known historical or currently known occurrences of this species. When a target species is located, polygons will be mapped to include the population. An estimate of number of individuals, associated plant species, threats and unusual disturbances will be recorded.

FIELD METHODS

At each site, disturbance trails (burro trails, off road vehicle tracks, and small drainages), which are common in this habitat, will be utilized as much as possible to set up plots and collect data. Vegetation is sparse in this habitat, which makes using disturbance trails for gathering data possible in most cases. The transect start and end points will be permanently marked, as well as the corners of all plots (except 1 x 1m) with an eight-inch spike and engraved washer. Meter tapes will be used the first year only in order to delineate the plots. In consecutive years, a range finder and pin flags will be used to mark each 10m interval, which will eliminate the need to walk tapes across the habitat. Cardboard cutouts representing percentages of each quadrat will be used as visual aids to more accurately estimate percent cover. GPS coordinates will be recorded at all plot corners. Data will be recorded on data sheets (Figs. 1-3) and transferred to electronic databases or Arcmap after completion of the field season.

Occasionally, researchers may need to collect a plant within a plot for identification. The specimen would be identified soon after collection and then processed as a voucher specimen and subsequently stored in the Lake Mead Study Collection Herbarium or at the Wes E. Niles Herbarium on the campus of the University of Nevada Las Vegas.

Upon completion of monitoring each year, researchers will enter data into the appropriate database and compile notes from all researchers involved in data collection.

DATA STORAGE, ANALYSIS, AND REPORTING

Consultations with a statistician resulted in a description of statistical analyses that will be performed on the monitoring data. Consultations with LMNRA data managers resulted in a database in which to store and access all monitoring data. Annual reports and presentations will be prepared upon request. Report formats will follow guidelines of each agency or organization requesting a written report.

PERSONNEL REQUIREMENTS AND TRAINING

One lead field researcher will be responsible for completing monitoring including, scheduling and preparing for data collection, training assistants, gathering all necessary equipment needed for monitoring, transportation to each site, making sure data is collected properly and is input into the database, and ensure that voucher specimens are processed. The lead researcher must meet the following requirements:

- Familiarity with local flora both native and invasive species
- Experience conducting plant surveys
- Familiarity with gypsum and biological crust habitats
- Rare plant knowledge
- Ability to hike up and down uneven terrain
- Ability to tolerate high ambient temperatures during field work

Assistant researcher(s) will be responsible for helping lead researcher in above described duties plus have the ability to hike up and down uneven terrain, tolerate high temperatures, and quickly learn several plant species commonly found in survey area.

OPERATIONAL REQUIREMENTS

Monitoring should be completed within twelve days unless unexpected problems occur (bad weather, damaged equipment, illness, etc.). Equipment needed to successfully complete monitoring for ringstem include: one four wheel drive vehicle, one or two GPS units, data sheets, binoculars, compass, meter tapes, pen and pencil, NPS park radio, camera, field notebook, plant press, and pruners. In the first year of monitoring additional equipment will be necessary to delineate plots and sub-plots including: eight-inch spikes and engraved washers.

References

Bangle, D. 2005. Report on surveys and mapping of *Anulocaulis leiosolenus* (Ringstem) and other select plants of concern within Lake Mead National Recreation Area during 2004 and 2005. Unpublished report to Clark County Multiple Species Habitat Conservation Plan from the National Park Service, Lake Mead National Recreation Area. Boulder City, NV. 24 pages.

The Nature Conservancy (TNC). 2007. A Conservation Management Strategy for Nine Low Elevation Rare Plants in Clark County, Nevada. TNC, Nevada Field Office Reno, Nevada. 390 pages.

Lake Mead National Recreation Area, National Park Service (NPS). 2002. Lake Management Plan. 455 pages.

[redacted]

Figure 1. Grid map used for spatially representing *Anulocaulis leiosolenus* var. *leiosolenus* within rare plant plots.

[redacted]

Figure 2. Community ecology grid map for *Anulocaulis leiosolenus* var. *leiosolenus* monitoring.

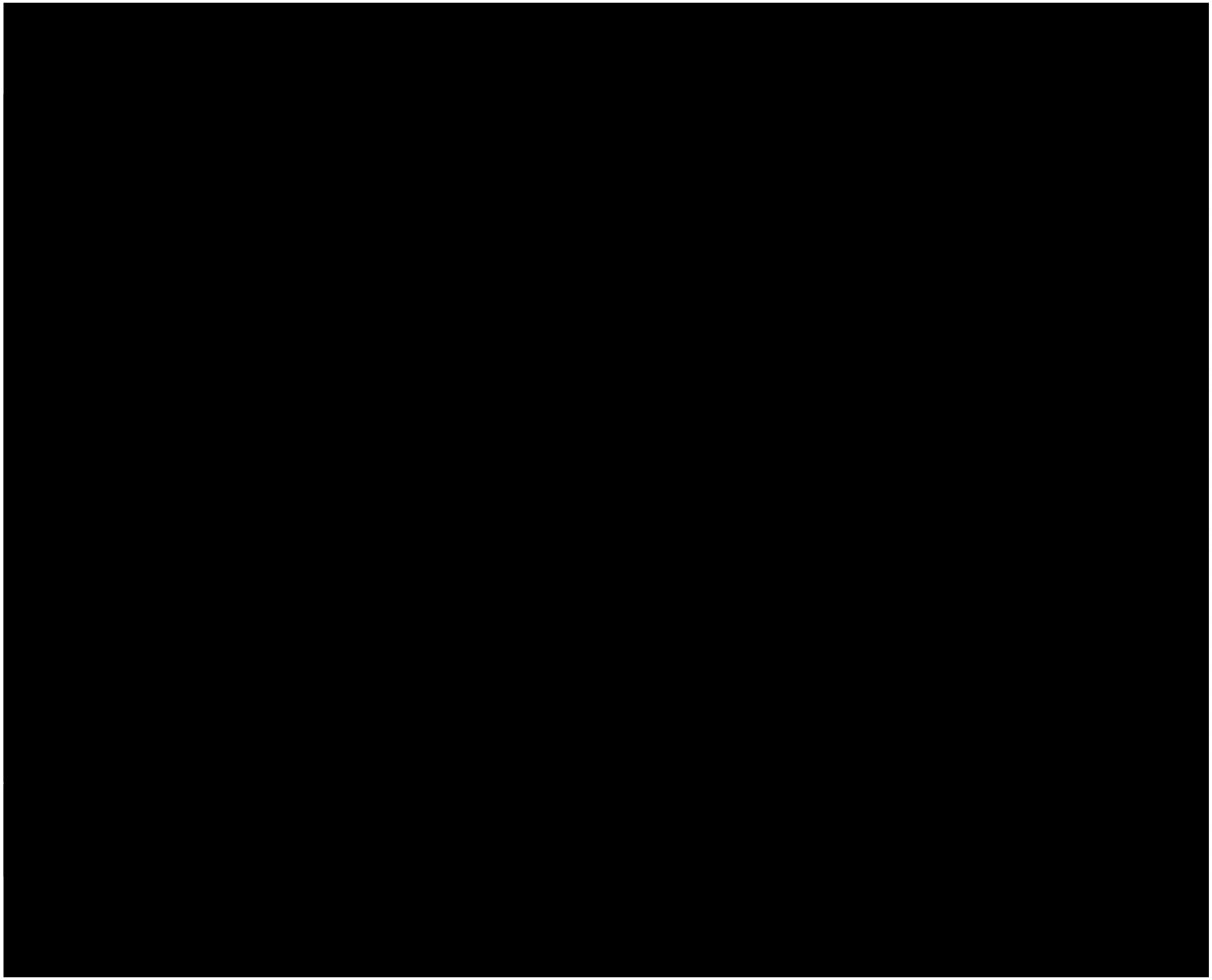


Figure 3. Data sheet used in *Anulocaulis leiosolenus var. leiosolenus* monitoring.

APPENDIX 3.

Monitoring methods and protocols for *Astragalus geyeri* var. *triquetrus* (threecorner milkvetch) within Lake Mead National Recreation Area

Monitoring period: April

BACKGROUND AND OBJECTIVES

National Park Service (NPS) Management Policies direct managers at Lake Mead National Recreation Area (LMNRA) to survey for, protect, and manage state and locally listed species and other native species that are of special concern to the park in order to maintain the species' natural distribution and abundance (NPS 2002). An additional concern of park managers is maintaining ecosystem health and stability by protecting habitat that supports high biodiversity areas including rare plant sites thus allowing natural processes to occur (i.e. energy flow through the system, natural fluctuations in species abundance). The Clark County Multiple Species Habitat Conservation Plan (MSHCP) lists specific goals for the management of rare plant species as outlined in the Low Elevation Rare Plant Conservation Management Strategy (TNC 2007). The key purposes of the MSHCP are to achieve a balance between 1) long-term conservation and recovery of the diversity of natural habitats and native species of plants and animals, 2) the orderly and beneficial use of land in order to promote the economy, health, well-being, custom and culture of Clark County residents (TNC 2007), as well as, having no net unmitigated loss or fragmentation of habitat in intensively managed areas and maintain stable or increasing plant populations.

Astragalus geyeri var. *triquetrus* (threecorner milkvetch) is a rare, sand loving, annual plant endemic to Clark and Lincoln Counties in southern Nevada and Mojave County in northwestern Arizona. This species is on the Nevada Natural Heritage Programs Sensitive List (ranks G2 S2-defined as imperiled), is listed as a covered species under the (MSHCP), and has status as a critically endangered species in the state of Nevada.

Sandy Cove supports the largest known population of threecorner milkvetch (Powell 2001). Annual monitoring of threecorner milkvetch on Sandy Cove was initiated during the 2000 field season and work was performed by contract botanists working closely with the NPS Resource Management. This work was conducted to determine population status, abundance and trends, and to identify potential threats so that appropriate actions could be taken to protect the habitat if necessary. These sand dunes cover approximately 1.45 km^2 and are comprised of both active and partially stabilized sand dunes. The threecorner milkvetch population at Sandy Cove should be monitored in years of average to above average rainfall (≥ 4 inches). Select historical populations should also be checked in average to above average rainfall years to re-evaluate their status and possibly add additional sites to the monitoring program (Bangle 2005).

This monitoring project is intended to be long term, but implementing the work will be dependent on land managers funding and personnel availability for the project.

MONITORING OBJECTIVES:

1. Determine if the current density of threecorner milkvetch measured in average to above average rainfall years remains within 30% of the first measurement at Sandy Cove population occurring on NPS land within Clark County over the next 6 years.
2. Determine the abiotic factors that might influence the occurrence of threecorner milkvetch and the biodiversity within the habitat at the Sandy Cove population occurring on NPS land within Clark County over the next 6 years.
3. Determine if native plant community biodiversity and density remain within 30% of the first measurement at Sandy Cove population occurring on NPS land within Clark County over the next 6 years.

SAMPLING OBJECTIVE:

1. We want to be 90% sure of detecting a 30% change in the confidence interval in good rainfall years and are willing to accept a 10% chance that a change did not take place.

MANAGEMENT OBJECTIVE:

1. If change is > 30%, we will attempt to determine the cause.
    - Stochastic event – such as change in climate or soil chemistry- No management action has been determined
    - Threat induced event – remove threat (invasive species, OHV access, trespass cattle/burros/horses)

PILOT YEAR STUDY

Monitoring protocols were developed and plans implemented in 2006 to determine an appropriate experimental design for monitoring threecorner milkvetch. After evaluating the pilot year data it was determined that a modified grid and quadrat size were necessary to decrease variability and number of zeros among sampling units while increasing area monitored.

SAMPLING DESIGN

A new monitoring design is necessary to incorporate randomization in positioning sampling units as well as good interspersion of sampling units throughout the population. A grid-cell sampling approach for this sand dune habitat will be employed. Eight 36 x 36 meter temporary grids will be placed each year (same location) to include three separate dune areas (~one hectare total area). Each grid location was selected randomly (using a blend between cluster and stratified approaches) by placing a “virtual grid” (in Arcmap) over known habitat after which we generated random numbers to select a coordinate (within the virtual grid). The randomly selected point translated to the southwest corner of each grid and once on site a compass bearing for each direction was recorded. Quadrats (18- 6 x12m) will be delineated within the grid and data collected will include threecorner milkvetch individual counts and locations for spatial patterning, plant species composition, and estimates of foliar cover for each species. Individual GPS coordinates will not be recorded for spatial analysis; instead, threecorner milkvetch locations will be recorded by marking plants on a field map (Figure 1) of each grid showing spatial arrangement within each quadrat. The field maps will be digitized in the office after the field season is complete. Plant community data will be collected every 5th year and/or in years of above average rainfall. All live annuals, perennial herbs, shrubs and trees will be recorded. Dead perennials will be combined into a “dead perennials” category unless the lead researcher can 100% positively identify the dead plant and sees value (i.e. another rare plant) in recording that species in its own dead category. GPS coordinates will be recorded at each grid corner for re-location each year including, easting, northing, elevation, and level of accuracy.

To measure abiotic factors we will collect data within 1x1m plots along a belt transect (number and length to be determined) that runs in and out of threecorner milkvetch habitat. Select abiotic data will be collected (in the same re-located plots) once in the beginning of the project and then periodically for comparison of climate change effects or other changes that may alter abiotic factors. Abiotic factors will include soil property analyses (chemistry, particle size, pH, total elements, and soil moisture). Additional abiotic factors will be collected at the site but not along a gradient including, ambient temperature, relative humidity, and rainfall.

Inventories for *Astragalus geyeri* var. *triquetrus* included in project 2005-NPS-535-P will occur each year. The inventories will include surveys of historical sites and an additional 20% in areas containing no known historical or currently known occurrences of this species. When a target species is located, polygons will be mapped to include the population. An estimate of number of individuals, associated plant species, threats and unusual disturbances will be recorded.

FIELD METHODS

Data will be recorded on data sheets while in the field (Figure 2). Occasionally, researchers may need to collect a plant within a plot for identification. The specimen would be identified soon after collection and then processed as a voucher specimen and subsequently stored in the Lake Mead Study Collection Herbarium or at the Wesley E. Niles Herbarium on the campus of the University of Nevada Las Vegas.

Upon completion of monitoring each year, researchers will enter data into the appropriate database and compile notes from all researchers involved in the current years monitoring.

DATA STORAGE, ANALYSIS, AND REPORTING

Consultations with a statistician resulted in a description of statistical analyses that will be performed on the monitoring data. Consultations with LMNRA data managers resulted in a database in which to store and access all monitoring data. Annual reports and presentations will be prepared upon request. Report formats will follow guidelines of each agency or organization requesting a written report.

Personnel requirements and training

One lead field researcher will be responsible for completing monitoring including, scheduling and preparing for data collection, training assistants, gathering all necessary equipment needed for monitoring, transportation to each site, making sure data is collected properly and is input in to the database, and ensure that voucher specimens are processed. The lead researcher must meet the following requirements:

- Strong familiarity with local flora both native and invasive species
- Experience conducting plant surveys
- Familiarity with sandy habitats
- Rare plant knowledge
- Ability to hike for considerable distances and up and down uneven terrain
- Ability to tolerate high ambient temperatures during field work
- Experience driving on 4-wheel drive roads

Assistant researcher(s) will be responsible for helping lead researcher in above described duties plus have the ability to hike for considerable distances and up and down uneven terrain, tolerate high ambient temperatures, and quickly learn several plant species commonly found in study area.

Operational requirements

Monitoring should be completed within 8 days unless unexpected problems occur (bad weather, damaged equipment, illness, boat availability). Equipment needed to successfully complete monitoring for threecorner milkvetch include: a vehicle, a boat, one or two GPS units, data sheets, compass, 1 x 1m frame, implements for abiotic sampling, several meter tapes, pen and pencil, sharpie, NPS park radio, camera, field notebook, plant press, and pruners.

References

Bangle, D. 2005. Report on *Astragalus geyeri* var. *triquetrus* (threecorner milkvetch) monitoring (2000-2005) within Lake Mead National Recreation Area. Unpublished report to Clark County Multiple Species Habitat Conservation Plan from the National Park Service, Lake Mead National Recreation Area. Boulder City, NV. 24 pages.

Elzinga, C.L. 1998. Measuring and monitoring plant populations. Bureau of Land Management. Denver, Colorado. 477 pages.

Fehmi, J.S. and J.W. Bartolome. 2001. A grid-based method for sampling and analyzing spatially ambiguous plants. Journal of vegetation science 12: 467-472.

Lake Mead National Recreation Area, National Park Service (NPS). 2002. Lake Management Plan. 455 pages.

Niles, W. E., P. Leary, J. S. Holland, and F. H. Landau. 1995. *Astragalus geyeri* var. *triquetrus* (Three-cornered milkvetch) and Eriogonum viscidulum (Sticky buckwheat) in Lake Mead National Recreation Area and adjacent regions of Nevada and Arizona. Report to Lake Mead National Recreation Area. Unpublished report to National Park Service, Lake Mead National Recreation Area, Boulder City, NV. (74 pages).

The Nature Conservancy (TNC). 2007. A conservation management strategy for nine low elevation rare plants in Clark County, Nevada. TNC, Nevada Field Office Reno, Nevada. 390 pages.

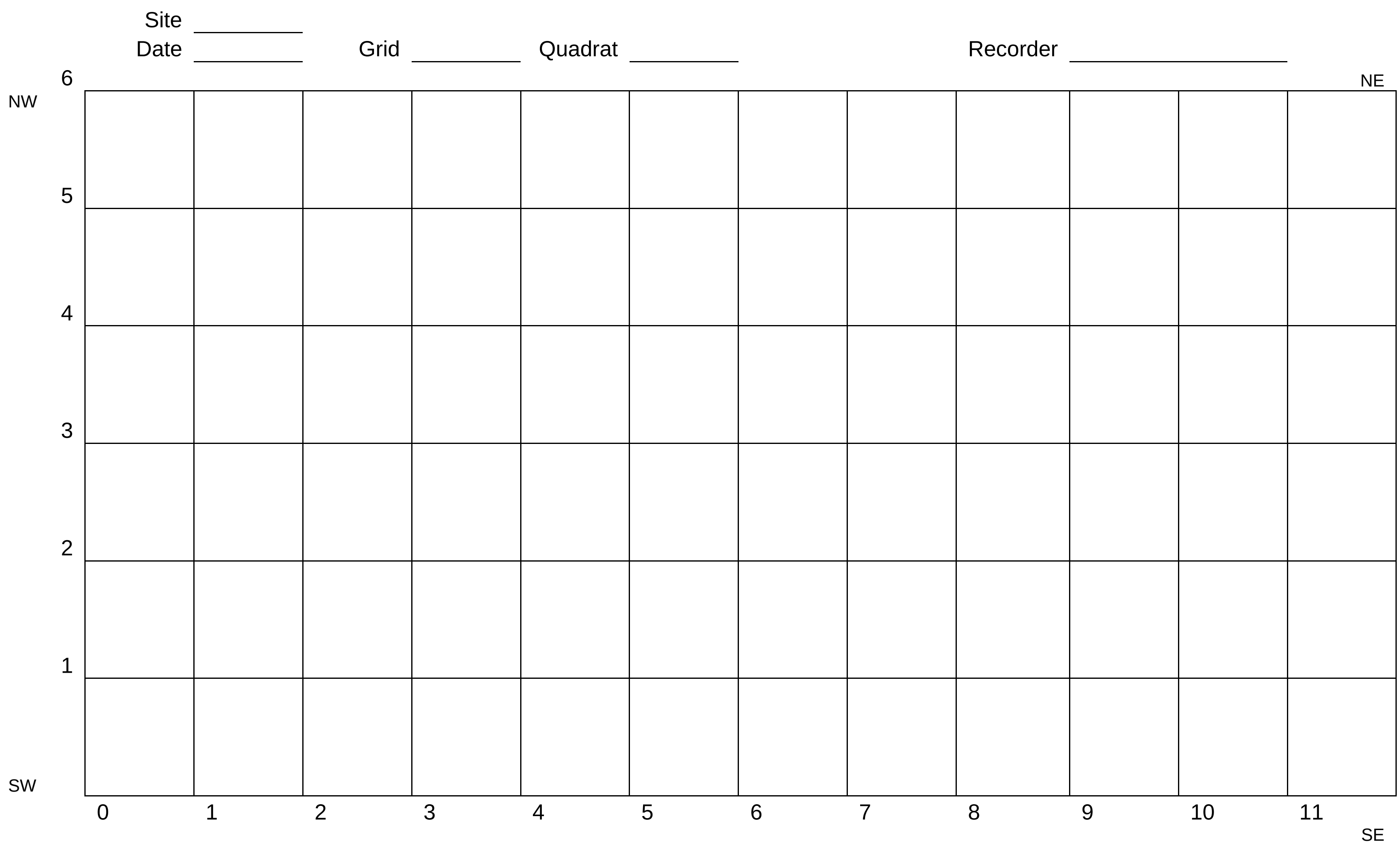


Figure 1. Example of mapping data sheet for *Astragalus geyeri* var. *triquetrus* (6 x12m grid).

Figure 2. Data sheet for *Astragalus geyeri* var. *triquetrus*

Threecorner milkvetch Grid data

Grid _______ Date _______________ Recorder ______________________

Quad:			Quad:			Quad:			Quad:		
Species	Cover	Asge Location	Species	Cover	Asge Location	Species	Cover	Asge Location	Species	Cover	Asge Location

VEG. COVER:

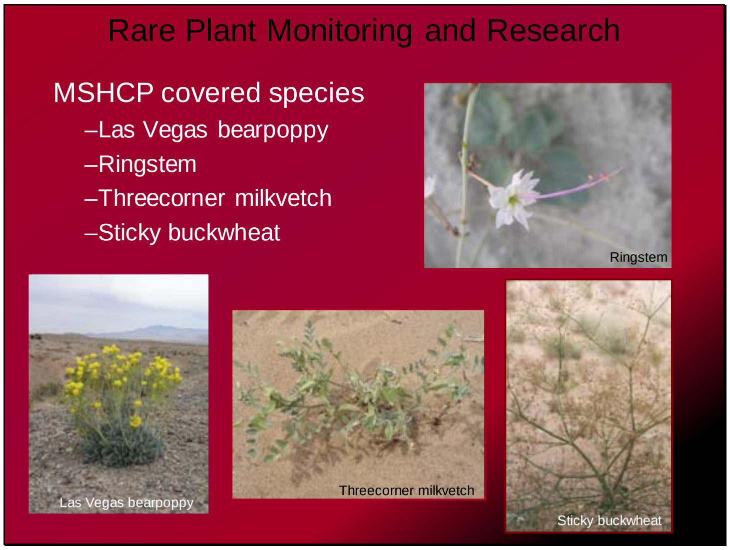
1 = 0-1%, 2 = 1-2%, 3 = 2-5%, 4 = 5-10%

5 = 10-25%, 6 = 25-50%, 7 = 50-75%, 8 = 75-95%, 9 = >95%

Appendix 5. Bangle, D. and A. C. Newton. 2009. Rare Plant Monitoring and Research. Presentation to the County August 2009.

Hello. I'm Dianne Bangle with UNLV Public lands Institute on contract with the NPS Lake Mead. Alice Newton who is here today is LMNRA vegetation manager and oversees all vegetation projects including the rare plant monitoring. I'm the project lead for the rare plant work that we'll be talking about today.

Slide 2



The 4 species covered in this project are…..
I won't be talking about ringstem today because the monitoring design is identical to Las Vegas bearpoppy and I'm currently still collecting 2008 data.

Slide 3

Project Outline

Rare Plant Monitoring

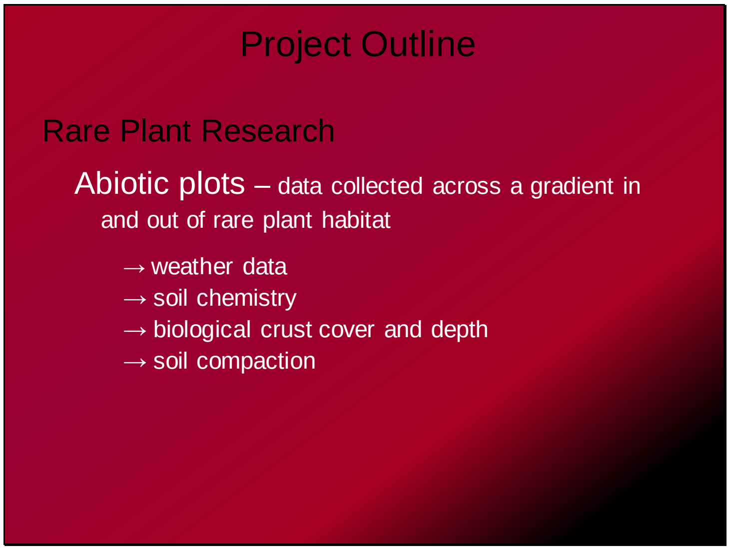
Gypsum Species

- *Las Vegas bearpoppy* – 6 sites on NPS/BLM (Blue Point Springs, Gale Hills, Rd 100, Sunrise Hills, Valley of Fire, Gold Butte)
- *Ringstem* – 3 sites on NPS/BLM (Rd 100, Sunrise Hills, Valley of Fire)

Sand Species

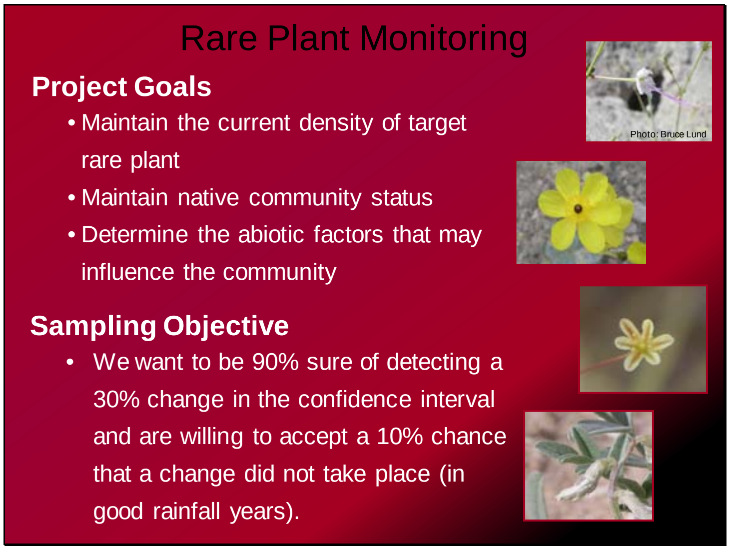
- *Threecorner milkvetch* – 3 sites on NPS/BLM (Sandy Cove, Ebony Cove, Weiser Wash)
- *Sticky buckwheat* – 2 sites on NPS (Glory Hole, Lime Cove)

Slide 4



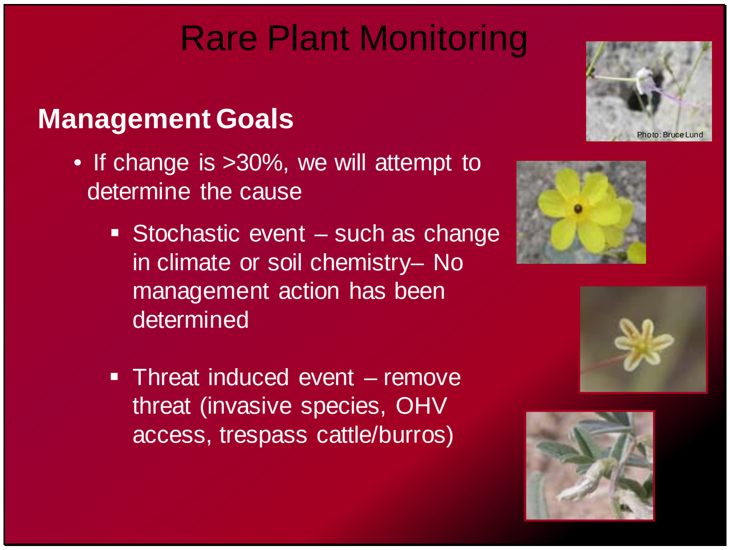
I’m not going to get into detail today about the abiotic plots. I just wanted to mention this component and its relevance to determining habitat use by these rare plant species…Why do they occur where they occur?
Weather- rain gauges, temp/RH
Soil- pH, P & K, Sulfur, C & N, total element (25 elements), particle size, bulk density
Crust- cover and depth

Slide 5

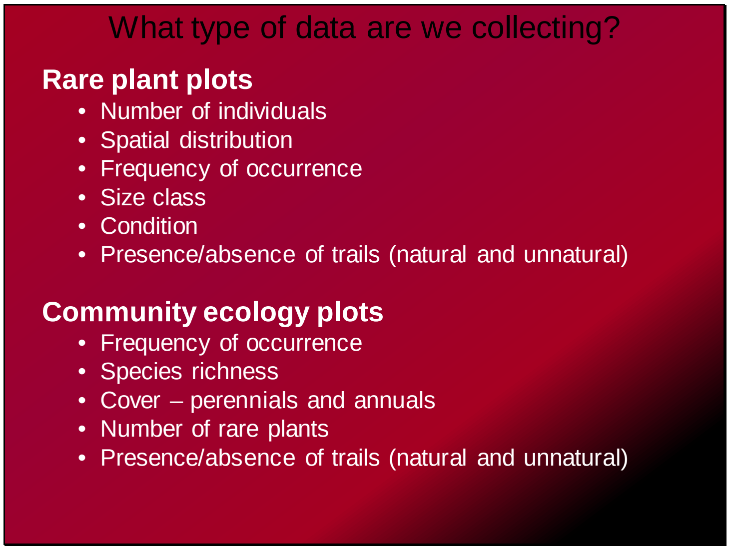


To determine if a change has taken place, we will compare measurements from average to above average rainfall years (≥5in/yr).

Slide 6


Rare Plant Monitoring
Photo: Bruce Lund
Management Goals
• If change is >30%, we will attempt to determine the cause
▪ Stochastic event – such as change in climate or soil chemistry– No management action has been determined
▪ Threat induced event – remove threat (invasive species, OHV access, trespass cattle/burros)

Slide 7



CE plots- Annual species data were not collected in 2008. We will compare annual species frequency and cover in good rainfall years.

Slide 8


Las Vegas bearpoppy- *Arctomecon californica*
Unique Characteristics
• Gypsum endemic
• Thrives in extreme environments
• Hairy “paw” shaped leaves
• Unique pollinators

Slide 9

Some of the threats we face at LMNRA, which may be evident in monitoring plots are…..
Trespass has occurred in the Bitter Springs area where riders have entered Park land via BLM lands. New fencing is in place to help deter this type of damage.
African malcomia is invading areas bordering sensitive gypsum habitat and has been observed on gypsum growing near Las Vegas bearpoppy. It likes disturbance and has been observed along disturbance trails in gypsum habitat including within footprints.

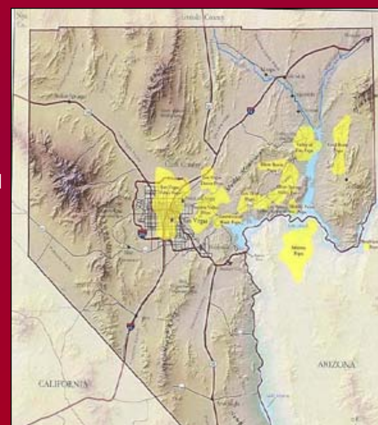
Slide 10

Tapes are used initially to set up permanent plots. After that, tapes are not necessary and a range finder is used to identify each 10 meter increment. Flags are then placed at each identified spot, which can be accessed via disturbance trails and drainage channels. This virtually eliminates new damage to the habitat. This method is more time consuming, but our efforts will likely reward us in the end with a valuable data set while maintaining our goal of habitat preservation.

Slide 11

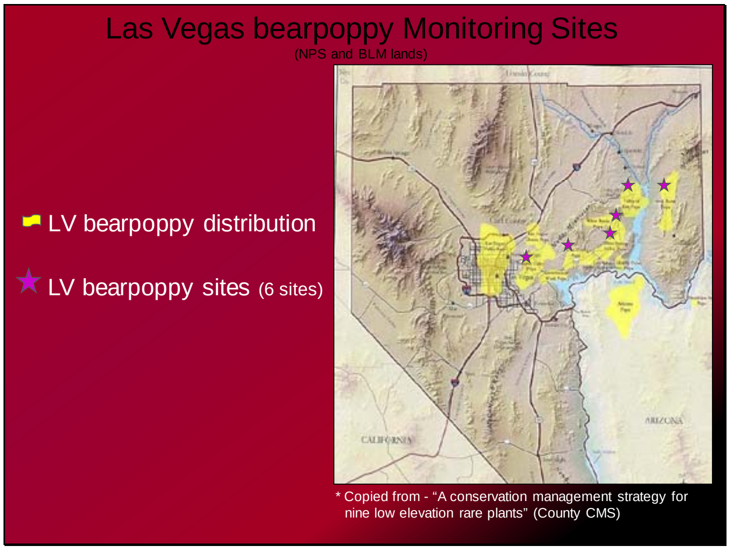
How did we choose the sites?

- We started with the distribution map from the County CMS*
- Re-evaluated most known LV bearpoppy populations described in the NNHP status report for Las Vegas bearpoppy and determined which patches (sub-populations) would be suitable for monitoring (≥ 300 plants, no private land, City of Las Vegas, or Mohave Co. populations).
- Randomly selected from remaining (sub-populations) so that select populations defined in the County CMS would have monitoring plots.



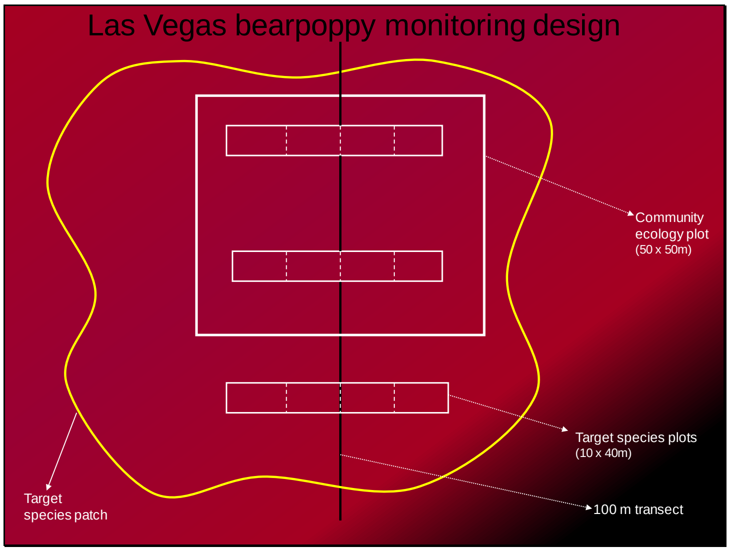
* Copied from - "A conservation management strategy for nine low elevation rare plants" (County CMS)

Slide 12



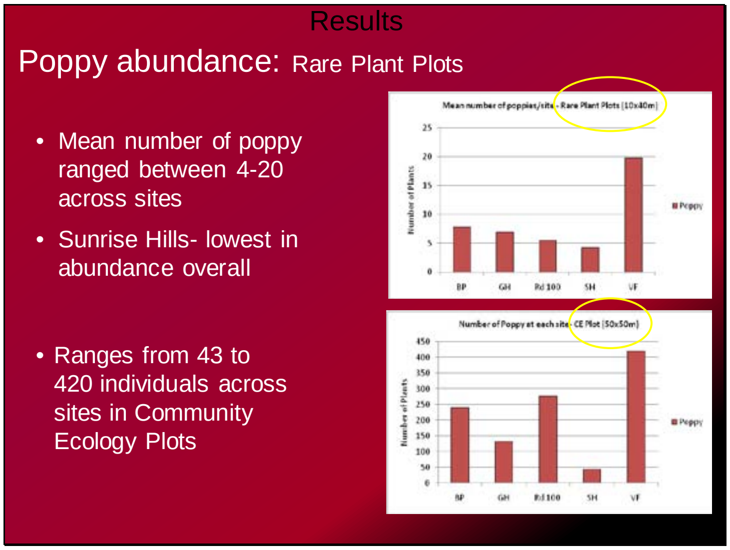
How did we choose these sites?

Slide 13



This design was not the first design we tested. In 2007, we implemented a pilot study for 3 of the covered species, Las Vegas bearpoppy, sticky buckwheat, and threecorner milkvetch. At last years monitoring workshop with Rob, we tested the power of the pilot year data and realized we needed to redesign the plot sizes to increase power. Based on what I learned at last years Clark County monitoring workshop, I redesigned each study and this slide shows the design for Las Vegas bearpoppy and ringstem.
I’ll be referring to Rare Plant Plots and Community Ecology Plots and here’s what they look like.

Slide 14



I can show you some basic results from this years data.
Top slide shows mean # of poppy within rare plant plots (3 per site), ranging from 4 at Sunrise Hills to 20 at Valley of Fire. The 2nd slide shows number of poppy recorded in CE plot (1/site), ranging between 43 at Sunrise Hills to 420 at Valley of Fire.

Slide 15

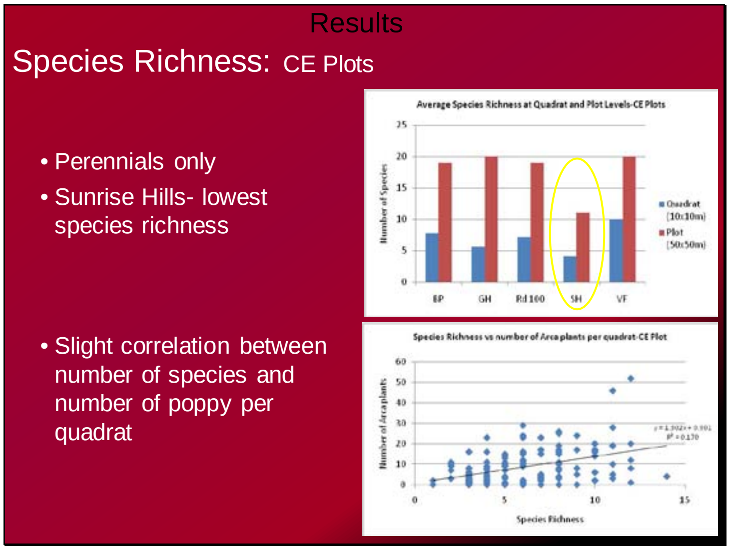
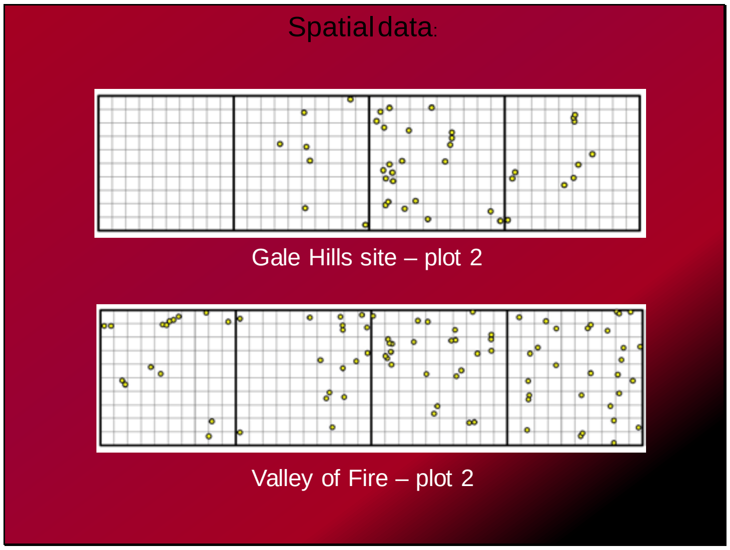
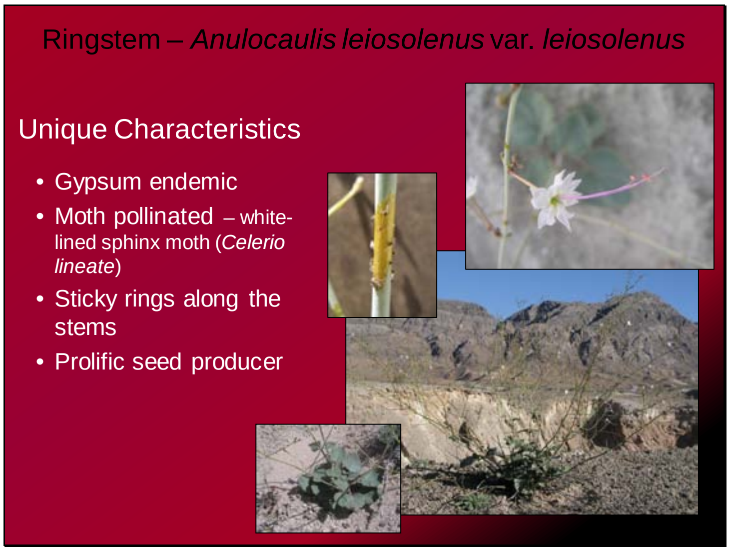


Chart1 - Perennials only for 2008. Species richness at quadrat and plot level.
Chart 2- Species richness does not strongly predict number of poppy.

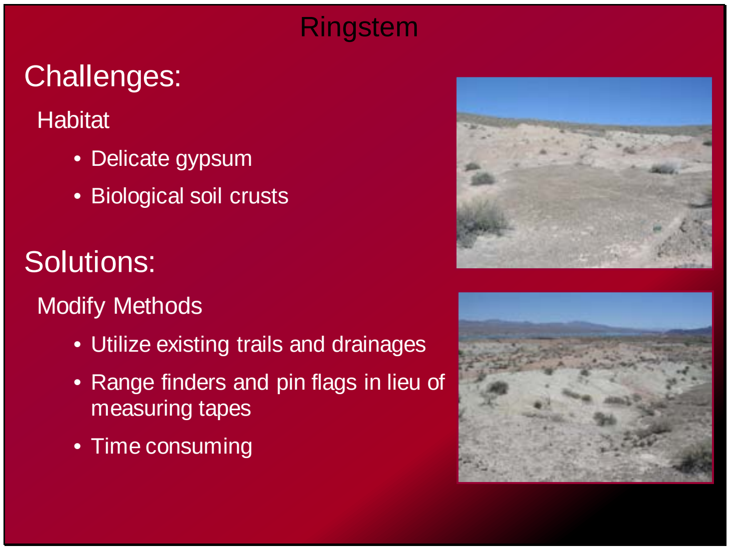
Slide 16



Slide 17


Ringstem – Anulocaulis leiosolenus var. leiosolenus
Unique Characteristics
• Gypsum endemic
• Moth pollinated – white-lined sphinx moth (Celerio lineate)
• Sticky rings along the stems
• Prolific seed producer

Slide 18



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Slide 19

Some of the threats we face at LMNRA, which may be evident in monitoring plots are…..
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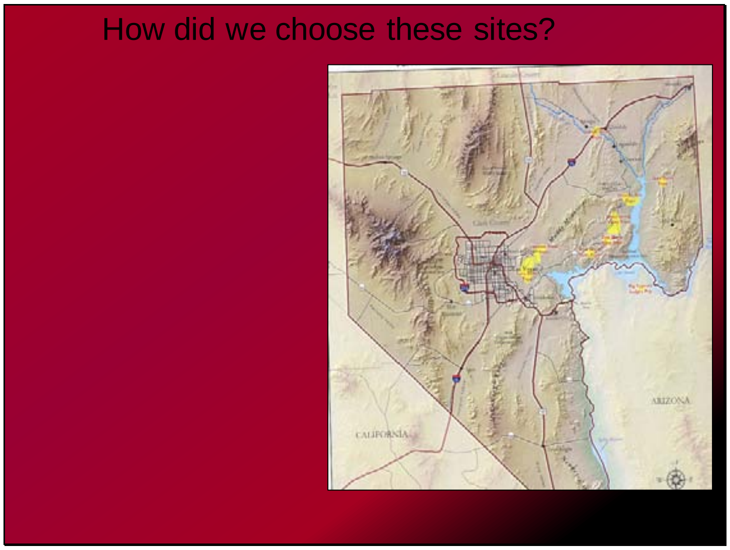
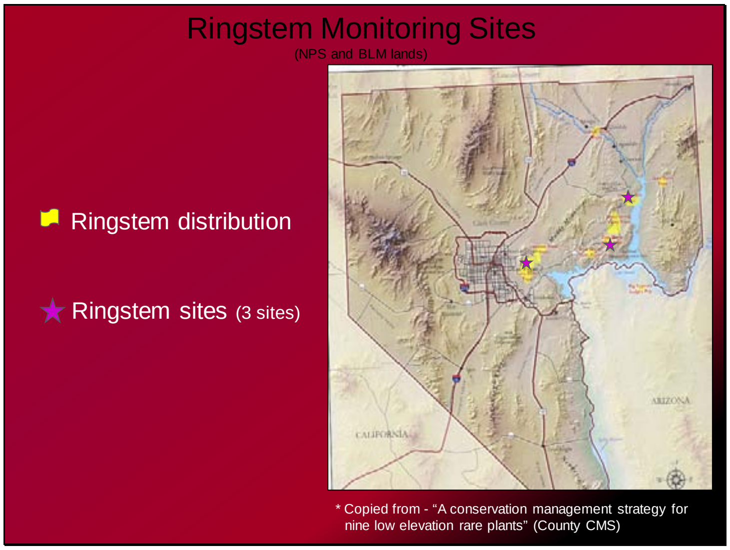
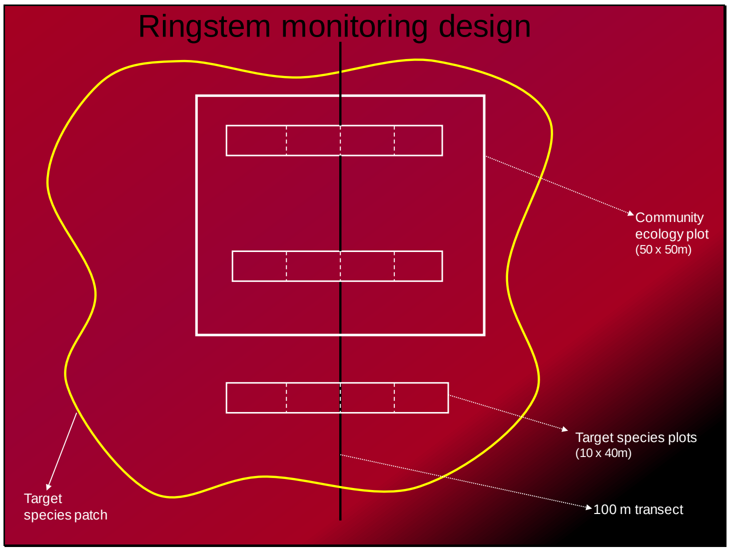
Slide 20



Slide 21


Ringstem Monitoring Sites
(NPS and BLM lands)
Ringstem distribution
Ringstem sites (3 sites)
ARIZONA
CALIFORNIA
* Copied from - "A conservation management strategy for nine low elevation rare plants" (County CMS)

Slide 22



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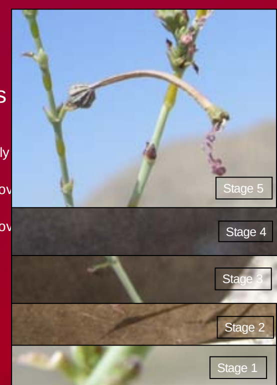
I'll be referring to Rare Plant Plots and Community Ecology Plots and here's what they look like.

Slide 23

Rare Plant Research: Ringstem phenology

Project Objectives:

- Track 3 populations, 21 plants/site
- Develop flowering phenological stages
  - Stage 1: Buds; perianth closed, bud stem visible
  - Stage 2: Perianth open, stamens/style straight or slightly curled
  - Stage 3: Perianth closed, stamens/style tightly curled; ov NOT swollen
  - Stage 4: Perianth closed, stamens/style tightly curled; ov swollen
  - Stage 5: fruit (brown/dry)



- Timing of flowering and fruit set
- Duration of flowering and fruit set
- Number of flowers and fruit produced per plant

Slide 24

The data hasn't been analyzed to date, but we can tell you that….points 2-4.

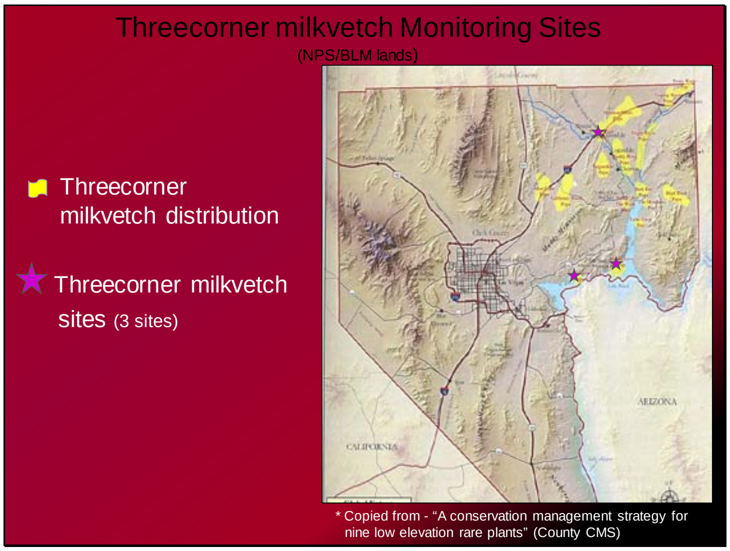
Slide 25


Threecorner milkvetch (*Astragalus geyeri var. triquetrus*)
Unique characteristics
• Small white flowers
• Three sided, sharply angled fruit
• Habitat – requires loose or active sand

Slide 26

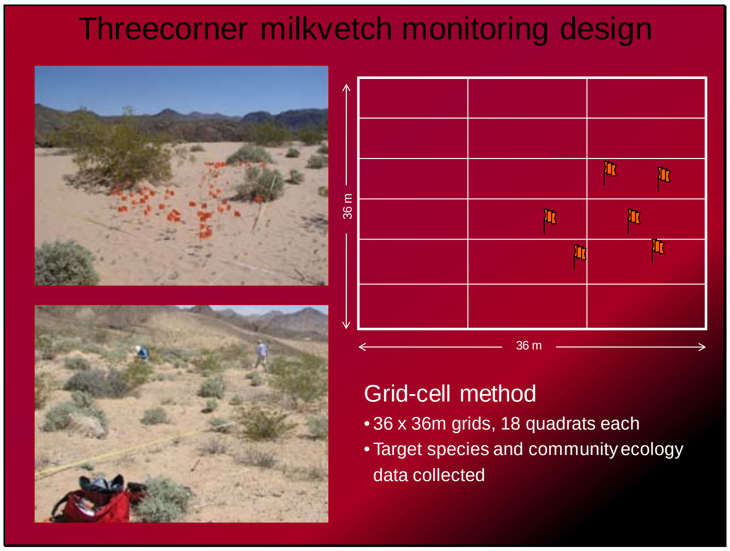
Photo top right was taken on Sandy Cove and shows the dramatic difference between an area infested with Sahara mustard versus a relatively weed free area. Photo on bottom right is at Gypsum Wash and shows how dense Sahara mustard can get if not controlled. Photo on left is at Sandy Cove and shows how thick Mediterranean grass can get, which can lead to sand dune stabilization.

Slide 27

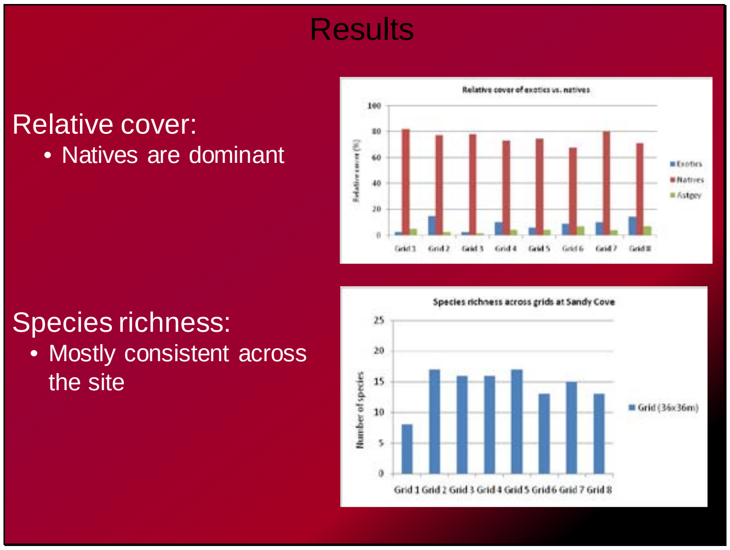


Why did we choose the site? This is the only suitable site for monitoring at Lake Mead. We would like to find a sites on BLM land to include in the monitoring, but first we need to re-evaluate the historical sites for suitability.

Slide 28


Threecorner milkvetch monitoring design
36 m
36 m
Grid-cell method
• 36 x 36m grids, 18 quadrats each
• Target species and community ecology data collected

Slide 29

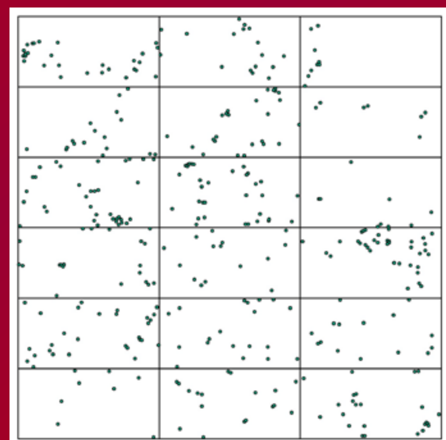


For relative cover, 70- 85% of vegetation cover is native; 2-15% exotic; 2-7% threecorner milkvetch

Slide 30

Spatial data

- An example of threecorner milkvetch distribution



A grid on Sandy Cove 2008

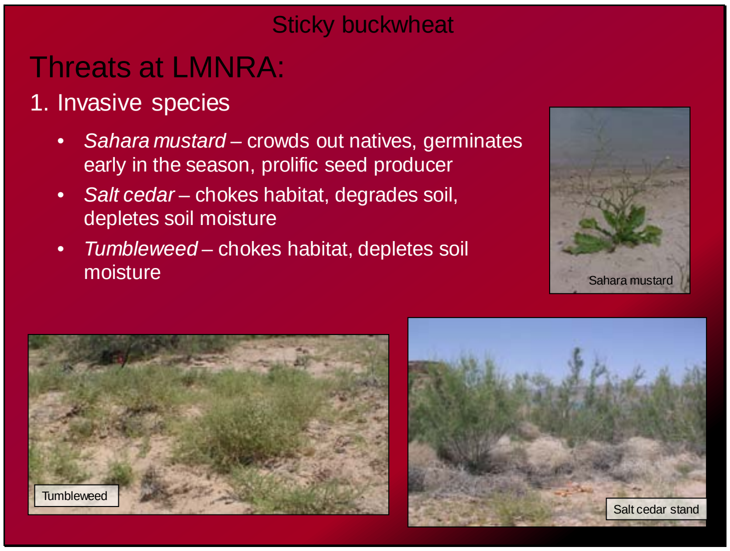
Slide 31

Sticky buckwheat (*Eriogonum viscidulum*)

Unique characteristics

- Sticky surface near the base of the plant usually covered by sand particles
- Very fine flowering stalks gives delicate appearance
- Habitat – open areas, loose sand

Slide 32

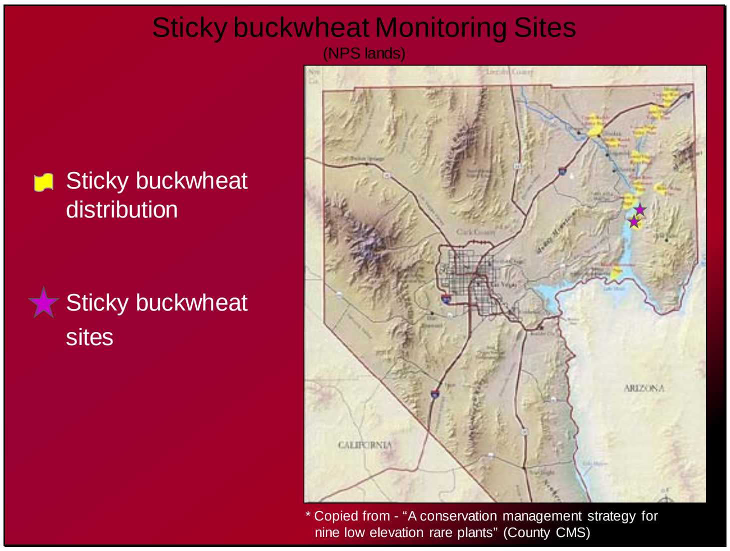


Two bottom photos taken at Glory Hole.

Slide 33

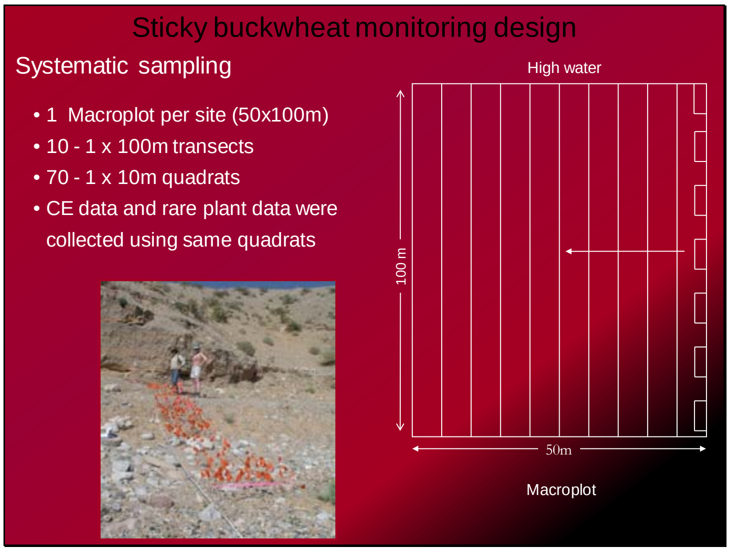
Feral cattle and burros damage habitat on their route to the Lake.

Slide 34



This area was chosen for monitoring because it is currently the only suitable area for monitoring. We would eventually like to add another monitoring site if future surveys help locate suitable sites on BLM land.
The plot locations were randomly selected from prior years survey data. We eliminated points with less than 300 plants and randomly selected from the rest.

Slide 35

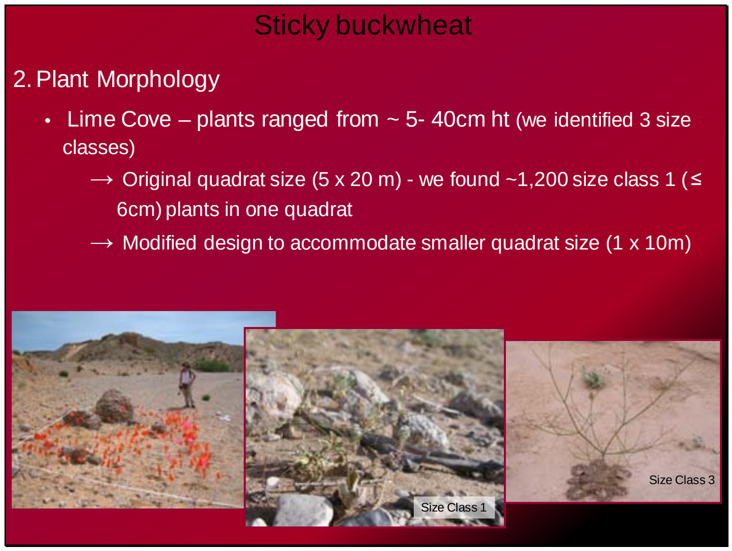


The most suitable habitat occurs near Lake Mead's high water mark. We laid the top of the transect at high water. In the past, portions of sticky buckwheat populations in this area were drowned by rising water levels, which is originally why I chose to use this sampling strategy, to track their movement towards the lake. With water levels at an all time low and global warming considerations, we don't expect rising lake levels to be a threat to sticky buckwheat anymore.

Slide 36

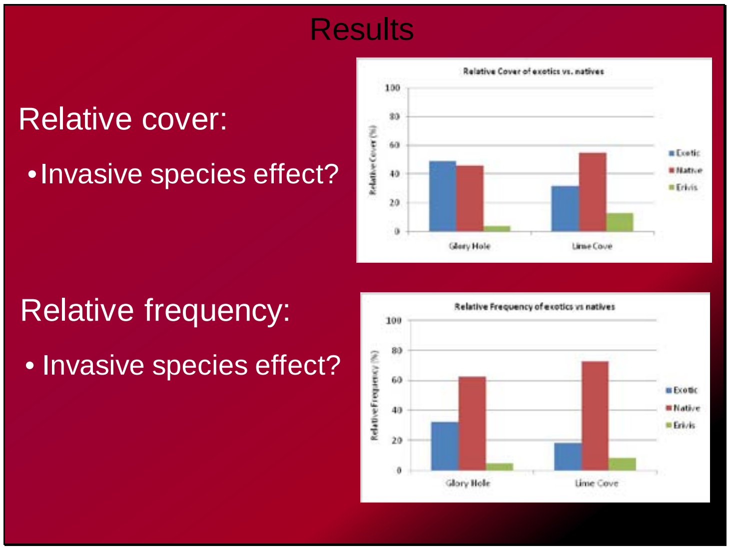
Can be difficult to travel up and down the tiered, sandy, rocky slope.
Cattle and/or burros were present each survey day; some tried walking through our plots.
Tamarix, Salsola, Brassica, and Schismus are the main problems. Where these weeds are dense, we don't see sticky buckwheat.

Slide 37

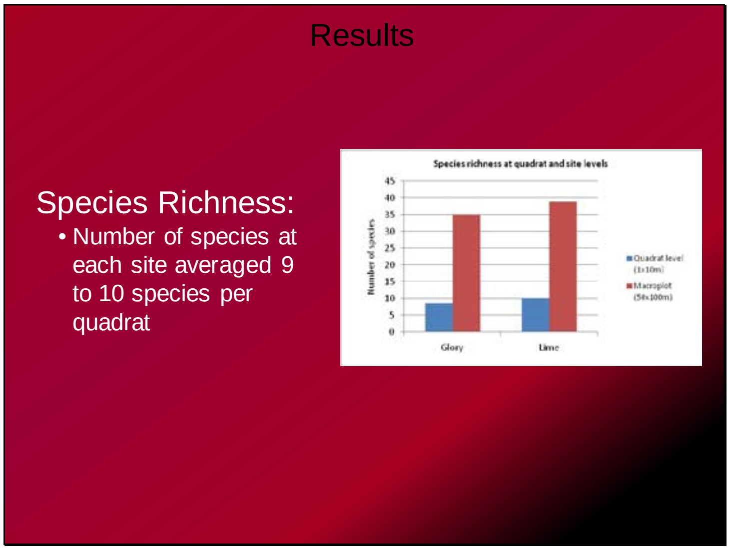


Another challenge was the plants varying morphology. The 3 size classes were identified based on height. There appears to be some relationship between ht and rosette size, but this has not been measured. In the field I needed to come up with 3 size classes and a separate cover assessment for sticky buckwheat based on the 3 size classes. Photo bottom left shows a section of the original quadrat size of 5 x 20 m. This quadrat size was not practical and monitoring would not have been completed during the plants short lifecycle if we had not modified the quadrat size.

Slide 38


Results
Relative cover:
• Invasive species effect?
Relative Cover of exotics vs. natives
Relative Cover (%)
100
80
60
40
20
0
Glory Hole
Lime Cove
Exotic
Native
Erivis
Relative frequency:
• Invasive species effect?
Relative Frequency of exotics vs natives
Relative Frequency (%)
100
80
60
40
20
0
Glory Hole
Lime Cove
Exotic
Native
Erivis

Slide 39

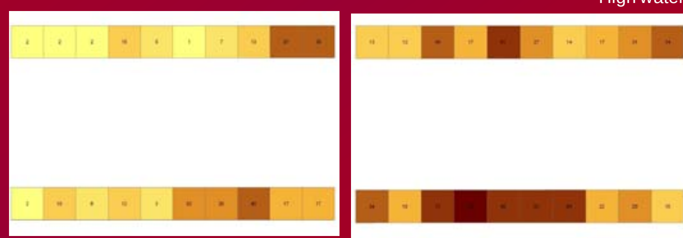

Results
Species Richness:
• Number of species at each site averaged 9 to 10 species per quadrat
Species richness at quadrat and site levels
Number of species
45
40
35
30
25
20
15
10
5
0
Glory
Lime
Quadrat level
(1x10m)
Macroplot

Slide 40

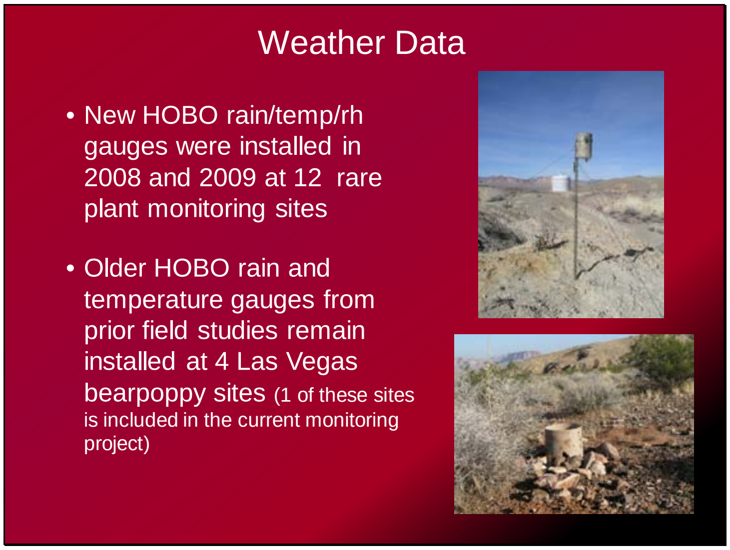
Spatial data

- 4 quadrats from Lime cove macroplot
- Higher density near high water

High water



Slide 41


Weather Data
• New HOBO rain/temp/rh gauges were installed in 2008 and 2009 at 12 rare plant monitoring sites
• Older HOBO rain and temperature gauges from prior field studies remain installed at 4 Las Vegas bearpoppy sites (1 of these sites is included in the current monitoring project)

Slide 42

Rare Plant Monitoring

This fall…

- Collect soil samples
- Soil compaction data (gypsum sites)
- Crust depth and cover (gypsum sites)

Slide 43


PUBLIC LANDS
PUBLIC LANDS INSTITUTE
Thank you!
Dianne Bangle – Phone: 702-293-8759
Email: dianne_bangle@partner.nps.gov
Alice Newton – Phone: 702-293-8977
Email: alice_corrine_newton@nps.gov

APPENDIX 4.

Monitoring methods and protocols for *Eriogonum viscidulum* (sticky buckwheat) within Lake Mead National Recreation Area
Monitoring period: June

BACKGROUND AND OBJECTIVES

National Park Service (NPS) Management Policies direct managers at Lake Mead National Recreation Area (LMNRA) to survey for, protect, and manage state and locally listed species and other native species that are of special concern to the parks in order to maintain the species' natural distribution and abundance (NPS 2002). An additional concern of park managers is maintaining ecosystem health and stability by protecting habitat that supports high biodiversity areas including rare plant sites thus allowing natural processes to occur (i.e. energy flow through the system, natural fluctuations in species abundance). The Clark County Multiple Species Habitat Conservation Plan (MSHCP) lists specific goals for the management of rare plant species as outlined in the Low Elevation Rare Plant Conservation Management Strategy (TNC 2007). The key purposes of the MSHCP are to achieve a balance between 1) long-term conservation and recovery of the diversity of natural habitats and native species of plants and animals, 2) the orderly and beneficial use of land in order to promote the economy, health, well-being, custom and culture of Clark County residents (TNC 2007), as well as, having no net unmitigated loss or fragmentation of habitat in intensively managed areas and maintain stable or increasing plant populations.

Eriogonum viscidulum (sticky buckwheat) is an annual plant endemic to Clark and Lincoln Counties in southern Nevada and Mojave County in northwestern Arizona (Howell 1942). The northern and eastern most distributions of this rare species are found at Sand Hollow Wash in Lincoln County and just across the state border at Coon Creek in Mojave County. Sticky buckwheat reaches its southern and western extensions in Nevada at Middle Point within LMNRA and Weiser Wash on Bureau of Land Management land (BLM), respectively (Niles et al. 1995). Sticky buckwheat is on the Nevada Natural Heritage Programs Sensitive List (ranks G2 S2-defined as imperiled), and has status as a critically endangered species in the state of Nevada.

D. Bangle
November 2008

Select sticky buckwheat populations (Lime Wash and Overton Arm-these are the only two populations where a current status of the population is known) will be monitored annually. Historical populations will be checked in high rainfall years in order to re-evaluate their status and possibly add additional sites for annual monitoring. Prior monitoring was conducted to determine the species distribution, abundance, and potential threats, and when necessary, take appropriate actions to protect the habitat of this species.

This monitoring project is intended to be long term, but implementing the work will be dependent on land managers funding and personnel availability for the project.

MONITORING OBJECTIVES:

1. Determine if the current density of sticky buckwheat measured in average to above average rainfall years remains within 30% of the first measurement at Overton Arm populations occurring on NPS land within Clark County over the next 10 years.
2. Determine the abiotic factors that might influence the occurrence of sticky buckwheat and the biodiversity within the habitat at the Overton Arm populations occurring on NPS land within Clark County over the next 10 years.
3. Determine if native plant community biodiversity and density remain within 30% of the first measurement at Overton Arm populations occurring on NPS land within Clark County over the next 10 years.

SAMPLING OBJECTIVE:

1. We want to be 90% sure of detecting a 30% change in the confidence interval in good rainfall years and are willing to accept a 10% chance that a change did not take place.

MANAGEMENT OBJECTIVE:

1. If change is > 30%, we will attempt to determine the cause.
    - Stochastic event – such as change in climate or soil chemistry- No management action has been determined
    - Threat induced event – remove threat (invasive species, OHV access, trespass cattle/burros/horses)

D. Bangle
November 2008

PILOT YEAR STUDY

Monitoring protocols were developed and plans implemented in 2006 to determine an appropriate experimental design for monitoring sticky buckwheat. After evaluating the pilot year data it was determined that a modified grid and quadrat size were necessary to decrease variability and number of zeros among sampling units while increasing area monitored.

SAMPLING DESIGN

A new monitoring design was necessary to incorporate randomization in positioning sampling units as well as good interspersion of sampling units throughout the population. Due to the nature of the habitat, terrain and location of sticky buckwheat plants, a systematic sampling approach for monitoring sticky buckwheat will be used. Two 50 x 100 m macroplots will be placed within the Overton Arm populations. Each macroplot location was selected in a stratified random approach by placing a "virtual grid" (in Arcmap) over known habitat after which random numbers were generated and a point selected (within the virtual grid). This random point translated to the high water corner (left end when facing the lake) of the macroplot. The macroplots will be divided into ten transects (1 x 100m) and each transect into seven quadrats (1 x 10m) with five meters separating each quadrat. Transects (perpendicular to the shoreline) were located using a random start and every five meters after that.

Data collected from macroplots will include, associated plant species, foliar cover of all species, threats, disturbance (type, amount, cause), and number of sticky buckwheat plants per m^2 within each quadrat. Because the target species is an annual plant, individual GPS coordinates will not be necessary for spatial analysis. Sticky buckwheat spatial distribution within the macroplot will be estimated by recording number of plants within 1 m^2 sections of each quadrat on a field map (Figure 1). This field map will be digitized at the office after the field season is complete. Dead material of saltcedar and Russian thistle were recorded separately from live plants. GPS coordinates were recorded at each corner of the macroplot and included: easting, northing, elevation, and accuracy.

To measure abiotic factors we will collect data in approximately 20 1 x1 meter plots placed across the macroplot so that the plots fall in and out of sticky buckwheat habitat. Select abiotic data will be collected (in the same re-located plots) once in the beginning of the project and then periodically for comparison of climate change effects or other changes that may alter abiotic factors. Abiotic factors will include soil property analyses (chemistry, particle size, pH, total elements, and soil moisture). Additional abiotic data will be collected at the site but not along a gradient including, ambient temperature, relative humidity, and rainfall.

Inventories for *Eriogonum viscidulum* included in project 2005-NPS-535-P will occur each year. The inventories will include surveys of historical sites and an additional 20% in areas containing no known historical or currently known occurrences of this species. When a target species is located, polygons will be mapped to include the population. An estimate of number of individuals, associated plant species, threats and unusual disturbances will be recorded.

FIELD METHODS

The macroplots and transects will be delineated using meter tapes and each quadrat will be identified using flagging tied to stakes stretched across transects. Data will be recorded on data sheets while in the field (Figure 2). Occasionally, researchers may need to collect a plant within a plot for identification. The specimen would be identified soon after collection and then processed as a voucher specimen and subsequently stored in the Lake Mead Study Collection Herbarium or at the Wes E. Niles Herbarium on the campus of the University of Nevada Las Vegas.

Upon completion of monitoring each year, researchers will enter data into the appropriate database and compile notes from all researchers involved in the current years monitoring.

DATA STORAGE, ANALYSIS, AND REPORTING

Consultations with a statistician resulted in a description of statistical analyses that will be performed on the monitoring data. Consultations with LMNRA data managers resulted in a database in which to store and access all monitoring data. Annual reports and presentations will be prepared upon request. Report formats will follow guidelines of each agency or organization requesting a written report.

PERSONNEL REQUIREMENTS AND TRAINING

One lead field researcher will be responsible for completing monitoring including, scheduling and preparing for data collection, training assistants, gathering all necessary equipment needed for monitoring, transportation to each site, making sure data is collected properly and is input in to the database, and ensure that voucher specimens are processed. The lead researcher must meet the following requirements:

- Strong familiarity with local flora both native and invasive species
- Experience conducting plant surveys
- Familiarity with sandy habitats in the Mojave Desert
- Rare plant knowledge
- Ability to hike for considerable distances and up and down uneven terrain
- Ability to tolerate high ambient temperatures during field work
- Experience driving on 4-wheel drive roads

Assistant researcher(s) will be responsible for helping lead researcher in above described duties plus have the ability to hike for considerable distances and up and down uneven terrain, tolerate high ambient temperatures, and quickly learn several plant species commonly found in study area.

Operational requirements

Monitoring should be completed within three days (with six researchers) unless unexpected problems occur (bad weather, damaged equipment, illness, etc.). Equipment needed to successfully complete monitoring for sticky buckwheat include: a vehicle, a boat, one or two GPS units, data sheets, compass, 1 x 1m frame, implements for abiotic sampling, several meter tapes, pen and pencil, sharpie, NPS park radio, camera, field notebook, plant press, and pruners.

Figure 1. Field map for *Eriogonum viscidulum* monitoring.

Date ____________ Macroplot ____________ Recorder ______________________________

Quadrat:									
10 E-Low	9	8	7	6	5	4	3	2	1 E-High

Quadrat:									
10 E-Low	9	8	7	6	5	4	3	2	1 E-High

Quadrat:									
10 E-Low	9	8	7	6	5	4	3	2	1 E-High

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Figure 2. Datasheet for *Eriogonum viscidulum* monitoring

Sticky buckwheat Datasheet

Macroplot ________ Date ______________ Recorder ______________________________

Quadrat ________

Quad:		Quad:		Quad:		Quad:		Quad:	
Species	Cover	Species	Cover	Species	Cover	Species	Cover	Species	Cover

VEG. COVER:
1 = 0-1%, 2 = 1-2%, 3 = 2-5%, 4 = 5-10%
5 = 10-25%, 6 = 25-50%, 7 = 50-75%, 8 = 75-95%, 9 = >95%

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REFERENCES

Bangle, D. 2005. Report on *Eriogonum viscidulum* (Sticky buckwheat) monitoring (1997-2005) within Lake Mead National Recreation Area. Unpublished report to Clark County Multiple Species Habitat Conservation Plan from the National Park Service, Lake Mead National Recreation Area. Boulder City, NV. 27 pages.

Elzinga, C.L. 1998. Measuring and monitoring plant populations. Bureau of Land Management. Denver, Colorado. 477 pages.

Howell, J.T. 1942. *Eriogonum viscidulum* J.T. Howell. Leaflets of Western Botany 3: 138.

Lake Mead National Recreation Area, National Park Service (NPS). 2002. Lake Management Plan. 455 pages.

Niles, W. E., P. Leary, J. S. Holland, and F. H. Landau. 1995. *Astragalus geyeri* var. *triquetrus* (Three-cornered milkvetch) and *Eriogonum viscidulum* (Sticky buckwheat) in Lake Mead National Recreation Area and adjacent regions of Nevada and Arizona. Report to Lake Mead National Recreation Area. Unpublished report to National Park Service, Lake Mead National Recreation Area, Boulder City, NV. (74 pages).

The Nature Conservancy (TNC). 2007. A Conservation Management Strategy for Nine Low Elevation Rare Plants in Clark County, Nevada. TNC, Nevada Field Office Reno, Nevada. 390 pages.

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November 2008

APPENDIX 6.

Rare Plant Survey analysis – ARCA species
3/2010

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Report

Climate variables

Rainfall, vapor density, and temperatures were quantified using monthly minima, maxima, mean, and interquartile range (iqr). Only months which had a complete set of data were used for a particular site.

ARCA

Methods

Total cover, richness, diversity, and the relative representation of life were estimated by mean values. Diversity was expressed as the numbers equivalent (aka effective number of species), but calculations used on the $\log_{10}$ transform of this value (Jost 2006) which was back-transformed for reporting. All other values except richness were $\log_{10}$ transformed prior to estimation of the mean and confidence intervals. Confidence intervals using the normal distribution tended to underestimate the 95% confidence interval, so bootstrapped estimates based on 10,000 resamples are reported. All analysis was completed in R 2.10.0 (R Development Core Team 2009), and diversity and species richness was estimated using the 'vegetarian' package (Jost 2006).

Six sites were available for examining patterns with climate variables. We used a Spearman rank correlation (rho) to estimate the relationship between the number of ARCA in a site and the climate variables for every month which had a full monthly data set available. Congruence of ranks, indicated by a low p-value associated with the correlation coefficient, was taken as a suggestion of an association for further study. No family-wise adjustment was made for the large number of p-values generated, as this was considered a preliminary study.

The potential relationships between quadrat-level species richness, species diversity, relative annual cover, relative perennial cover, relative shrub cover, and total cover (all except richness were $\log_{10}$+1 transformed to meet model expectations) and the number of ARCA individuals ($\log_{10}$+1 transformed) were fit using a mixed model ANOVA. The model included quadrat within site as a subject effect, and an unstructured covariance matrix (determined by corrected Akaike information criterion). Fixed effects were site, year, site by year, and each continuous independent variable above with year, site, and year by site interactions to examine heterogeneity of slopes. Spatial arrangement of quadrats was not available in this case, so this information is not incorporated into the analysis. In addition, the relative proportion of annual cover was analyzed alone because these data were not available in 2008. The minimum adequate model was determined by comparing nested models using AICC. Although significance was determined in the full model, slopes and least-squares means (lsmeans) were estimated in a model containing only the continuous independent variable of interest and its interactions with site and year. Covariance was not stable across sites, yielding misleading coefficients when the slopes were estimated from the full model. This analysis was performed in SAS v9.1 (SAS Institute 2002-2003) 'proc mixed'.

The effect of a plant's size and condition on seeding success was modeled in a generalized linear model (glm) with binomial error. The initial five size classes (ranging from 1 to 5) were reduced to three (combining size class 1-2 and 4-5) because the extreme size classes were too small to gain a reliable estimate of their performance. The initial five condition classes (ranging from 1 to 5) were combined into two classes (1-2 and 3-5) for the same reason. Condition was not noted in 2008, so size was first modeled with site, size class, and their interaction as fixed effects in a separate model for each year (all sites were not measured in both years). The values for success in seeding were computed at the plot level within sites because the quadrat level yielded insufficient sample size to compute success. To examine the effect of condition and size together, we fit another glm, which included site, condition, and size class with all interactions. As before, the minimum adequate model was determined by AICC. For reporting, response values from the minimum adequate model were back-transformed to provide the lsmean and standard error (SE) for the proportion seeding for each treatment. Significant differences between treatment means were tested post-hoc for terms in the minimum adequate model. No adjustments were made for multiple comparisons due to the small sample and exploratory nature of the analysis.

Results: Tables are located in 'ARCA tables.xls'. Full code and selected output are below. Supporting information such as the pairwise contrast output and results from the full model (not the minimum adequate model) are available in 'arca catmod.xls', which is available upon request. The general patterns are reviewed below.

Total cover varied among sites, but was stable between 2008-2009 (Table 1a). The relative make-up of total cover, however, changed between the two years in a site-specific fashion. Percent cover of ARCA trended downward in all sites, significantly so for GAHI, GOBU and RD100. Annuals were not included in sampling 2008, so the numbers for overall diversity and richness for this year are misleadingly low. Species richness and diversity trended upwards from 2008 to 2009, even when annuals were excluded, but these differences were not significant (Table 1b).

We observed no significant trends between the number of plants at a site and the temperature measured from May to November (Table 3). More data is needed to explore these patterns. The vapor density had a slightly stronger correlation with plant presence, with higher minimum or maximum humidity in November or May corresponding to more ARCA plants. Sites that had a greater range of vapor density values in June and August also tended to have more ARCA individuals (Table 3). Finally, higher rainfall in July was positively correlated with ARCA presence.

Many of the measures describing the biotic community had a significant relationship with the number of ARCA on a local scale. The relationship between ARCA numbers and species diversity, proportion of perennials, proportion of shrubs, and total cover varied significantly by site and year (Table 4). Species richness did not significantly predict ARCA numbers, alone or within sites or years. The proportion of annuals was related to ARCA in different ways among sites, but was consistent between years (Table 4). Slopes were estimated for each biotic community variable alone to avoid misleading coefficients. Trends are reviewed below; some are significant, while others are notable for their consistency in trends across sites. In all but one site (SUHI), biodiversity was a stronger predictor of ARCA numbers in 2009 than in 2008 (Table 5). The number of ARCA was negatively related to the proportion of annual species in all sites. The proportion of perennials was a positive predictor of ARCA 2008, but a negative predictor in 2009 in five of the six sites. (Table 5). In almost all sites, the number of ARCA was negatively correlated with the proportion of shrubs. The coefficients are provided for species richness, although their magnitude corroborates the ANCOVA result that richness was not a strong determinant of ARCA numbers. Total cover was either a positive or a negative predictor of ARCA individuals, depending upon year and site (Table 5). The slope was weak or negative in 2008, while in 2009 the slope for total cover was positive and large (with the exception of SUHI). SUHI stands out as different from the other sites in a variety of ways from this table.

The size class of individual plants predicted seeding success, and this pattern was consistent across sites (Table 6). The smallest individuals had a 26-37% chance of seeding, while the largest seeded had a 92-96% chance of seeding (Table 7). The effect of a plant’s condition on seeding was dependent on the size class of the plant (Table 6; Fig. 1).

Table 1a. Summary of mean and bootstrapped 95% confidence limits (CL) of quadrat-level and whole-plot measurements at sites containing ARCA. Values are expressed as percent cover in the plot. Non-overlapping confidence intervals between years are denoted by '*'.

		2008		2009		sig diff
	site	Mean	95% CL	Mean	95% CL	between years
Total Cover	BLPO	10.29	8.57,12.26	7.71	6.68,8.74	
	GAHI	4.89	3.65,6.50	3.87	3.18,4.69	
	GOBU	3.50	2.91,4.25	4.80	4.10,5.61	
	RD100	8.36	6.04,11.54	6.39	4.88,8.39	
	SUHI	3.37	2.35,4.79	3.65	2.68,4.97	
	VFArca	14.73	12.43,17.6	11.64	10.36,12.93	
Annual cover	BLPO			0.87	0.68,1.08	
	GAHI			1.01	0.78,1.31	
	GOBU			1.16	0.94,1.40	
	RD100			2.25	1.69,2.92	
	SUHI			0.88	0.73,1.04	
	VFArca			1.69	1.43,1.97	
Perennial cover	BLPO	0.99	0.81,1.17	1.69	1.22,2.34	*
	GAHI	1.92	1.57,2.32	1.97	1.53,2.52	
	GOBU	1.40	1.23,1.58	1.88	1.67,2.11	*
	RD100	3.85	2.88,5.08	2.85	1.98,4.06	
	SUHI	0.88	0.73,1.03	1.72	1.15,2.55	*
	VFArca	2.35	1.93,2.82	2.73	2.31,3.25	
Shrub cover	BLPO	9.15	7.45,11.13	5.63	4.24,7.14	*
	GAHI	2.68	1.73,4.04	1.16	0.73,1.72	*
	GOBU	1.96	1.43,2.65	2.27	1.74,2.90	
	RD100	3.51	2.02,5.82	5.87	3.82,8.57	
	SUHI	2.30	1.40,3.58	1.55	0.88,2.52	
	VFArca	11.75	9.37,14.79	7.59	6.69,8.63	*
ARCA cover	BLPO	6.93	4.59,9.97	3.53	2.10,5.49	
	GAHI	3.22	1.89,5.16	0.66	0.25,1.32	*
	GOBU	3.00	2.20,3.96	1.28	0.75,1.96	*
	RD100	8.92	6.76,11.75	2.30	1.57,3.23	*
	SUHI	1.30	0.79,2.01	0.62	0.29,1.05	
	VFArca	12.62	8.56,17.71	6.99	4.12,11.18	

Table 1b. Summary of mean and bootstrapped 95% confidence limits (CL) of quadrat-level and whole-plot measurements at sites containing ARCA. Diversity is back-transformed to Hill's number, richness is average number of species (for quadrat) or total number of species in the site (whole-plot). Non-overlapping confidence intervals between years are denoted by '*'.

		2008		2009		sig diff
	site	Mean	95% CL	Mean	95% CL	between years
Hill diversity	BLPO	3.93	3.41,4.46	5.96	5.27,6.76	*
	GAHI	3.46	3.07,3.90	4.99	4.41,5.62	*
	GOBU	4.57	4.03,5.12	7.15	6.27,8.02	*
	RD100	4.63	3.97,5.36	5.70	4.91,6.61	
	SUHI	2.62	2.23,3.03	3.43	2.92,3.98	
	VFArca	4.99	4.15,5.91	9.63	8.66,10.65	*
Richness	BLPO	5.84	5.30,6.44	7.70	6.82,8.61	*
	GAHI	4.48	3.96,5.02	5.55	4.86,6.28	
	GOBU	5.10	4.58,5.62	7.81	6.84,8.83	*
	RD100	6.01	5.12,7.04	6.80	5.71,8.10	
	SUHI	3.29	2.79,3.79	4.23	3.56,4.96	
	VFArca	8.96	8.14,9.84	13.03	11.98,14.09	*
Hill diversity (Annuals excluded)	BLPO	3.93	3.35,4.43	4.97	4.40,5.51	
	GAHI	3.46	3.03,3.86	4.29	3.75,4.81	
	GOBU	4.57	3.97,5.09	5.61	5.05,6.15	
	RD100	4.63	3.90,5.31	5.28	4.56,6.00	
	SUHI	2.62	2.16,2.99	2.92	2.47,3.30	
	VFArca	4.99	4.07,5.84	7.17	6.52,7.81	*
Richness (Annuals excluded)	BLPO	5.84	5.28,6.40	6.35	5.63,7.02	
	GAHI	4.48	3.93,4.98	4.78	4.12,5.42	
	GOBU	5.10	4.54,5.61	6.17	5.55,6.75	
	RD100	6.01	5.04,6.96	6.32	5.31,7.35	
	SUHI	3.29	2.68,3.75	3.58	2.98,4.06	
	VFArca	8.96	8.11,9.83	9.71	9.07,10.40	
Whole-plot diversity	BLPO	7.48		11.40		
	GAHI	8.63		14.45		
	GOBU	7.65		13.90		
	RD100	13.15		17.60		
	SUHI	4.53		6.71		
	VFArca	7.20		15.30		
Whole-plot richness	BLPO	16		24		
	GAHI	18		28		
	GOBU	10		21		
	RD100	17		28		
	SUHI	9		19		
	VFArca	18		28		
Whole-plot diversity (Annuals excluded)	BLPO	6.48		8.01		
	GAHI	7.64		10.60		
	GOBU	7.65		9.19		
	RD100	12.47		14.57		
	SUHI	4.53		4.95		
	VFArca	6.75		10.27		
Whole-plot richness (Annuals excluded)	BLPO	15		15		
	GAHI	17		19		
	GOBU	10		12		
	RD100	16		18		
	SUHI	9		9		
	VFArca	17		16		

Table 2. Proportional representation for each life form as a function of total cover. These were the values used for deriving ranks for comparison with the climate data to avoid confounding total cover with individual categories' representation.

	a		p		s	
site	2008	2009	2008	2009	2008	2009
BLPO	NA	0.11	0.10	0.22	0.89	0.73
GAHI	NA	0.26	0.39	0.51	0.55	0.30
GOBU	NA	0.24	0.40	0.39	0.56	0.47
RD100	NA	0.35	0.46	0.45	0.42	0.92
SUHI	NA	0.24	0.26	0.47	0.68	0.42
VFArca	NA	0.15	0.16	0.23	0.80	0.65

Table 3. Spearman correlations (rho) and P-values for relationships between plant variables and climate variables by month. All correlations were based on six sites.

	Minimum Temp.		Maximum Temp.		Mean Temp.		IQR Temp.	
	rho	P-value	rho	P-value	rho	P-value	rho	P-value
May	-0.77	0.1028	0.31	0.5639	-0.03	1.0000	0.43	0.4194
June	-0.26	0.6583	0.26	0.6583	0.26	0.6583	-0.54	0.2972
July	-0.26	0.6583	0.31	0.5639	0.26	0.6583	0.20	0.7139
August	-0.26	0.6583	0.31	0.5639	0.26	0.6583	0.20	0.7139
September	-0.26	0.6583	0.26	0.6583	0.60	0.2417	0.14	0.8028
October	-0.09	0.9194	0.37	0.4972	0.37	0.4972	0.14	0.8028
November	0.43	0.4194	-0.77	0.1028	0.20	0.7139	0.20	0.7139

	Minimum VD		Maximum VD		Mean VD		IQR VD		Rainfall	
	rho	P-value	rho	P-value	rho	P-value	rho	P-value	rho	P-value
May	-0.14	0.8028	0.89	**0.0333**	0.49	0.3556	0.77	0.1028		
June	-0.26	0.6583	0.83	0.0583	0.54	0.2972	0.89	**0.0333**	-0.13	0.8047
July	0.09	0.9194	0.66	0.1750	0.54	0.2972	-0.37	0.4972	0.81	**0.0499**
August	-0.09	0.9194	0.83	0.0583	0.60	0.2417	0.89	**0.0333**	-0.06	0.9131
September	-0.09	0.9194	0.14	0.8028	0.60	0.2417	0.60	0.2417		
October	-0.14	0.8028	-0.37	0.4972	0.83	0.0583	0.71	0.1361	-0.03	0.9493
November	0.89	**0.0333**	-0.03	1.0000	0.83	0.0583	-0.54	0.2972		

Table 4. ANOVA results predicting presence of ARCA (log10-transformed +1) for species richness and log10+1 transformed diversity, relative proportion of perennial cover, relative proportion of shrub cover, and total cover. Model included quadrat as the subject effect and an unstructured covariance structure (determined by AICC). Proportion of annuals (propa) was treated alone because this variable was not measured the first year of the study (2008). The minimum adequate model was based on AICC. The high dimensionality and strong relationships among some variables make the AICC a more reliable estimator of the best model compared to using p-values.

		Full model		Reduced model	
Effect	df	FValue	P-value	FValue	P-value
Site	5,144	0.46	0.8090	0.60	0.6981
Year	1,144	0.00	0.9961	0.00	0.9668
Site*Year	5,144	0.88	0.4975	0.84	0.5212
arca_richness	1,144	2.21	0.1397		
arca_richness*Site	5,144	1.74	0.1286		
arca_richness*Year	1,144	1.59	0.2097		
arca_richn*Site*Year	5,144	0.75	0.5901		
log10diversity	1,144	0.86	0.3543	1.58	0.2111
log10diversity*Site	5,144	1.10	0.3622	0.19	0.9644
log10diversity*Year	1,144	3.37	0.0684	4.97	0.0273
log10diver*Site*Year	5,144	0.68	0.6421	1.43	0.2173
log10propp	1,144	0.30	0.5854	0.09	0.7680
log10propp*Site	5,144	0.61	0.6917	1.17	0.3286
log10propp*Year	1,144	0.54	0.4617	0.31	0.5771
log10propp*Site*Year	5,144	0.57	0.7199	1.01	0.4121
log10props	1,144	0.00	0.9438	0.00	0.9547
log10props*Site	5,144	0.54	0.7448	0.81	0.5447
log10props*Year	1,144	0.07	0.7899	0.02	0.8809
log10props*Site*Year	5,144	0.66	0.6556	0.80	0.5487
log10total	1,144	2.61	0.1081	1.59	0.2100
log10total*Site	5,144	2.57	0.0292	1.52	0.1875
log10total*Year	1,144	0.03	0.8646	1.92	0.1682
log10total*Site*Year	5,144	1.16	0.3296	1.88	0.1017

Site	5,137	3.95	0.0022
log10propa	1,137	9.73	0.0022
log10propa*Site	5,137	1.59	0.1665

Table 5. Slopes, slope SE, and P-values for testing slope significance relative to zero. Estimates were derived from the model in Table 4 for each continuous predictor variable individually to avoid misleading coefficient signs or magnitudes.

Variable	Site Year	Slope	SE	DF	tValue	P (slope=0)
biodiversity	BLPO 2008	0.475	0.497	144	0.96	0.3402
biodiversity	BLPO 2009	1.760	0.520	144	3.38	**0.0009**
biodiversity	GAHI 2008	0.346	0.561	144	0.62	0.5384
biodiversity	GAHI 2009	1.206	0.541	144	2.23	**0.0274**
biodiversity	GOBU 2008	-0.459	0.542	144	-0.85	0.3986
biodiversity	GOBU 2009	1.211	0.511	144	2.37	**0.0192**
biodiversity	RD100 2008	0.190	0.465	144	0.41	0.6826
biodiversity	RD100 2009	0.641	0.461	144	1.39	0.1670
biodiversity	SUHI 2008	0.539	0.490	144	1.10	0.2737
biodiversity	SUHI 2009	0.213	0.447	144	0.48	0.6340
biodiversity	VFARCA 2008	0.469	0.355	144	1.32	0.1882
biodiversity	VFARCA 2009	1.882	0.587	144	3.21	**0.0017**
proportion annuals	BLPO 2009	-2.650	1.816	137	-1.46	0.1468
proportion annuals	GAHI 2009	-2.248	1.314	137	-1.71	0.0894
proportion annuals	GOBU 2009	-3.231	1.159	137	-2.79	**0.0060**
proportion annuals	RD100 2009	-0.042	0.903	137	-0.05	0.9629
proportion annuals	SUHI 2009	-0.167	1.046	137	-0.16	0.8735
proportion annuals	VFARCA 2009	-4.034	2.731	137	-1.48	0.1419
proportion perennials	BLPO 2008	3.888	2.297	144	1.69	0.0927
proportion perennials	BLPO 2009	-3.354	0.773	144	-4.34	**0.0000**
proportion perennials	GAHI 2008	0.267	0.875	144	0.30	0.7609
proportion perennials	GAHI 2009	-0.499	1.449	144	-0.34	0.7309
proportion perennials	GOBU 2008	0.318	1.017	144	0.31	0.7550
proportion perennials	GOBU 2009	-1.078	0.849	144	-1.27	0.2063
proportion perennials	RD100 2008	0.517	0.690	144	0.75	0.4546
proportion perennials	RD100 2009	0.215	0.972	144	0.22	0.8256
proportion perennials	SUHI 2008	0.728	0.716	144	1.02	0.3114
proportion perennials	SUHI 2009	-0.291	0.811	144	-0.36	0.7204
proportion perennials	VFARCA 2008	2.554	1.317	144	1.94	0.0543
proportion perennials	VFARCA 2009	-1.686	1.565	144	-1.08	0.2831
proportion shrubs	BLPO 2008	-1.163	3.720	144	-0.31	0.7550
proportion shrubs	BLPO 2009	-1.657	0.475	144	-3.49	**0.0006**
proportion shrubs	GAHI 2008	0.317	0.785	144	0.40	0.6871
proportion shrubs	GAHI 2009	-0.816	0.330	144	-2.47	**0.0147**
proportion shrubs	GOBU 2008	-1.599	0.934	144	-1.71	0.0893
proportion shrubs	GOBU 2009	-1.608	0.717	144	-2.24	**0.0263**
proportion shrubs	RD100 2008	-0.068	0.605	144	-0.11	0.9103
proportion shrubs	RD100 2009	-0.436	0.250	144	-1.74	0.0832
proportion shrubs	SUHI 2008	-0.509	0.683	144	-0.75	0.4574
proportion shrubs	SUHI 2009	-0.355	0.288	144	-1.23	0.2195
proportion shrubs	VFARCA 2008	-3.052	1.648	144	-1.85	0.0660
proportion shrubs	VFARCA 2009	-2.378	0.630	144	-3.78	**0.0002**
richness	BLPO 2008	0.055	0.041	144	1.35	0.1795
richness	BLPO 2009	0.090	0.029	144	3.15	**0.0020**
richness	GAHI 2008	-0.022	0.044	144	-0.50	0.6181
richness	GAHI 2009	0.070	0.033	144	2.09	**0.0382**
richness	GOBU 2008	-0.028	0.047	144	-0.59	0.5549
richness	GOBU 2009	0.056	0.025	144	2.28	**0.0239**
richness	RD100 2008	-0.001	0.026	144	-0.03	0.9759
richness	RD100 2009	0.019	0.020	144	0.93	0.3524
richness	SUHI 2008	0.012	0.052	144	0.23	0.8169
richness	SUHI 2009	0.021	0.037	144	0.57	0.5699
richness	VFARCA 2008	0.014	0.027	144	0.52	0.6023
richness	VFARCA 2009	0.070	0.024	144	2.90	**0.0043**
total cover	BLPO 2008	-0.016	0.327	144	-0.05	0.9603
total cover	BLPO 2009	0.443	0.506	144	0.88	0.3825
total cover	GAHI 2008	-0.608	0.223	144	-2.73	**0.0071**
total cover	GAHI 2009	0.318	0.394	144	0.81	0.4210
total cover	GOBU 2008	0.010	0.357	144	0.03	0.9778
total cover	GOBU 2009	0.947	0.457	144	2.07	**0.0400**

Table 6 Generalized linear model results for size and condition of plants as well as their site of origin relative to success in seeding. Size class was first treated in a separate model because a larger number of date and sites were available compared to those for condition. The minimum adequate model was chosen by using the AICC.

Full model						Minimum adequate model			
Year	Effect	NumDF	DenDF	FValue	ProbF	NumDF	DenDF	FValue	ProbF
2008	Site	2	17	0.0	0.9993	2	21	18.5	**0.0000**
2008	sizeclass	2	17	25.2	0.0000	2	21	37.8	**0.0000**
2008	Site*sizeclass	4	17	0.8	0.5354				
2009	Site	5	26	1.3	0.3049	5	36	3.4	**0.0123**
2009	sizeclass	2	26	0.0	0.9991	2	36	47.2	**0.0000**
2009	Site*sizeclass	10	26	0.1	0.9997				

Minimum adequate model					
Year	Effect	NumDF	DenDF	FValue	ProbF
2009	Site	5	66	2.0	0.0903
2009	Condition	1	66	15.1	0.0002
2009	sizeclass	2	66	35.9	0.0000
2009	Condition*sizeclass	2	66	4.3	**0.0169**

Table 7 Estimated proportion seeding from first model in Table 6 for terms in the minimum adequate model. Letters denote significant differences within effects and years (α=0.05).

Year	Effect	Site	Size class	Mean	SE	
2008	Site	BLPO		0.793	0.056	b
2008	Site	GAHI		0.498	0.086	a
2008	Site	VFArca		0.915	0.023	c
2008	Size class		1-2	0.267	0.036	a
2008	Size class		3	0.841	0.041	b
2008	Size class		4-5	0.955	0.027	b
2009	Site	BLPO		0.889	0.033	b
2009	Site	GAHI		0.765	0.080	ab
2009	Site	GOBU		0.729	0.073	ab
2009	Site	RD100		0.556	0.072	a
2009	Site	SUHI		0.775	0.081	ab
2009	Site	VFArca		0.755	0.035	b
2009	Size class		1-2	0.365	0.042	a
2009	Size class		3	0.819	0.037	b
2009	Size class		4-5	0.921	0.021	c

Table 8 Estimated proportion seeding from second model in Table 6 for terms in the minimum adequate model. Letters denote significant differences within effects and years (α=0.05).

Year	Effect	Site	Condition	Size class	Mean	SE	
2009	Site	BLPO			0.891	0.035	
2009	Site	GAHI			0.765	0.085	
2009	Site	GOBU			0.748	0.074	
2009	Site	RD100			0.680	0.069	
2009	Site	SUHI			0.798	0.075	
2009	Site	VFArca			0.744	0.044	
2009	Condition		1-2		0.876	0.032	b
2009	Condition		3-5		0.638	0.050	a
2009	Size class			1-2	0.368	0.050	a
2009	Size class			3	0.823	0.039	b
2009	Size class			4-5	0.942	0.022	c
2009	Condition*Size class		1-2	1-2	0.389	0.049	a
2009	Condition*Size class		1-2	3	0.902	0.035	c
2009	Condition*Size class		1-2	4-5	0.984	0.012	d
2009	Condition*Size class		3-5	1-2	0.346	0.086	a
2009	Condition*Size class		3-5	3	0.702	0.068	b
2009	Condition*Size class		3-5	4-5	0.814	0.051	bc

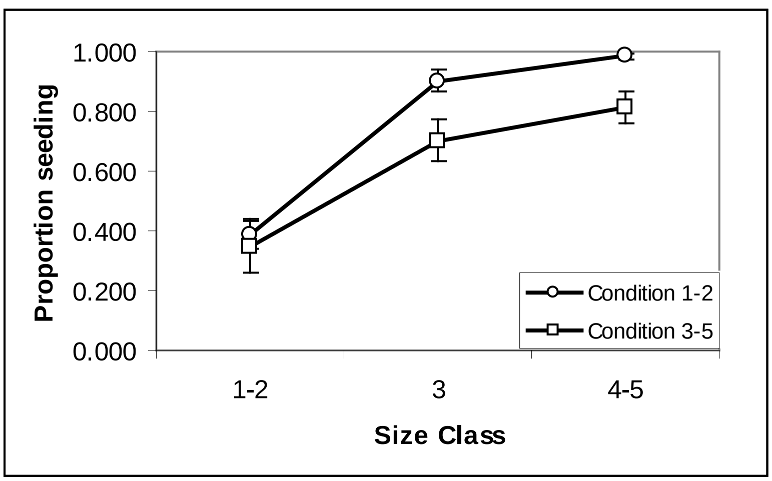


Figure 1 Mean (SE) proportion of plants seeding across age and size classes.

Literature cited

Jost, L. 2006. Entropy and diversity. Oikos 113(2): 363-375.

R Development Core Team. 2009. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

SAS Institute. 2002-2003. SAS v 9.1. Cary, NC.

Analysis notes: Environmental variables

Relative humidity was converted to vapor density by using the following to estimate saturated vapor density:

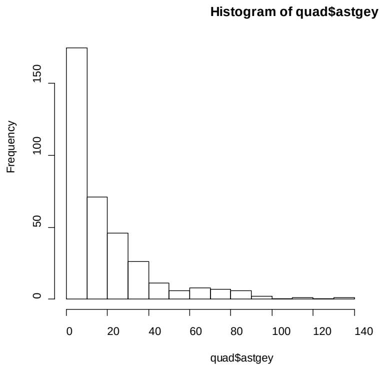
$6.335 + 0.6718Tc - 0.020887Tc^2 + 0.00073095Tc^3$

Where Tc=temperature in C, and

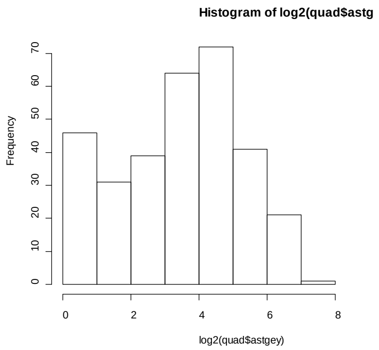
RH=VD/saturatedVD

Distribution:

```
> par(mfrow=c(1,1))
> hist(quad$astgey)
> mean(quad$astgey)
[1] 18.04722
> sum(quad$astgey)
[1] 6497
```



This distribution shows extreme clumping relative to Poisson with lambda=18 (not formally tested; available upon request).



These could possibly be modeled as normal after a log-transform, given the large sample size and range of possible values. Residual plots will tell.

Code and preparation:

```
#computed in Excel, then brought into R as text files:

fles=as.matrix(read.delim("rhtempfiles.txt",header=FALSE))
temp_rh=matrix(ncol=9)
for(k in 1:length(fles)){
temp=read.delim(fles[k,])
tt=cbind(levels(temp$Site),tapply(temp$Tc,temp$Month,min),
tapply(temp$Tc,temp$Month,max),tapply(temp$Tc,temp$Month,mean),
tapply(temp$Tc,temp$Month,IQR),tapply(temp$vd_mb,temp$Month,min),tapply(temp$
vd_mb,temp$Month,max),tapply(temp$vd_mb,temp$Month,mean),tapply(temp$vd_mb,t
emp$Month,IQR))
temp_rh=rbind(temp_rh,tt)}
```

```
temp_rh.df=data.frame(cbind(row.names(temp_rh),temp_rh),row.names=NULL)

names(temp_rh.df)=c("month","site","min_temp","max_temp","mean_temp","iqr_temp",
"min_vd","max_vd","mean_vd","iqr_vd")
write.table(temp_rh.df,"temperature rh fromR.txt",row.names=FALSE)
```

Used Pivot table in Excel to get final format.

ARCA Analysis notes:

Relationship between quad-level variables and ASTGEY presence

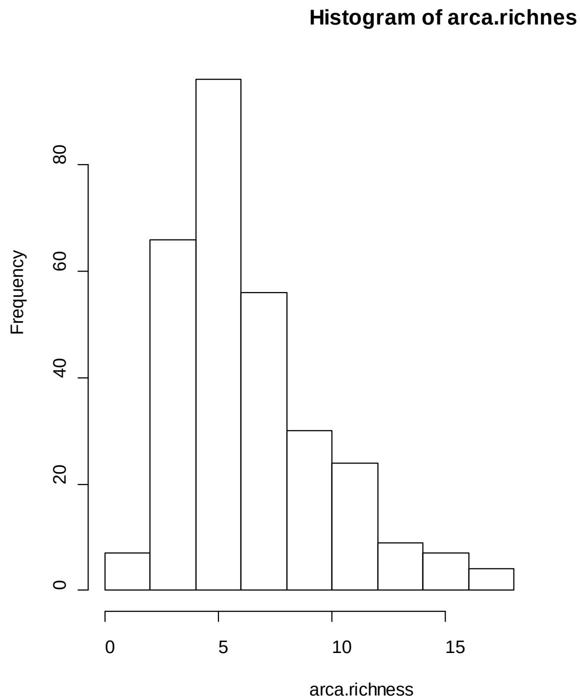
```
library(MASS)
raw=read.delim("arca_quadrat.txt")
attach(raw)
table(Year,Site)

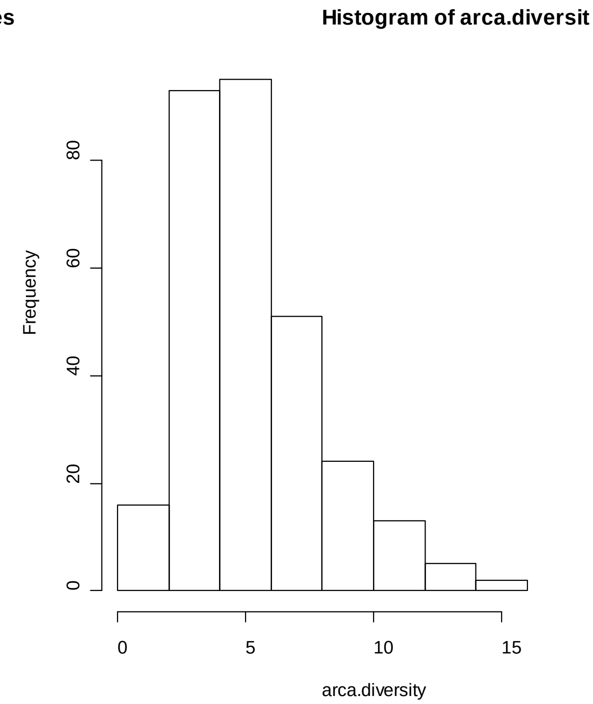
      Site
Year   BLPO GAHI GOBU RD100 SUHI VFArca
  2008   25   25   25    25   24     25
  2009   25   25   25    25   25     25

#created diversity and species richness data sets for each site
arca.richness=matrix(ncol=1,nrow=length(raw[,1]))
arca.diversity=matrix(ncol=1,nrow=length(raw[,1]))
library(vegetarian)

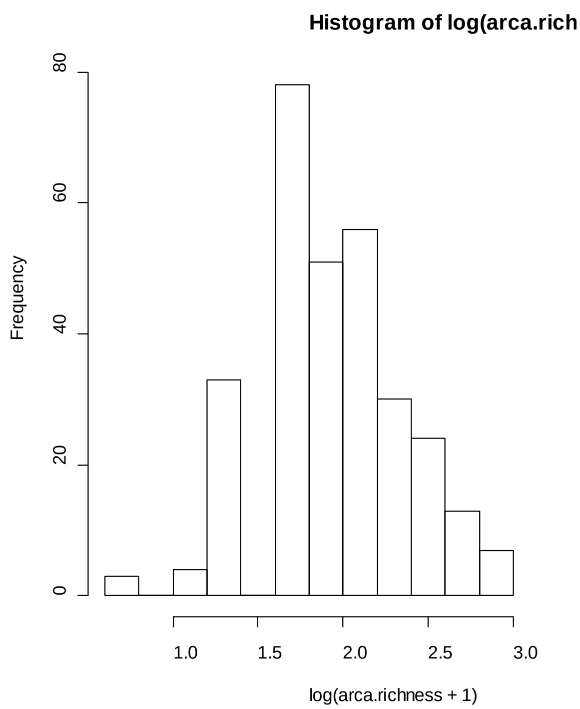
for(j in 1:length(raw[,1])){
arca.richness[j]=d(raw[j,4:70],q=0)
arca.diversity[j]=d(raw[j,4:70],q=1)}

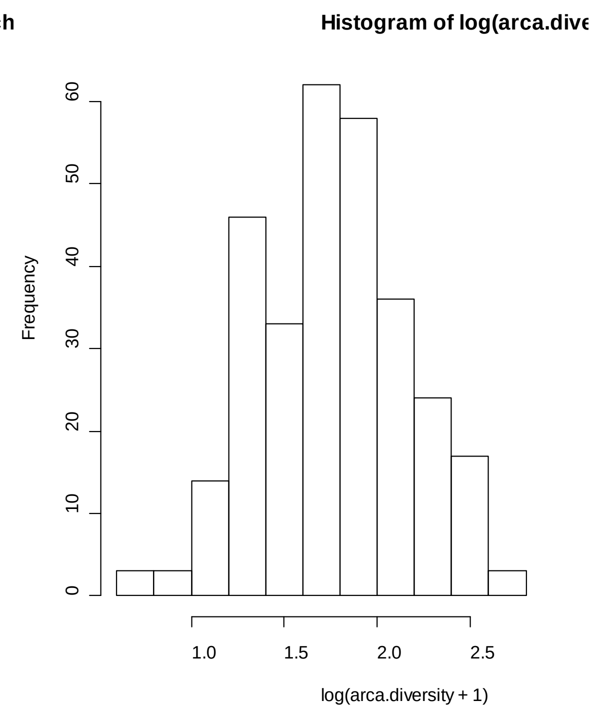
par(mfrow=c(1,2))
hist(arca.richness)
hist(arca.diversity)
```





#Both of these benefited from log transformation, below;





Mean and bootstrapped 95% CI for log(diversity) and log(species richness) for each site/year.

(10^tapply(log10(arca.richness+1),paste(raw$Year,raw$Site),mean))-1

	BLPO	GAHI	GOBU	RD100	SUHI	VFArca
2008	5.8	4.5	5.1	6.0	3.3	9.0
2009	7.7	5.6	7.8	6.8	4.2	13.0

(10^tapply(log10(arca.diversity+1),paste(raw$Year,raw$Site),mean))-1

	BLPO	GAHI	GOBU	RD100	SUHI	VFArca
2008	3.9	3.5	4.6	4.6	2.6	5.0
2009	6.0	5.0	7.1	5.7	3.4	9.6

#95% CI- these values were larger than the parametric CI, so I used the bootstrapped ones.

```
10^tapply(log10(arca.richness),paste(raw$Year,raw$Site),mean)+(qnorm(0.975)*tapply(log10(arca.richness),paste(raw$Year,raw$Site),sd)/tapply(arca.richness,paste(raw$Year,raw$Site),length))

10^tapply(log10(arca.richness),paste(raw$Year,raw$Site),mean)-(qnorm(0.975)*tapply(log10(arca.richness),paste(raw$Year,raw$Site),sd)/tapply(arca.richness,paste(raw$Year,raw$Site),length))

>
10^tapply(log10(arca.richness),paste(raw$Year,raw$Site),mean)+(qnorm(0.975)*tapply(log10(arca.richness),paste(raw$Year,raw$Site),sd)/tapply(arca.richness,paste(raw$Year,raw$Site),length))
  2008 BLPO   2008 GAHI   2008 GOBU  2008 RD100   2008 SUHI 2008 VFArca
2009 BLPO   2009 GAHI   2009 GOBU  2009 RD100
   5.826811    4.451361    5.078434    5.950936    3.227078    8.943316    7.666493
5.514100    7.765742    6.725109
  2009 SUHI 2009 VFArca
   4.156100   13.017061
>
> 10^tapply(log10(arca.richness),paste(raw$Year,raw$Site),mean)-(qnorm(0.975)*tapply(log10(arca.richness),paste(raw$Year,raw$Site),sd)/tapply(arca.richness,paste(raw$Year,raw$Site),length))
  2008 BLPO   2008 GAHI   2008 GOBU  2008 RD100   2008 SUHI 2008 VFArca
2009 BLPO   2009 GAHI   2009 GOBU  2009 RD100
   5.809579    4.430191    5.059729    5.922166    3.196374    8.926263    7.645106
5.490987    7.742702    6.693699
  2009 SUHI 2009 VFArca
   4.124619   13.002557


rich.resamp=matrix(nrow=10000,ncol=4)
div.resamp=matrix(nrow=10000,ncol=4)
for(x in 1:4){
div.temp=subset(arca.diversity,
as.factor(paste(raw$Year,raw$Site))==levels(as.factor(paste(raw$Year,raw$Site)))[x])
rich.temp=subset(arca.richness,
as.factor(paste(raw$Year,raw$Site))==levels(as.factor(paste(raw$Year,raw$Site)))[x])
for(k in 1:10000){
xx=sample(rich.temp,length(rich.temp),replace=TRUE)
rich.resamp[k,x]=10^mean(log10(xx))
xy=sample(div.temp,length(div.temp),replace=TRUE)
div.resamp[k,x]=10^mean(log10(xy))}}

resamp.out=matrix(ncol=4,nrow=4)
```

```
for(y in 1:4){
resamp.out[y,1:2]=(quantile(div.resamp[,y],c(0.025,0.975)))
resamp.out[y,3:4]=(quantile(rich.resamp[,y],c(0.025,0.975)))}

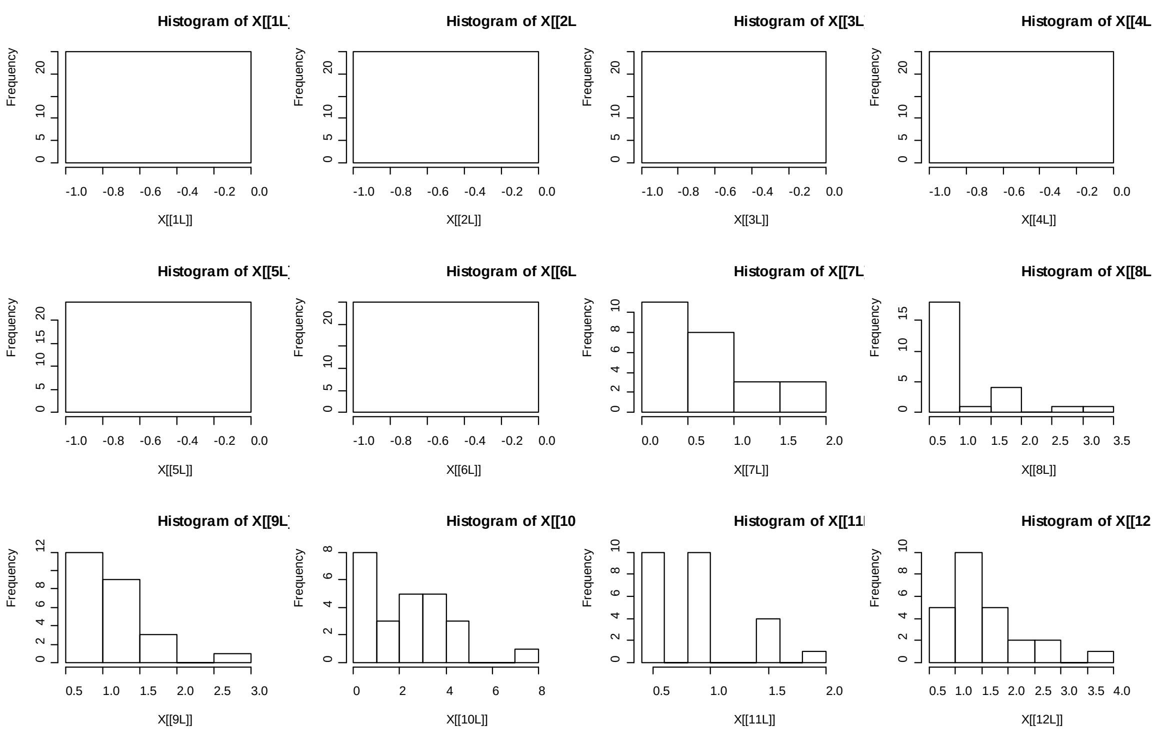
> resamp.out
         [,1]     [,2]     [,3]     [,4]
[1,] 3.345157 4.430080 5.282148 6.421028
[2,] 3.033732 3.856943 3.925875 4.985136
[3,] 3.972074 5.080452 4.533215 5.617924
[4,] 3.900985 5.303655 5.050485 6.975323
```

```
arca.out=as.data.frame(cbind(raw,arca.diversity,arca.richness))
cor(arca.out[,71:78])
```

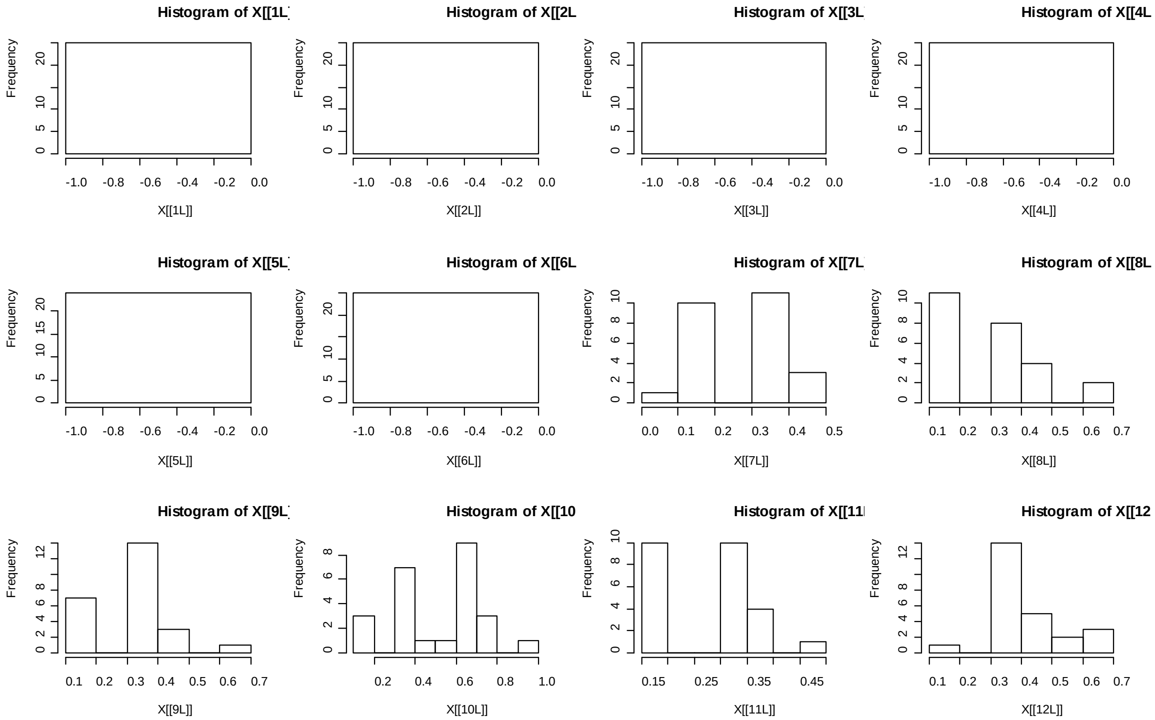
	total	a	p	s	numARCA	numANLE	arca.diversity	arca.richness
total	1.00	0.03	0.45	0.83	0.27	-0.05	0.22	0.54
a	0.03	1.00	0.21	0.06	-0.19	-0.16	0.45	0.40
p	0.45	0.21	1.00	0.09	0.15	0.11	0.21	0.29
s	0.83	0.06	0.09	1.00	0.17	-0.12	0.04	0.33
numARCA	0.27	-0.19	0.15	0.17	1.00	0.10	0.22	0.32
numANLE	-0.05	-0.16	0.11	-0.12	0.10	1.00	-0.09	-0.11
arca.diversity	0.22	0.45	0.21	0.04	0.22	-0.09	1.00	0.90
arca.richness	0.54	0.40	0.29	0.33	0.32	-0.11	0.90	1.00

Diversity and richness may be highly correlated; need to interpret output carefully.

```
par(mfrow=c(3,4))
tapply((raw$a),paste(raw$Year,raw$Site),hist)
```




```
par(mfrow=c(3,4))
tapply((log10(raw$a+1)),paste(raw$Year,raw$Site),hist)
```



#as for the above, the distribution was much more symmetrical with a log transform, so I transformed prior to getting the means, then reported back-transformed values.
#95% CI- these values were larger than the parametric CI, so I used the bootstrapped ones.

```
lfn.means=matrix(ncol=12,nrow=8)
lfn.resamp=matrix(nrow=10000,ncol=124)

for(l in 71:78){
lfn.means[l-
70,]=10^tapply(log10(arca.out[,l]+1),(as.factor(paste(arca.out$Year,arca.out$Site))),mea
n)-1}

for(x in 1:12){
lfn.temp=subset(arca.out,
as.factor(paste(arca.out$Year,arca.out$Site))==levels(as.factor(paste(arca.out$Year,arca.
out$Site)))[x])
for(k in 1:10000){
for(l in 71:78){
xx=sample(log10(lfn.temp[,l]+1),length(lfn.temp[,l]),replace=TRUE)
lfn.resamp[k,((l-70)*13+x)]=10^mean(xx)-1
}}}

lfn.resamp.out=matrix(ncol=2,nrow=124)
for(y in 1:124){
lfn.resamp.out[y,]=quantile(lfn.resamp[,y],c(0.025,0.975),na.rm=TRUE)}

lfn.means
        [,1]     [,2]     [,3]     [,4]     [,5]      [,6]      [,7]     [,8]      [,9]     [,10]     [,11]     [,12]
[1,] 10.2855445 4.894333 3.504339 8.357553 3.3699133 14.725501 7.7085318 3.867230 4.79695952 6.387636 3.6503165 11.638484
```

```
[2,]  0.0000000 0.000000 0.000000 0.000000 0.0000000  0.000000 0.8697066 1.014821 1.15827562 2.248371 0.8776029  1.688176
[3,]  0.9888018 1.917802 1.398590 3.848247 0.8817933  2.346270 1.6860055 1.969827 1.88319918 2.848378 1.7249117  2.726846
[4,]  9.1466139 2.680164 1.956567 3.506607 2.2958581 11.754037 5.6329784 1.159939 2.27277192 5.868226 1.5458989  7.585929
[5,]  6.9254434 3.220701 2.997622 8.916806 1.3024514 12.616602 3.5310380 0.661934 1.28268793 2.295742 0.6173075  6.987971
[6,]  0.0000000 0.000000 0.000000 1.662322 0.7624073  0.000000 0.0000000 0.000000 0.05701804 0.234048 0.3531067  0.000000
[7,]  3.9319491 3.459533 4.566484 4.629517 2.6232363  4.986956 5.9598062 4.985612 7.14520546 5.702364 3.4251246  9.630504
[8,]  5.8444155 4.480131 5.101175 6.013758 3.2871807  8.962527 7.7008406 5.551271 7.80695630 6.797767 4.2317382 13.031248

write.table(lfn.resamp.out,"arca lfn bootstrap output.txt",row.names=FALSE)
write.table(arca.out,"arca quad level data.txt",row.names=FALSE)
write.table(lfn.means,"arca means.txt",row.names=FALSE)



    # diversity and richness without annuals
> raw.quad=read.delim("arca quadrat level community updated.txt")
> raw.site=read.delim("arca site level community updated.txt")

arca.richness=matrix(ncol=1,nrow=length(raw.quad[,1]))
arca.diversity=matrix(ncol=1,nrow=length(raw.quad[,1]))
library(vegetarian)

for(j in 1:length(raw.quad[,1])){
arca.richness[j]=d(raw.quad[j,4:47],q=0)
arca.diversity[j]=d(raw.quad[j,4:47],q=1)}


rich.resamp=matrix(nrow=10000,ncol=12)
div.resamp=matrix(nrow=10000,ncol=12)
for(x in 1:12){
div.temp=subset(arca.diversity,
as.factor(paste(raw.quad$Year,raw.quad$Site))==levels(as.factor(paste(raw.quad$Year,r
aw.quad$Site)))[x])
rich.temp=subset(arca.richness,
as.factor(paste(raw.quad$Year,raw.quad$Site))==levels(as.factor(paste(raw.quad$Year,r
aw.quad$Site)))[x])
for(k in 1:10000){
xx=sample(rich.temp,length(rich.temp),replace=TRUE)
rich.resamp[k,x]=10^mean(log10(xx))
xy=sample(div.temp,length(div.temp),replace=TRUE)
div.resamp[k,x]=10^mean(log10(xy))}}

resamp.out=matrix(ncol=4,nrow=12)
for(y in 1:12){
resamp.out[y,1:2]=(quantile(div.resamp[,y],c(0.025,0.975)))
resamp.out[y,3:4]=(quantile(rich.resamp[,y],c(0.025,0.975)))}

arca.gamma=matrix(nrow=12,ncol=43)
for(i in 4:46){arca.gamma[,i-
3]=tapply(raw.site[,i],(as.factor(paste(raw.site$Year,raw.site$Site))),sum)}

library(vegetarian)
rich.div=matrix(nrow=12,ncol=2)
```

```
for(x in 1:12){
rich.div[x,1]=d(arca.gamma[x,],q=0)
rich.div[x,2]=d(arca.gamma[x,],q=1)}


#Whole-site alpha level diversity and richness
arca.out=read.table("arca quad level data.txt",header=TRUE)
arca.gamma=matrix(nrow=12,ncol=67)
for(i in 4:70){arca.gamma[,i-
3]=tapply(arca.out[,i],(as.factor(paste(arca.out$Year,arca.out$Site))),sum)}

library(vegetarian)
rich.div=matrix(nrow=12,ncol=2)
for(x in 1:12){
rich.div[x,1]=d(arca.gamma[x,],q=0)
rich.div[x,2]=d(arca.gamma[x,],q=1)}

#######relationships between ARCA and environmental variables
env=read.delim("arca environment analysis.txt")
estimate.out=matrix(ncol=1,nrow=61)
pval.out=matrix(ncol=1,nrow=61)
for(i in 2:62){w=cor.test(env[,i],env$ARCA,method="spearman")
estimate.out[i-1,]=w$estimate
pval.out[i-1,]=w$p.value}
write.table(cbind(estimate.out,pval.out),"arca env corr.txt",row.names=FALSE)


##########Relationships Among Variables for ARCA (SAS)
```

```
proc import datafile="C:\Documents and Settings\cheryl vanier\My
Documents\UNLV\dianne\rare plant surveys\arca quad level data.txt"
out=raw replace; delimiter=' '; run;
data raw; set raw; yearsite=year||site; log10arca=log10(numarca+1);
log10diversity=log10(arca_diversity+1); log10a=log10(a+1);
log10p=log10(p+1);
log10s=log10(s+1);
log10total=log10(total+1); propa=a/total;
propp=p/total; props=s/total; log10propa=log10(propa+1);
log10propp=log10(propp+1);
log10props=log10(props+1); run;

proc gplot data=raw;
plot log10arca*log10diversity;
plot log10arca*arca_richness;
plot log10arca*log10a;
plot log10arca*log10p;
plot log10arca*log10s;
plot log10arca*log10total;
plot log10arca*propa;
plot log10arca*propp;
plot log10arca*props;
plot log10arca*log10propa;
plot log10arca*log10propp;
plot log10arca*log10props;
run;
```

```
proc gplot data=raw;
plot numarca*arca_diversity;
plot numarca*arca_richness;
plot numarca*a;
plot numarca*p;
plot numarca*s;
plot numarca*total;
run;
proc sort data=raw; by site year quadrat;

*full model;
proc mixed data=raw; class site year quadrat;
model log10arca=site|year
arca_richness arca_richness*site  arca_richness*year
arca_richness*site*year
log10diversity log10diversity*site log10diversity*year
log10diversity*site*year
log10propp log10propp*site log10propp*year  log10propp*site*year
log10props log10props*site log10props*year log10props*site*year
log10total  log10total*site log10total*year
log10total*site*year/solution;
repeated year/subject= quadrat(site) type=un;
ods output tests3=afullanva; run;
*reduced model;
proc mixed data=raw; class site year quadrat;
model log10arca=site|year
log10diversity log10diversity*site log10diversity*year
log10diversity*site*year
log10propp log10propp*site log10propp*year  log10propp*site*year
log10props log10props*site log10props*year log10props*site*year
log10total  log10total*site log10total*year log10total*site*year;
repeated year/subject= quadrat(site) type=un; ods output
tests3=areducedanva; run;
*effect sizes were estimated for each variable individually due to high
covariance in some sites but not others;
proc mixed data=raw; class site year quadrat;
model log10arca=site|year
arca_richness arca_richness*site  arca_richness*year
arca_richness*site*year;
repeated year/subject= quadrat(site) type=un;
lsmeans site|year/pdiff;
estimate 'blpo div 2008' arca_richness 1 arca_richness*site 1
arca_richness*year 1 arca_richness*site*year 1;
estimate 'gahi div 2008' arca_richness 1 arca_richness*site 0 1
arca_richness*year 1 arca_richness*site*year 0 0 1;
estimate 'gobu div 2008' arca_richness 1 arca_richness*site 0 0 1
arca_richness*year 1 arca_richness*site*year 0 0 0 0 1;
estimate 'rd100 div 2008' arca_richness 1 arca_richness*site 0 0 0 1
arca_richness*year 1 arca_richness*site*year 0 0 0 0 0 0 1;
estimate 'suhi div 2008' arca_richness 1 arca_richness*site 0 0 0 0 1
arca_richness*year 1 arca_richness*site*year 0 0 0 0 0 0 0 0 1;
estimate 'vfarca div 2008' arca_richness 1 arca_richness*site 0 0 0 0 0
1 arca_richness*year 1 arca_richness*site*year 0 0 0 0 0 0 0 0 0 0 1;
estimate 'blpo div 2009' arca_richness 1 arca_richness*site 1
arca_richness*year 0 1 arca_richness*site*year 0 1;
estimate 'gahi div 2009' arca_richness 1 arca_richness*site 0 1
arca_richness*year 0 1 arca_richness*site*year 0 0 0 1;
estimate 'gobu div 2009' arca_richness 1 arca_richness*site 0 0 1
arca_richness*year 0 1 arca_richness*site*year 0 0 0 0 0 1;
estimate 'rd100 div 2009' arca_richness 1 arca_richness*site 0 0 0 1
arca_richness*year 0 1 arca_richness*site*year 0 0 0 0 0 0 0 1;
```

```
estimate 'suhi div 2009' arca_richness 1 arca_richness*site 0 0 0 0 1
arca_richness*year 0 1 arca_richness*site*year 0 0 0 0 0 0 0 0 0 1;
estimate 'vfarca div 2009' arca_richness 1 arca_richness*site 0 0 0 0 0
1 arca_richness*year 0 1 arca_richness*site*year 0 0 0 0 0 0 0 0 0 0 0
1;
ods output estimates=est_richness; run;
proc mixed data=raw; class site year quadrat;
model log10arca=site|year log10diversity log10diversity*site
log10diversity*year log10diversity*site*year/solution;
*log10propp log10propp*site log10propp*year  log10propp*site*year
log10props log10props*site log10props*year log10props*site*year
log10total  log10total*site log10total*year log10total*site*year site
year/ solution;
repeated year/subject= quadrat(site) type=un;
estimate 'blpo div 2008' log10diversity 1 log10diversity*site 1
log10diversity*year 1 log10diversity*site*year 1;
estimate 'gahi div 2008' log10diversity 1 log10diversity*site 0 1
log10diversity*year 1 log10diversity*site*year 0 0 1;
estimate 'gobu div 2008' log10diversity 1 log10diversity*site 0 0 1
log10diversity*year 1 log10diversity*site*year 0 0 0 0 1;
estimate 'rd100 div 2008' log10diversity 1 log10diversity*site 0 0 0 1
log10diversity*year 1 log10diversity*site*year 0 0 0 0 0 0 1;
estimate 'suhi div 2008' log10diversity 1 log10diversity*site 0 0 0 0 1
log10diversity*year 1 log10diversity*site*year 0 0 0 0 0 0 0 0 1;
estimate 'vfarca div 2008' log10diversity 1 log10diversity*site 0 0 0 0
0 1 log10diversity*year 1 log10diversity*site*year 0 0 0 0 0 0 0 0 0 0
1;
estimate 'blpo div 2009' log10diversity 1 log10diversity*site 1
log10diversity*year 0 1 log10diversity*site*year 0 1;
estimate 'gahi div 2009' log10diversity 1 log10diversity*site 0 1
log10diversity*year 0 1 log10diversity*site*year 0 0 0 1;
estimate 'gobu div 2009' log10diversity 1 log10diversity*site 0 0 1
log10diversity*year 0 1 log10diversity*site*year 0 0 0 0 0 1;
estimate 'rd100 div 2009' log10diversity 1 log10diversity*site 0 0 0 1
log10diversity*year 0 1 log10diversity*site*year 0 0 0 0 0 0 0 1;
estimate 'suhi div 2009' log10diversity 1 log10diversity*site 0 0 0 0 1
log10diversity*year 0 1 log10diversity*site*year 0 0 0 0 0 0 0 0 0 1;
estimate 'vfarca div 2009' log10diversity 1 log10diversity*site 0 0 0 0
0 1 log10diversity*year 0 1 log10diversity*site*year 0 0 0 0 0 0 0 0 0
0 0 1;
lsmeans year|site/pdiff;
ods output estimates=est_biodiv; run;

proc mixed data=raw; class site year quadrat;
model log10arca= site|year
log10propp log10propp*site log10propp*year  log10propp*site*year;*
log10props log10props*site log10props*year log10props*site*year
log10total  log10total*site log10total*year log10total*site*year site
year/ solution;
repeated year/subject= quadrat(site) type=un;
estimate 'blpo propp 2008' log10propp 1 log10propp*site 1
log10propp*year 1 log10propp*site*year 1;
estimate 'gahi propp 2008' log10propp 1 log10propp*site 0 1
log10propp*year 1 log10propp*site*year 0 0 1;
estimate 'gobu propp 2008' log10propp 1 log10propp*site 0 0 1
log10propp*year 1 log10propp*site*year 0 0 0 0 1;
estimate 'rd100 propp 2008' log10propp 1 log10propp*site 0 0 0 1
log10propp*year 1 log10propp*site*year 0 0 0 0 0 0 1;
estimate 'suhi propp 2008' log10propp 1 log10propp*site 0 0 0 0 1
log10propp*year 1 log10propp*site*year 0 0 0 0 0 0 0 0 1;
```

```
estimate 'vfarca propp 2008' log10propp 1 log10propp*site 0 0 0 0 0 1
log10propp*year 1 log10propp*site*year 0 0 0 0 0 0 0 0 0 0 1;
estimate 'blpo propp 2009' log10propp 1 log10propp*site 1
log10propp*year 0 1 log10propp*site*year 0 1;
estimate 'gahi propp 2009' log10propp 1 log10propp*site 0 1
log10propp*year 0 1 log10propp*site*year 0 0 0 1;
estimate 'gobu propp 2009' log10propp 1 log10propp*site 0 0 1
log10propp*year 0 1 log10propp*site*year 0 0 0 0 0 1;
estimate 'rd100 propp 2009' log10propp 1 log10propp*site 0 0 0 1
log10propp*year 0 1 log10propp*site*year 0 0 0 0 0 0 0 1;
estimate 'suhi propp 2009' log10propp 1 log10propp*site 0 0 0 0 1
log10propp*year 0 1 log10propp*site*year 0 0 0 0 0 0 0 0 0 1;
estimate 'vfarca propp 2009' log10propp 1 log10propp*site 0 0 0 0 0 1
log10propp*year 0 1 log10propp*site*year 0 0 0 0 0 0 0 0 0 0 0 1;
lsmeans year|site/pdiff;
ods output estimates=est_propp ; run;
proc mixed data=raw; class site year quadrat;
model log10arca= site|year
log10props log10props*site log10props*year  log10props*site*year;*
log10props log10props*site log10props*year log10props*site*year
log10total  log10total*site log10total*year log10total*site*year site
year/ solution;
repeated year/subject= quadrat(site) type=un;
estimate 'blpo props 2008' log10props 1 log10props*site 1
log10props*year 1 log10props*site*year 1;
estimate 'gahi props 2008' log10props 1 log10props*site 0 1
log10props*year 1 log10props*site*year 0 0 1;
estimate 'gobu props 2008' log10props 1 log10props*site 0 0 1
log10props*year 1 log10props*site*year 0 0 0 0 1;
estimate 'rd100 props 2008' log10props 1 log10props*site 0 0 0 1
log10props*year 1 log10props*site*year 0 0 0 0 0 0 1;
estimate 'suhi props 2008' log10props 1 log10props*site 0 0 0 0 1
log10props*year 1 log10props*site*year 0 0 0 0 0 0 0 0 1;
estimate 'vfarca props 2008' log10props 1 log10props*site 0 0 0 0 0 1
log10props*year 1 log10props*site*year 0 0 0 0 0 0 0 0 0 0 1;
estimate 'blpo props 2009' log10props 1 log10props*site 1
log10props*year 0 1 log10props*site*year 0 1;
estimate 'gahi props 2009' log10props 1 log10props*site 0 1
log10props*year 0 1 log10props*site*year 0 0 0 1;
estimate 'gobu props 2009' log10props 1 log10props*site 0 0 1
log10props*year 0 1 log10props*site*year 0 0 0 0 0 1;
estimate 'rd100 props 2009' log10props 1 log10props*site 0 0 0 1
log10props*year 0 1 log10props*site*year 0 0 0 0 0 0 0 1;
estimate 'suhi props 2009' log10props 1 log10props*site 0 0 0 0 1
log10props*year 0 1 log10props*site*year 0 0 0 0 0 0 0 0 0 1;
estimate 'vfarca props 2009' log10props 1 log10props*site 0 0 0 0 0 1
log10props*year 0 1 log10props*site*year 0 0 0 0 0 0 0 0 0 0 0 1;
lsmeans year|site/pdiff;
ods output estimates=est_props; run;

proc mixed data=raw; class site year quadrat;
model log10arca= site|year
log10total log10total*site log10total*year  log10total*site*year;
repeated year/subject= quadrat(site) type=un;
estimate 'blpo total 2008' log10total 1 log10total*site 1
log10total*year 1 log10total*site*year 1;
estimate 'gahi total 2008' log10total 1 log10total*site 0 1
log10total*year 1 log10total*site*year 0 0 1;
estimate 'gobu total 2008' log10total 1 log10total*site 0 0 1
log10total*year 1 log10total*site*year 0 0 0 0 1;
```

```
estimate 'rd100 total 2008' log10total 1 log10total*site 0 0 0 1
log10total*year 1 log10total*site*year 0 0 0 0 0 0 1;
estimate 'suhi total 2008' log10total 1 log10total*site 0 0 0 0 1
log10total*year 1 log10total*site*year 0 0 0 0 0 0 0 0 1;
estimate 'vfarca total 2008' log10total 1 log10total*site 0 0 0 0 0 1
log10total*year 1 log10total*site*year 0 0 0 0 0 0 0 0 0 0 1;
estimate 'blpo total 2009' log10total 1 log10total*site 1
log10total*year 0 1 log10total*site*year 0 1;
estimate 'gahi total 2009' log10total 1 log10total*site 0 1
log10total*year 0 1 log10total*site*year 0 0 0 1;
estimate 'gobu total 2009' log10total 1 log10total*site 0 0 1
log10total*year 0 1 log10total*site*year 0 0 0 0 0 1;
estimate 'rd100 total 2009' log10total 1 log10total*site 0 0 0 1
log10total*year 0 1 log10total*site*year 0 0 0 0 0 0 0 1;
estimate 'suhi total 2009' log10total 1 log10total*site 0 0 0 0 1
log10total*year 0 1 log10total*site*year 0 0 0 0 0 0 0 0 0 1;
estimate 'vfarca total 2009' log10total 1 log10total*site 0 0 0 0 0 1
log10total*year 0 1 log10total*site*year 0 0 0 0 0 0 0 0 0 0 0 1;
lsmeans year|site/pdiff;
ods output estimates=est_total ; run;
*full model- check for heterogeneity by site;
data raw; set raw; if log10a=0 then log10a=""; if propa=0 then
propa="";
if log10propa=0 then log10propa=""; run;
data raw09; set raw; if year=2008 then delete; run;
proc mixed data=raw09; class site quadrat;
model log10arca=site log10propa log10propa*site/solution;
repeated intercept/subject= quadrat(site) type=un;
estimate 'blpo proportion annuals 2009' log10propa 1 log10propa*site 1;
estimate 'gahi proportion annuals 2009' log10propa 1 log10propa*site 0
1;
estimate 'gobu proportion annuals 2009' log10propa 1 log10propa*site 0
0 1;
estimate 'rd100 proportion annuals 2009' log10propa 1 log10propa*site 0
0 0 1;
estimate 'suhi proportion annuals 2009' log10propa 1 log10propa*site 0
0 0 0 1;
estimate 'vfarca proportion annuals 2009' log10propa 1 log10propa*site
0 0 0 0 0 1;
lsmeans site/pdiff;
ods output tests3=apropafullanva estimates=est_propa ;
run;

*reduced model and full model are the same;
proc export data=afullanva
outfile="C:\Documents and Settings\cheryl vanier\My
Documents\UNLV\dianne\rare plant surveys\arca ancovas.xls";
proc export data=areducedanva
outfile="C:\Documents and Settings\cheryl vanier\My
Documents\UNLV\dianne\rare plant surveys\arca ancovas.xls";
proc export data=apropafullanva
outfile="C:\Documents and Settings\cheryl vanier\My
Documents\UNLV\dianne\rare plant surveys\arca ancovas.xls";
proc export data=est_total
outfile="C:\Documents and Settings\cheryl vanier\My
Documents\UNLV\dianne\rare plant surveys\arca ancovas.xls";
proc export data=est_props
outfile="C:\Documents and Settings\cheryl vanier\My
Documents\UNLV\dianne\rare plant surveys\arca ancovas.xls";
proc export data=est_propp
```

```
outfile="C:\Documents and Settings\cheryl vanier\My
Documents\UNLV\dianne\rare plant surveys\arca ancovas.xls";
proc export data=est_biodiv
outfile="C:\Documents and Settings\cheryl vanier\My
Documents\UNLV\dianne\rare plant surveys\arca ancovas.xls";
proc export data=est_propa
outfile="C:\Documents and Settings\cheryl vanier\My
Documents\UNLV\dianne\rare plant surveys\arca ancovas.xls";
proc export data=est_richness
outfile="C:\Documents and Settings\cheryl vanier\My
Documents\UNLV\dianne\rare plant surveys\arca ancovas.xls";


proc import datafile="C:\Documents and Settings\cheryl vanier\My
Documents\UNLV\dianne\rare plant surveys\arca seed.xls"
out=seed replace; sheet="arca seed"; run;
proc sort data=seed;by year site sizeclass seeded;
*separated years because seeding was not measured in some sites in
2008;
*used success at the plot rather than quadrat level due to very few
plants available in the latter;
proc means data=seed n sum; class year site plot sizeclass; var seeded;
output out=seed_sum n(seeded)=n_seed sum(seeded)=sum_seed; run;
data seed_sum; set seed_sum; if _type_<15 then delete; run;
proc glimmix data=seed_sum; by year;
class site sizeclass;
model sum_seed/n_seed=site sizeclass;
lsmeans site sizeclass/pdiff ilink;
ods output lsmeans=sizelsmnoint diffs=sizedfsnoint tests3=sizemodelmin;
run;
proc means data=seed n sum; class year site sizeclass; var seeded;
output out=size_out n(seeded)=n_seed sum(seeded)=sum_seed; run;

proc export data=sizelsm
outfile="C:\Documents and Settings\cheryl vanier\My
Documents\UNLV\dianne\rare plant surveys\arca catmod.xls";
proc export data= sizelsmnoint
outfile="C:\Documents and Settings\cheryl vanier\My
Documents\UNLV\dianne\rare plant surveys\arca catmod.xls";
proc export data=sizedfsnoint
outfile="C:\Documents and Settings\cheryl vanier\My
Documents\UNLV\dianne\rare plant surveys\arca catmod.xls";
proc export data=sizedfs
outfile="C:\Documents and Settings\cheryl vanier\My
Documents\UNLV\dianne\rare plant surveys\arca catmod.xls";
proc export data=sizemodel
outfile="C:\Documents and Settings\cheryl vanier\My
Documents\UNLV\dianne\rare plant surveys\arca catmod.xls";
proc export data= sizemodelmin
outfile="C:\Documents and Settings\cheryl vanier\My
Documents\UNLV\dianne\rare plant surveys\arca catmod.xls";
run;


proc means data=seed n sum; class year site plot sizeclass condition;
var seeded;
output out=seed_sum n(seeded)=n_seed sum(seeded)=sum_seed; run;
data seed_sum; set seed_sum; if _type_<31 then delete; run;
proc sort data=seed_sum; by year site sizeclass condition;
proc glimmix data=seed_sum; by year;
class site condition sizeclass;
```

```
model sum_seed/n_seed=site condition|sizeclass ;
lsmeans site condition|sizeclass/pdiff ilink;
ods output lsmeans=bothlsm diffs=bothdfs tests3=bothanova; run;
proc means data=seed n sum; class year site condition; var seeded;
output out=condition_out n(seeded)=n_seed sum(seeded)=sum_seed; run;

proc export data=bothlsm
outfile="C:\Documents and Settings\cheryl vanier\My
Documents\UNLV\dianne\rare plant surveys\arca catmod.xls";
proc export data=bothdfs
outfile="C:\Documents and Settings\cheryl vanier\My
Documents\UNLV\dianne\rare plant surveys\arca catmod.xls";
proc export data=bothanova
outfile="C:\Documents and Settings\cheryl vanier\My
Documents\UNLV\dianne\rare plant surveys\arca catmod.xls";
run;
```

APPENDIX 7.

ANLE Analysis
C. Vanier 3/29/10
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702-630-3902

Report

Climate variables

Rainfall, vapor density, and temperatures were quantified using monthly minima, maxima, mean, and interquartile range (iqr). Only months which had a complete set of data were used for a particular site.

ANLE

Methods

Total cover, richness, diversity, and the relative representation of life forms were estimated by mean values. Diversity was expressed as the numbers equivalent (aka effective number of species), but calculations used the $\log_{10}$ transform of this value (Jost 2006), which was back-transformed for reporting. All other values were $\log_{10}$ transformed prior to estimation of the mean and confidence intervals, and back-transformed in the report. Confidence intervals using the normal distribution tended to underestimate the 95% confidence interval, so bootstrapped estimates based on 10,000 resamples are reported. All analysis was completed in R 2.10.0 (R Development Core Team 2009), and diversity and species richness were estimated using the 'vegetarian' package (Jost 2006).

Three sites were available for examining patterns with climate variables, so formal testing of the relationships between plants and these variables was not possible. Simple congruence of ranks between a certain plant variable and a given climate variable was taken as a suggestion of an association which might be the target of further study.

The potential relationships between quadrat-level species richness, species diversity, relative proportion of annual cover, relative proportion of perennial cover, relative proportion of shrub cover, and total cover (all except richness were $\log_{10}+1$ transformed to meet model expectations) and the number of ANLE individuals ($\log_{10}+1$ transformed) were fit using a mixed model ANOVA. A generalized linear model is more appropriate for these data (O'Hara and Kotze 2010), but no stable solution could be obtained in this situation, most likely a consequence of the sample size in conjunction with the model's complexity. The model included quadrat within site as a subject effect, and a covariance matrix with compound symmetry (optimized by corrected Akaike information criterion; AICC). Fixed effects were site, year, site by year, and each continuous independent variable above (except proportion of annuals) with year, site, and year by site interactions to examine heterogeneity of slopes. Spatial arrangement of quadrats was not available in this case, so this information was not incorporated into the analysis. The relative proportion of annual cover was analyzed in a separate model because these data were not available in 2008. The minimum adequate model was determined by comparing nested models using AICC. Although significance was determined in the full model, slopes and least-squares means (lsmeans) were estimated in a model containing the categorical effects of site and year and the continuous independent variable of interest, with all possible interactions among them. Covariance among variables was not consistent across sites, yielding misleading coefficients when the slopes were estimated from the full model. This analysis was performed in SAS v9.1 (SAS Institute 2002-2003) 'proc mixed'.

The effect of a plant's size on bolting success was modeled in a generalized linear model (glm) with binomial error. Size was estimated by the number of stems and number of leaves on each plant surveyed. The number of leaves was not noted in 2008, so the two size variables were handled in different models, although it should be noted that the two variables were moderately correlated (Spearman rank correlation (rho=0.596, n=113, P<0.0001). Numbers of leaves and stems provided sparse coverage of large portions of the function relating these variables to bolting success, so plants were grouped into those containing 1-10 stems (leaves) and greater than 11 stems (leaves). Success in bolting was modeled separately for each site and year because some sites did not have sufficient samples to estimate some parameters and some plants were measured in both years while others were not. The size variable was the fixed effect. For reporting, response values were back-transformed to provide the lsmean and standard error (SE) for the proportion bolting for each treatment.

Results: Tables are located in 'anle tables.xls'. Code and selected output are below. Supporting information such as the pairwise contrast output and results from models are available in the output file. General patterns are reviewed below.

Total cover was consistent between years and was under 10% in all three sites, but there was some variation among the three sites (Table 1). The relative make-up of total cover was consistent between years for shrubs and perennials. Annuals were not measured in both years, but in 2009 less than 10% of all vegetative cover was annuals (Table 2). Percent cover of ANLE was also consistent between years, and was relatively equal among sites (Table 1). Annuals were not included in sampling 2008, so the numbers for overall diversity and richness for this year are slightly low. Richness and diversity values with and without annuals are presented, but annuals represented such a small portion of cover that results were unchanged. Species diversity and richness did not differ between years in RD100 and SUHI, and the relative magnitude of those values suggests high evenness among species represented (Table 1). Richness and diversity increased in 2009 relative to 2008 in the VFAnle site at the quadrat level.

At the whole-plot level, annuals disproportionately contributed to species richness relative to their cover in 2009, but not 2008, for RD100 and SUHI (Table 1). When annuals were excluded, the diversity values relative to richness at the whole-plot level suggested high species evenness in RD100, moderate species evenness in SUHI, and fairly low species evenness in VFAnle (due to YUCUTA and SPOAIR). The average cover by quadrat is provided in the 'vegetative community' tab of the output file to help interpret these results.

Several environmental variables were congruent in rank with plant variables in 2009 (Table 3). The proportion of annuals matched with the minimum temperature during three months. The proportion of perennials, total cover, and cover of ANLE all ranked the same as variation in temperature (IQR=interquartile range) and vapor density during several months, maximum vapor density during July, and rainfall in July. Diversity and richness values matched with minimum, maximum and average vapor density, in addition to variation in temperature. More data are needed to verify these patterns.

Many of the measures describing the biotic community had a significant relationship with the number of ANLE on a local scale. The relationship between ANLE numbers and species diversity (both linear and quadratic portions), proportion of perennials, proportion of shrubs, and total cover varied significantly by site and year (Table 4). Species richness did not significantly predict ANLE numbers, alone or within sites or years. The proportion of annuals was related to ANLE in different ways among sites in 2009 (Table 4).

Slopes were estimated for each biotic community variable alone to avoid misleading coefficients. Trends are reviewed below; some are significant, while others are notable for their consistency in trends across sites. Diversity was not strongly related to ANLE in SUHI, but for the other two sites, the relationship was strongly concave, with low and high extreme values of diversity being associated with low numbers of ANLE. Intermediate levels of diversity were associated with higher numbers of ANLE in RD100 and VFAnle (Table 5). The relationship between the number of ANLE and the proportion of annual species had a negative trend in RD100, but not in the other two sites. The proportion of perennials was a positive predictor of ANLE in 2008 for RD100 and SUHI, but this relationship was weak, absent or negative in 2009 and for VFAnle in both years. Because shrub cover was negatively correlated with perennial cover, we observed a negative relationship between proportion shrubs and number of ANLE for RD100 and SUHI in 2008, but weak or positive coefficients for 2009 and VFAnle (Table 5). The coefficients are provided for species richness, although their magnitude corroborates the ANCOVA result that richness was not a strong determinant of ANLE numbers. Total cover did not have a strong relationship with ANLE numbers, probably due to the low cover overall (Table 1).

The size of plants played a significant role in predicting bolting success across all sites as evaluated by AICC (supplementary material). Smaller plants’ bolting success was highly dependent on the site, ranging from a low of 8% in 2008 SUHI to a high of 76% in RD100 in 2008 (Table 6). Larger plants also varied by site, with a low of 57% in SUHI and a high of 100% in RD100. We observed significant temporal variation in SUHI but not in RD100. The number of leaves as a measure of size provided similar estimates of bolting success for 2009 (Table 7). It is notable that although the plants at the VFAnle site were substantially smaller than those in SUHI (Table 8), their bolting success was similar. The plants in the RD100 site were both larger (Table 8) and had greater bolting success than plants living in the other two sites (Tables 6, 7).

Table 1. Summary of mean and bootstrapped 95% confidence limits (CL) of quadrat-level and whole-plot measurements at sites containing ANLE. Cover values are expressed as percent cover in the plot. Diversity is back-transformed to Hill's number, richness is average number of species (for quadrat) or total number of species in the site (whole-plot). Non-overlapping confidence intervals between years are denoted by '*'.

		2008		2009		Sig.
	Site	Mean	95% CL	Mean	95% CL	diff
Total Cover	RD100	8.38	6.02,11.61	6.39	4.89,8.44	
	SUHI	3.27	2.26,4.67	3.65	2.66,5.02	
	VFAnle	5.84	4.81,7.21	4.84	4.34,5.35	
Annual cover	RD100	0.03	0,0.08	0.27	0.09,0.51	*
	SUHI	0.00	0,0	0.30	0.15,0.48	*
	VFAnle	0.00	0,0	0.14	0.07,0.23	*
Perennial cover	RD100	3.83	2.84,5.06	2.94	2.40,3.59	
	SUHI	0.86	0.70,1.01	0.91	0.72,1.09	
	VFAnle	1.65	1.16,2.40	1.78	1.52,2.08	
Shrub cover	RD100	3.51	2.01,5.82	2.79	1.81,4.21	
	SUHI	2.18	1.28,3.50	2.22	1.46,3.38	
	VFAnle	3.61	2.92,4.56	2.78	2.45,3.14	
ANLE cover	RD100	1.66	0.99,2.54	1.68	1.13,2.35	
	SUHI	0.84	0.45,1.40	0.67	0.30,1.19	
	VFAnle	0.69	0.34,1.15	1.17	0.72,1.83	
Hill diversity	RD100	4.66	4.00,5.38	5.70	4.88,6.61	
	SUHI	2.60	2.20,3.00	3.43	2.91,3.99	
	VFAnle	4.76	4.05,5.48	6.96	6.13,7.82	*
Richness	RD100	6.05	5.16,7.06	6.80	5.68,8.09	
	SUHI	3.24	2.73,3.76	4.23	3.55,4.94	
	VFAnle	6.32	5.74,6.93	7.71	6.88,8.57	
Hill diversity (Annuals excluded)	RD100	4.59	3.93,5.32	5.25	4.58,6.01	
	SUHI	2.60	2.22,3.01	2.92	2.53,3.33	
	VFAnle	4.76	4.06,5.48	6.69	5.96,7.46	*
Richness (Annuals excluded)	RD100	5.95	5.03,6.98	6.28	5.34,7.35	
	SUHI	3.24	2.74,3.75	3.58	3.07,4.11	
	VFAnle	6.32	5.74,6.95	7.42	6.70,8.20	
Whole-plot diversity	RD100	13.26		17.50		
	SUHI	4.52		6.71		
	VFAnle	7.69		13.35		
Whole-plot richness	RD100	18.00		27.00		
	SUHI	9.00		19.00		
	VFAnle	17.00		23.00		
Whole-plot diversity (Annuals excluded)	RD100	13.04		14.83		
	SUHI	4.52		4.95		
	VFAnle	7.69		12.13		
Whole-plot richness (Annuals excluded)	RD100	16.00		18.00		
	SUHI	9.00		9.00		
	VFAnle	17.00		20.00		

Table 2. Proportional representation for each life form as a function of total cover. These were the values used for deriving ranks for comparison with the climate data to avoid confounding total cover with individual categories' representation.

	a		p		s	
site	2008	2009	2008	2009	2008	2009
RD100	0.01	0.05	0.52	0.49	0.42	0.43
SUHI	0	0.09	0.35	0.29	0.58	0.58
VFAnle	0	0.03	0.30	0.37	0.66	0.58

Table 3. Listing of congruent order by site for plant variables and climate variables by month. Numbers denote months (e.g., 5=May) in 2009. Dates analyzed include months 2-9 for all variables except rainfall, which included only months 5-8.

Plant variable	**Environment**
Proportion annuals	Min temp (5,7,8)
Proportion perennials, Total cover, ANLE cover	IQR temp (3,6)
	Max vd (7)
	IQR vd (4,5)
	Rainfall (7)
Proportion shrubs	Min temp (3,4,6,9)
	Mean temp (3,5,8)
	Max vd (3)
Diversity, Richness	IQR temp (4,5,8)
	Min vd (2)
	Max vd (2,4,5,6,8)
	Mean vd (2,3,4)
	IQR vd (2,6,8)

Table 4. ANOVA results predicting presence of ANLE (log_{10}-transformed +1) for species richness and log_{10}+1 transformed diversity, relative proportion of perennial cover, relative proportion of shrub cover, and total cover. Model included quadrat as the subject effect and a compound symmetry covariance structure (determined by AICC). Proportion of annuals was treated alone because this variable was not reliably measured the first year of the study (2008). The minimum adequate model was based on AICC.

	Full model			Reduced model		
Effect	df	FValue	P-value	df	FValue	P-value
Site	2,72	0.11	0.8936	2,72	0.31	0.7318
Year	1,35	1.46	0.2356	1,41	4.18	0.0474
Site*Year	2,35	0.58	0.5650	2,41	1.22	0.3056
Richness	1,35	0.80	0.3771			
Richness*Site	2,35	0.25	0.7786			
Richness*Year	1,35	0.44	0.5107			
Richness*Site*Year	2,35	0.08	0.9256			
Diversity	1,35	0.01	0.9113	1,41	2.88	0.0970
Diversity*Site	2,35	0.52	0.5970	2,41	1.51	0.2326
Diversity*Year	1,35	0.43	0.5186	1,41	5.27	0.0269
Diversity*Site*Year	2,35	0.13	0.8777	2,41	0.69	0.5074
Diversity2	1,35	5.64	0.0232	1,41	5.33	0.0260
Diversity2*Site	2,35	1.03	0.3686	2,41	1.28	0.2902
Diversity2*Year	1,35	1.57	0.2192	1,41	0.62	0.4372
Diversity2*Site*Year	2,35	0.80	0.4593	2,41	0.57	0.5700
Prop_Perennials	1,35	0.80	0.3769	1,41	0.21	0.6523
Prop_Perennials*Site	2,35	0.54	0.5859	2,41	0.13	0.8763
Prop_Perennials*Year	1,35	0.16	0.6885	1,41	0.31	0.5810
Prop_Perennials*Site*Year	2,35	0.28	0.7545	2,41	0.20	0.8224
Prop_Shrubs	1,35	0.46	0.5032	1,41	0.10	0.7511
Prop_Shrubs*Site	2,35	0.08	0.9202	2,41	0.07	0.9294
Prop_Shrubs*Year	1,35	1.25	0.2707	1,41	1.51	0.2256
Prop_Shrubs*Site*Year	2,35	0.77	0.4717	2,41	0.65	0.5273
Total Cover	1,35	0.18	0.6751	1,41	0.14	0.7090
Total Cover*Site	2,35	0.29	0.7495	2,41	0.15	0.8589
Total Cover*Year	1,35	0.11	0.7396	1,41	0.27	0.6041
Total Cover*Site*Year	2,35	0.01	0.9898	2,41	0.58	0.5667

Effect	df	FValue	P-value
Site	2,69	3.46	0.0370
Prop_Annuals	1,69	0.03	0.8549
Prop_Annuals*Site	2,69	0.56	0.5750

Table 5. Slopes, slope SE, and P-values for testing slope significance relative to zero. Estimates were derived from the model in Table 4 for each continuous predictor variable individually to avoid misleading coefficient signs or magnitudes. The exception to this is the quadratic term for Hill diversity, which was fit with the linear Hill diversity term present.

Variable	Year	Site	Slope	SE	DF	tValue	P (slope=0)
Hill diversity- linear	2008	RD100	-0.020	0.345	59	-0.06	0.9533
Hill diversity- linear	2009	RD100	0.823	0.489	59	1.68	0.0978
Hill diversity- linear	2008	SUHI	-0.177	1.022	59	-0.17	0.8631
Hill diversity- linear	2009	SUHI	0.068	0.458	59	0.15	0.8827
Hill diversity- linear	2008	VFAnle	0.075	0.337	59	0.22	0.8251
Hill diversity- linear	2009	VFAnle	1.323	0.677	59	1.95	0.0554
Hill diversity- quadratic	2008	RD100	-2.050	1.512	59	-1.36	0.1803
Hill diversity- quadratic	2009	RD100	-4.007	2.026	59	-1.98	0.0526
Hill diversity- quadratic	2008	SUHI	-0.435	2.269	59	-0.19	0.8487
Hill diversity- quadratic	2009	SUHI	-0.231	1.560	59	-0.15	0.8828
Hill diversity- quadratic	2008	VFAnle	-2.678	1.551	59	-1.73	0.0895
Hill diversity- quadratic	2009	VFAnle	-3.692	2.311	59	-1.60	0.1155
Proportion annuals	2009	RD100	-1.605	1.565	69	-1.03	0.3087
Proportion annuals	2009	SUHI	0.363	1.162	69	0.31	0.7556
Proportion annuals	2009	VFAnle	0.603	2.883	69	0.21	0.8350
Proportion perennials	2008	RD100	0.978	0.516	65	1.89	0.0628
Proportion perennials	2009	RD100	0.670	0.705	65	0.95	0.3453
Proportion perennials	2008	SUHI	0.931	0.432	65	2.15	**0.0349**
Proportion perennials	2009	SUHI	0.223	0.605	65	0.37	0.7141
Proportion perennials	2008	VFAnle	-0.528	0.661	65	-0.80	0.4275
Proportion perennials	2009	VFAnle	-1.007	1.226	65	-0.82	0.4146
Proportion shrubs	2008	RD100	-0.856	0.472	65	-1.81	0.0743
Proportion shrubs	2009	RD100	-0.572	0.650	65	-0.88	0.3819
Proportion shrubs	2008	SUHI	-0.910	0.425	65	-2.14	**0.0359**
Proportion shrubs	2009	SUHI	0.120	0.574	65	0.21	0.8354
Proportion shrubs	2008	VFAnle	0.686	0.670	65	1.02	0.3098
Proportion shrubs	2009	VFAnle	1.624	1.328	65	1.22	0.2257
Richness	2008	RD100	0.000	0.020	65	0.01	0.9907
Richness	2009	RD100	0.002	0.015	65	0.14	0.8876
Richness	2008	SUHI	-0.018	0.035	65	-0.52	0.6030
Richness	2009	SUHI	0.021	0.024	65	0.85	0.3968
Richness	2008	VFAnle	-0.019	0.027	65	-0.70	0.4885
Richness	2009	VFAnle	0.005	0.020	65	0.27	0.7907
Total cover	2008	RD100	-0.085	0.158	65	-0.54	0.5903
Total cover	2009	RD100	-0.070	0.196	65	-0.36	0.7210
Total cover	2008	SUHI	-0.082	0.151	65	-0.55	0.5862
Total cover	2009	SUHI	0.091	0.169	65	0.54	0.5936
Total cover	2008	VFAnle	-0.287	0.195	65	-1.47	0.1460
Total cover	2009	VFAnle	0.100	0.393	65	0.25	0.7997

Table 6 Least squares means and SE for proportions bolting for two size classes (measured by number of stems) of plants for three sites and two years. No plants larger than ten stems were present in VFAnle either year. There was a significant difference between years in SUHI but not RD100, and there was a significant effect of the number of stems in both sites.

Site	Year	Bolting 0-10 stems	SE	Bolting >11 stems	SE
RD100	2008	0.76	0.10	1.00	0.00
RD100	2009	0.72	0.11	1.00	0.00
SUHI	2008	0.08	0.06	0.57	0.19
SUHI	2009	0.29	0.07	0.89	0.10
VFAnle	2008	0.34	0.08		
VFAnle	2009	0.24	0.07		

Table 7 Least squares means and SE for proportions bolting for two size classes (measured by number of leaves) of plants for three sites in 2009. There was a significant difference between the two size classes (number of leaves) in SUHI and VFAnle, but not in RD100.

Site	Bolting 0-10 leaves	SE	Bolting >11 leaves	SE
RD100	0.79	0.07	0.89	0.07
SUHI	0.32	0.06	0.56	0.09
VFAnle	0.19	0.05	0.50	0.14

Table 8 Summary of mean and bootstrapped 95% confidence limits (CL) for the numbers of leaves and stems at each site in each year they were measured. These are intended as a reference for Tables 6-7.

		2008		2009	
	Site	Mean	95% CL	Mean	95% CL
Leaves	RD100			8.07	6.75,9.60
	SUHI			7.77	6.19,9.87
	VFAnle			6.75	5.75,8.02
Stems	RD100	5.28	3.40,7.77	7.40	5.49,9.76
	SUHI	2.53	1.36,4.39	2.79	1.77,4.24
	VFAnle	1.01	0.53,1.66	1.40	0.93,1.97

Literature cited

Jost, L. 2006. Entropy and diversity. Oikos 113(2): 363-375.

O'Hara, R.B. and D.J. Kotze. 2010. Do not log-transform count data. Methods in Ecology and Evolution *in press.*

R Development Core Team. 2009. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

SAS Institute. 2002-2003. SAS v 9.1. Cary, NC.

Analysis notes: Environmental variables

Relative humidity was converted to vapor density by using the following to estimate saturated vapor density:

$6.335 + 0.6718Tc - 0.020887Tc^2 + 0.00073095Tc^3$

ANLE Analysis notes:

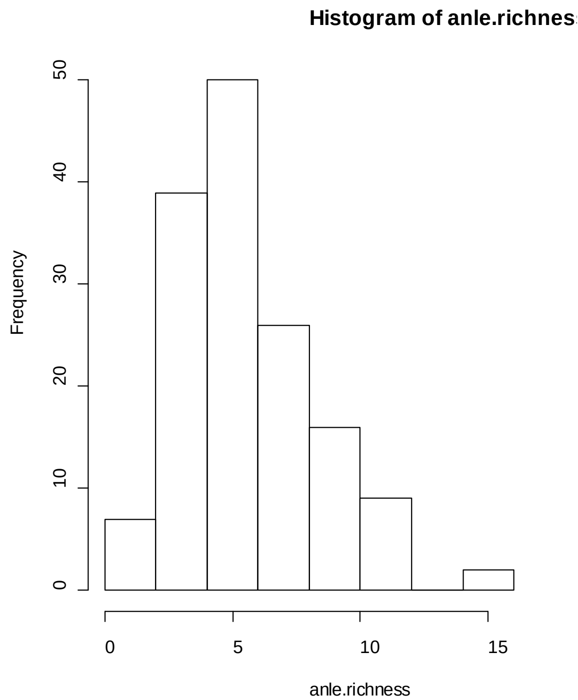
Relationship between quad-level variables and ASTGEY presence

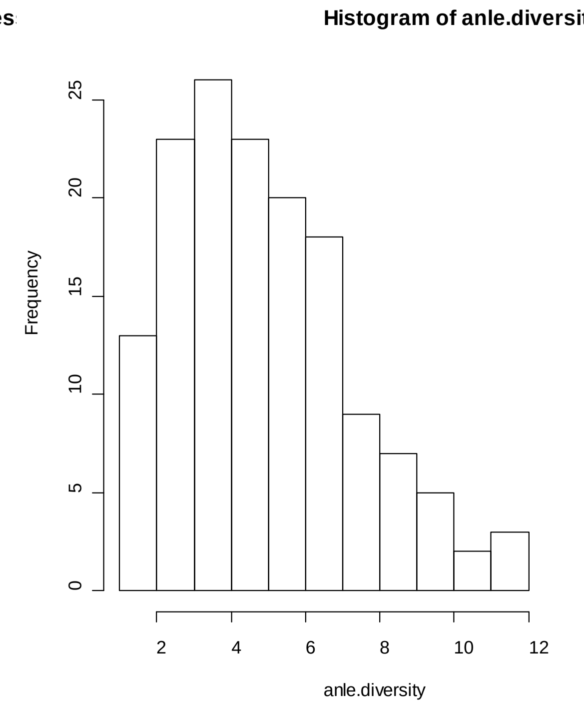
```
library(MASS)
raw=read.table("anle quad level data.txt",header=TRUE)
attach(raw)
table(Year,Site)
      Site
Year   RD100 SUHI VFAnle
  2008    25   24     25
  2009    25   25     25

#created diversity and species richness data sets for each site
anle.richness=matrix(ncol=1,nrow=length(raw[,1]))
anle.diversity=matrix(ncol=1,nrow=length(raw[,1]))
library(vegetarian)

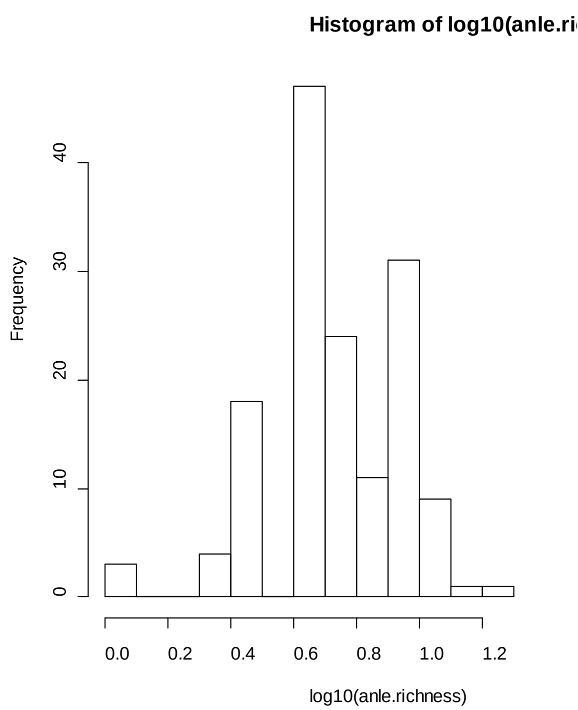
for(j in 1:length(raw[,1])){
anle.richness[j]=d(raw[j,4:54],q=0)
anle.diversity[j]=d(raw[j,4:54],q=1)}

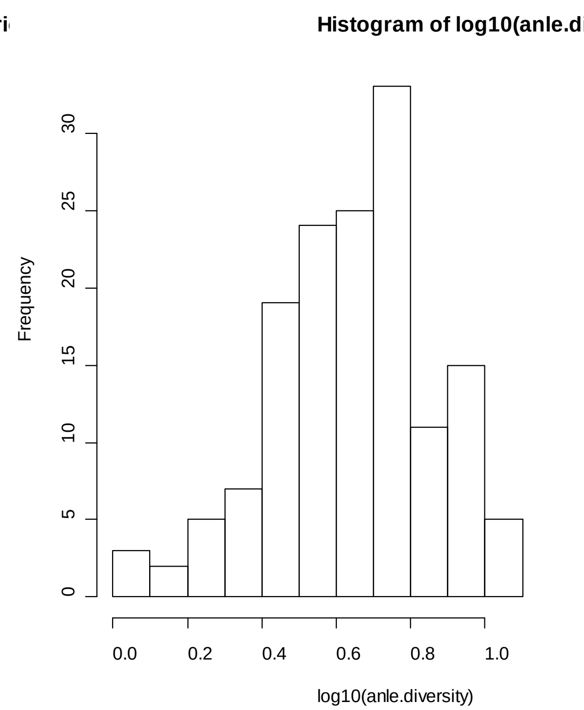
par(mfrow=c(1,2))
hist(anle.richness)
hist(anle.diversity)
```





#Both of these benefited from log transformation, below;
hist(log(anle.richness))
hist(log(anle.diversity))





Mean and bootstrapped 95% CI for log(diversity) and log(species richness) for each site/year.

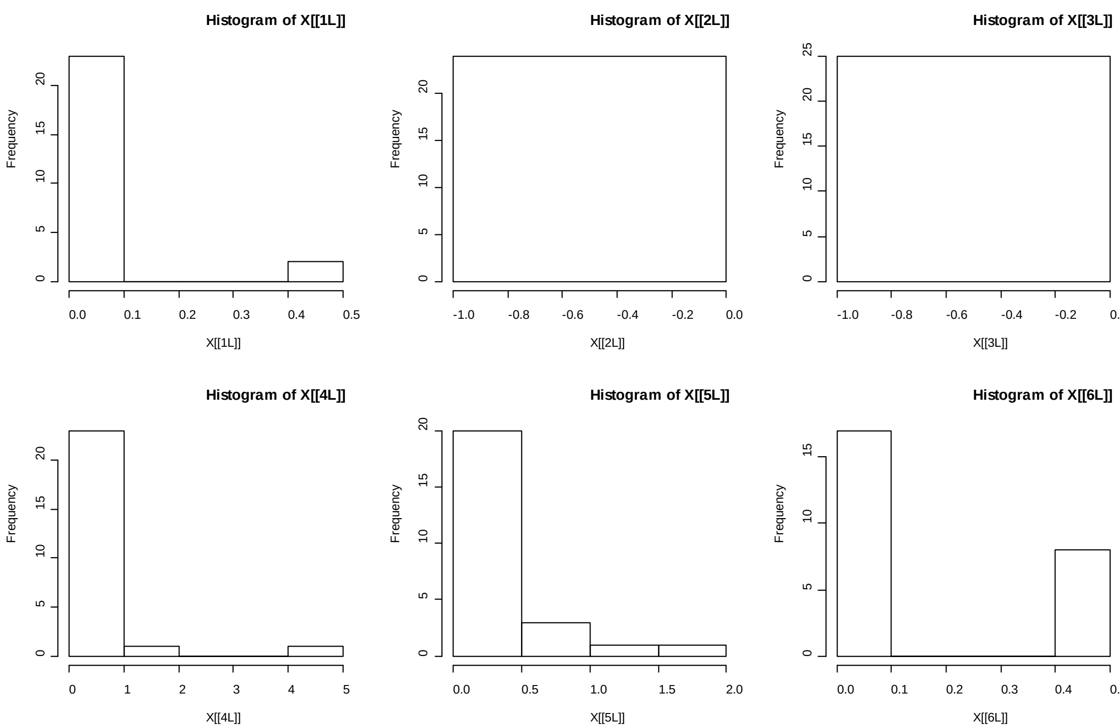
95% CI- bootstrapped values yielded a larger interval than the parametric CI, so I used the bootstrapped ones.

```
anle.out=as.data.frame(cbind(raw,anle.diversity,anle.richness,propa=a/totalcov,propp=p/totalcov,props=s/totalcov))
cor(anle.out[,55:64])
```

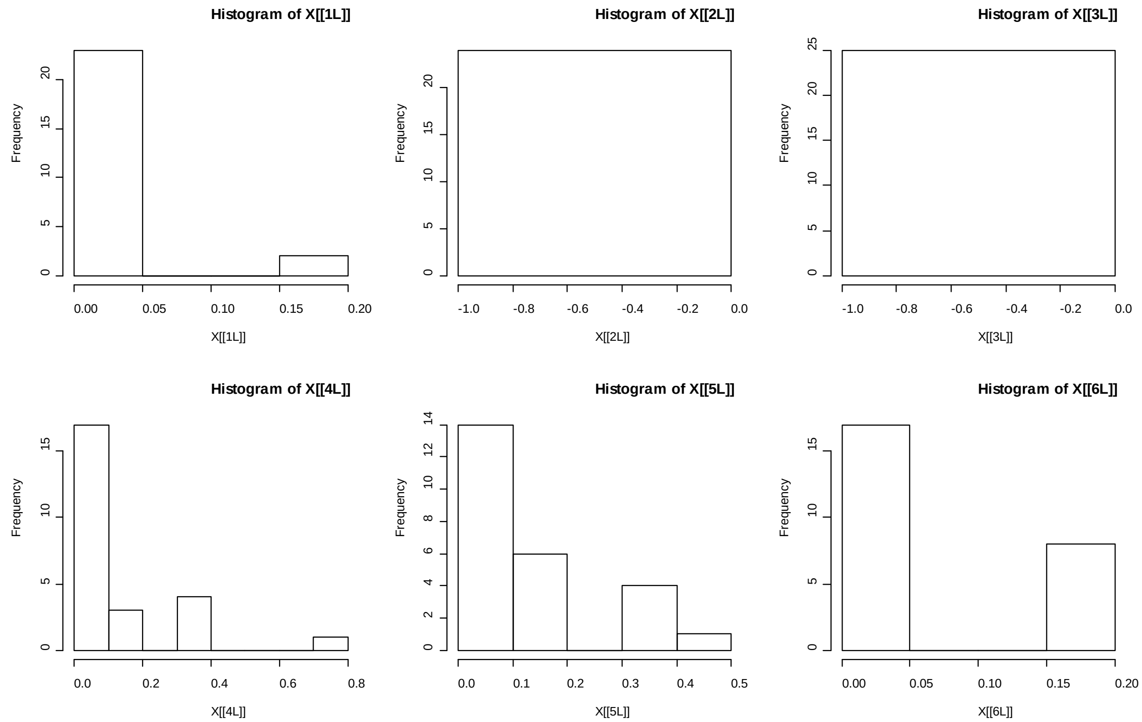
	totalcov	a	p	s	anle	anle.diversity	anle.richness	propa	propp
totalcov	1								
a	0.09	1							
p	**0.63**	-0.02	1						
s	**0.94**	0.03	0.32	1					
anle	-0.06	-0.04	0.09	-0.11	1				
anle.diversity	0.26	0.32	0.27	0.16	0.10	1			
anle.richness	**0.55**	0.36	0.41	0.45	0.07	**0.90**	1		
propa	-0.09	0.78	-0.11	-0.13	-0.03	0.22	0.16	1	
propp	-0.25	-0.13	0.38	-0.47	0.22	-0.06	-0.18	-0.07	1
props	0.28	-0.11	-0.33	0.50	-0.21	-0.03	0.12	-0.24	**-0.95**

Diversity and richness are be highly correlated, as are total cover with shrub cover, and the proportion of perennials is almost exactly inversely proportional to the proportion of shrubs; need to interpret output carefully.

```
par(mfrow=c(2,3))
tapply((raw$a),paste(raw$Year,raw$Site),hist)
```



```
par(mfrow=c(2,3))
tapply((log10(raw$a+1)),paste(raw$Year,raw$Site),hist)
```



#For this dataset, there is not a transform that will make the distribution symmetrical due to the large # of zeroes. Per the CLT, still used means, but required quantile bootstrap intervals to express error.

```
lfn.means=matrix(ncol=12,nrow=8)
lfn.resamp=matrix(nrow=10000,ncol=124)

for(l in 55:61){
lfn.means[l-54,]=10^tapply(log10(anle.out[,l]+1),(as.factor(paste(anle.out$Year,anle.out$Site))),mean)-1}

for(x in 1:6){
lfn.temp=subset(anle.out,
as.factor(paste(anle.out$Year,anle.out$Site))==levels(as.factor(paste(anle.out$Year,anle.out$Site)))[x])
for(k in 1:10000){
for(l in 55:61){
xx=sample(log10(lfn.temp[,l]+1),length(lfn.temp[,l]),replace=TRUE)
lfn.resamp[k,((l-54)*10+x)]=10^mean(xx)-1
}}}

lfn.resamp.out=matrix(ncol=2,nrow=124)
```

```
for(y in 1:124){
lfn.resamp.out[y,]=quantile(lfn.resamp[,y],c(0.025,0.975),na.rm=TRUE)}

lfn.means

write.table(lfn.resamp.out,"anle lfn bootstrap output.txt",row.names=FALSE)
write.table(anle.out,"anle quad level data.txt",row.names=FALSE)
write.table(lfn.means,"anle means.txt",row.names=FALSE)

#Whole-site alpha level diversity and richness
anle.out=read.table("anle quad level data.txt",header=TRUE)
anle.gamma=matrix(nrow=6,ncol=51)
for(i in 4:54){anle.gamma[,i-
3]=tapply(anle.out[,i],(as.factor(paste(anle.out$Year,anle.out$Site))),sum)}

library(vegetarian)
rich.div=matrix(nrow=6,ncol=2)
for(x in 1:6){
rich.div[x,1]=d(anle.gamma[x,],q=0)
rich.div[x,2]=d(anle.gamma[x,],q=1)}

> rich.div
     [,1]      [,2]
[1,]   18 13.258646
[2,]    9  4.519628
[3,]   17  7.690414
[4,]   27 17.502329
[5,]   19  6.707149
[6,]   23 13.345291

#quadrat level without annuals;
rawa=read.delim("anle quad level data no annuals.txt")

#created diversity and species richness data sets for each site
anle.richness=matrix(ncol=1,nrow=length(raw[,1]))
anle.diversity=matrix(ncol=1,nrow=length(raw[,1]))
library(vegetarian)

for(j in 1:length(rawa[,1])){
anle.richness[j]=d(rawa[j,4:38],q=0)
anle.diversity[j]=d(rawa[j,4:38],q=1)}

10^tapply(log10(anle.richness+1),(as.factor(paste(rawa$Year,rawa$Site))),mean)-1
10^tapply(log10(anle.diversity+1),(as.factor(paste(rawa$Year,rawa$Site))),mean)-1
```

```
lfn.resamp.div=matrix(nrow=10000,ncol=6)
lfn.resamp.rich=matrix(nrow=10000,ncol=6)
for(x in 1:6){
rich.temp=subset(anle.richness,
as.factor(paste(rawa$Year,rawa$Site))==levels(as.factor(paste(rawa$Year,rawa$Site)))[x
])
div.temp=subset(anle.diversity,
as.factor(paste(rawa$Year,rawa$Site))==levels(as.factor(paste(rawa$Year,rawa$Site)))[x
])
for(k in 1:10000){
xx=sample(log10(div.temp+1),length(div.temp),replace=TRUE)
lfn.resamp.div[k,x]=10^mean(xx)-1
xx2=sample(log10(rich.temp+1),length(rich.temp),replace=TRUE)
lfn.resamp.rich[k,x]=10^mean(xx2)-1
}}

lfn.resamp.out=matrix(ncol=4,nrow=6)
for(y in 1:6){
lfn.resamp.out[y,1:2]=quantile(lfn.resamp.div[,y],c(0.025,0.975),na.rm=TRUE)
lfn.resamp.out[y,3:4]=quantile(lfn.resamp.rich[,y],c(0.025,0.975),na.rm=TRUE)}
lfn.resamp.out


#whole plot without annuals
anle.gamma=matrix(nrow=6,ncol=35)
for(i in 4:38){anle.gamma[,i-
3]=tapply(rawa[,i],(as.factor(paste(rawa$Year,rawa$Site))),sum)}

library(vegetarian)
rich.div=matrix(nrow=6,ncol=2)
for(x in 1:6){
rich.div[x,1]=d(anle.gamma[x,],q=0)
rich.div[x,2]=d(anle.gamma[x,],q=1)}


anle.gamma2=matrix(nrow=6,ncol=51)
for(i in 4:54){anle.gamma2[,i-
3]=tapply(raw[,i],(as.factor(paste(rawa$Year,rawa$Site))),sum)}
library(vegetarian)

rich.div2=matrix(nrow=6,ncol=2)
for(x in 1:6){
rich.div2[x,1]=d(anle.gamma2[x,],q=0)
rich.div2[x,2]=d(anle.gamma2[x,],q=1)}

#proportion of annuals, shrubs, perennials
```

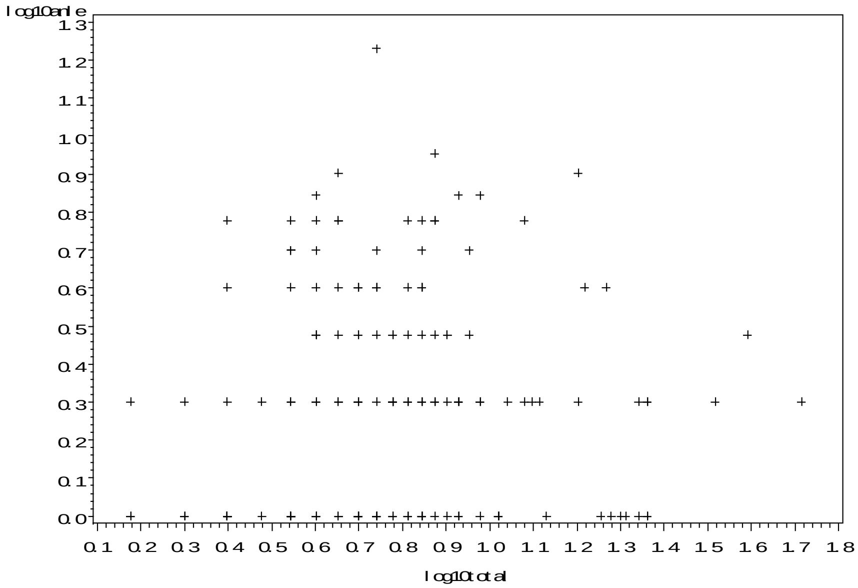
```
10^tapply(log10(anle.out$propa+1),(as.factor(paste(anle.out$Year,anle.out$Site))),mean)
-1
10^tapply(log10(anle.out$propp+1),(as.factor(paste(anle.out$Year,anle.out$Site))),mean)
-1
10^tapply(log10(anle.out$props+1),(as.factor(paste(anle.out$Year,anle.out$Site))),mean)
-1
```

#######relationships between ANLE and environmental variables
Used congruence of order (only 3 sites for 2009) in Excel.

##########Relationships Among Variables for ANLE (SAS)

```
proc import datafile="C:\Documents and Settings\cheryl vanier\My
Documents\UNLV\dianne\rare plant surveys\anle quad level data.txt"
out=raw replace; delimiter=' '; run;
data raw; set raw; yearsite=year||site; log10anle=log10(anle+1);
log10diversity=log10(anle_diversity+1); log10a=log10(a+1);
log10p=log10(p+1);
log10s=log10(s+1);
log10total=log10(totalcov+1); log10propa=log10(propa+1);
log10propp=log10(propp+1);
log10props=log10(props+1); run;

proc gplot data=raw;
plot log10anle*log10diversity;
plot log10anle*anle_richness;
plot log10anle*log10a;
plot log10anle*log10p;
plot log10anle*log10s;
plot log10anle*log10total;
plot log10anle*propa;
plot log10anle*propp;
plot log10anle*props;
plot log10anle*log10propa;
plot log10anle*log10propp;
plot log10anle*log10props;
run;
```




```
include log10total quadratic term;

proc means data=raw mean; var log10diversity; run;
data raw; set raw; cent_log10diversity=log10diversity=0.7415129; run;

proc sort data=raw; by site year quadrat;
proc glimmix data=raw; class site year quadrat;
model anle=site|year
anle_richness anle_richness*site  anle_richness*year
anle_richness*site*year
log10diversity log10diversity*site log10diversity*year
log10diversity*site*year
cent_log10diversity*cent_log10diversity
cent_log10diversity*cent_log10diversity*site
cent_log10diversity*cent_log10diversity*year
cent_log10diversity*cent_log10diversity*year*site
log10propp log10propp*site log10propp*year  log10propp*site*year
log10props log10props*site log10props*year log10props*site*year
log10total  log10total*site log10total*year
log10total*site*year/dist=poisson;
random year/subject= quadrat(site) type=cs;
*ods output tests3=afullanva; run;

proc mixed data=raw; class site year quadrat;
model log10anle=site|year
log10diversity log10diversity*site log10diversity*year
log10diversity*site*year
cent_log10diversity*cent_log10diversity
cent_log10diversity*cent_log10diversity*site
cent_log10diversity*cent_log10diversity*year
cent_log10diversity*cent_log10diversity*year*site
log10propp log10propp*site log10propp*year  log10propp*site*year
log10props log10props*site log10props*year log10props*site*year
log10total  log10total*site log10total*year log10total*site*year;
repeated year/subject= quadrat(site) type=cs;
```

```
ods output tests3=areducedanva; run;

*effect sizes were estimated for each variable individually due to high
covariance in some sites but not others;
proc mixed data=raw; class site year quadrat;
model log10anle=site|year
anle_richness anle_richness*site  anle_richness*year
anle_richness*site*year;
repeated year/subject= quadrat(site) type=cs;
estimate 'rd100 rich 2008' anle_richness 1 anle_richness*site 1
anle_richness*year 1 anle_richness*site*year 1;
estimate 'suhi rich 2008' anle_richness 1 anle_richness*site 0 1
anle_richness*year 1 anle_richness*site*year 0 0 1;
estimate 'vfanle rich 2008' anle_richness 1 anle_richness*site 0 0 1
anle_richness*year 1 anle_richness*site*year 0 0 0 0 1;
estimate 'rd100 rich 2009' anle_richness 1 anle_richness*site 1
anle_richness*year 0 1 anle_richness*site*year 0 1;
estimate 'suhi rich 2009' anle_richness 1 anle_richness*site 0 1
anle_richness*year 0 1 anle_richness*site*year  0 0 0 1;
estimate 'vfanle rich 2009' anle_richness 1 anle_richness*site 0 0 1
anle_richness*year 0 1 anle_richness*site*year 0 0 0 0 0 1;
ods output estimates=est_richness; run;



proc mixed data=raw; class site year quadrat;
model log10anle=site|year
log10diversity log10diversity*site log10diversity*year
log10diversity*site*year
cent_log10diversity*cent_log10diversity
cent_log10diversity*cent_log10diversity*site
cent_log10diversity*cent_log10diversity*year
cent_log10diversity*cent_log10diversity*year*site;
repeated year/subject= quadrat(site) type=cs;
estimate 'rd100 diversity 2008' log10diversity 1 log10diversity*site 1
log10diversity*year 1 log10diversity*site*year 1;
estimate 'suhi diversity 2008' log10diversity 1 log10diversity*site 0 1
log10diversity*year 1 log10diversity*site*year 0 0 1;
estimate 'vfanle diversity 2008' log10diversity 1 log10diversity*site 0
0 1 log10diversity*year 1 log10diversity*site*year 0 0 0 0 1;
estimate 'rd100 diversity 2009' log10diversity 1 log10diversity*site 1
log10diversity*year 0 1 log10diversity*site*year 0 1;
estimate 'suhi diversity 2009' log10diversity 1 log10diversity*site 0 1
log10diversity*year 0 1 log10diversity*site*year  0 0 0 1;
estimate 'vfanle diversity 2009' log10diversity 1 log10diversity*site 0
0 1 log10diversity*year 0 1 log10diversity*site*year 0 0 0 0 0 1;
estimate 'rd100 diversity 2008 quadratic'
cent_log10diversity*cent_log10diversity 1
cent_log10diversity*cent_log10diversity*site 1
cent_log10diversity*cent_log10diversity*year 1
cent_log10diversity*cent_log10diversity*site*year 1;
estimate 'suhi diversity 2008 quadratic'
cent_log10diversity*cent_log10diversity 1
cent_log10diversity*cent_log10diversity*site 0 1
cent_log10diversity*cent_log10diversity*year 1
cent_log10diversity*cent_log10diversity*site*year 0 0 1;
```

```
estimate 'vfanle diversity 2008 quadratic'
cent_log10diversity*cent_log10diversity 1
cent_log10diversity*cent_log10diversity*site 0 0 1
cent_log10diversity*cent_log10diversity*year 1
cent_log10diversity*cent_log10diversity*site*year 0 0 0 0 1;
estimate 'rd100 diversity 2009 quadratic'
cent_log10diversity*cent_log10diversity 1
cent_log10diversity*cent_log10diversity*site 1
cent_log10diversity*cent_log10diversity*year 0 1
cent_log10diversity*cent_log10diversity*site*year 0 1;
estimate 'suhi diversity 2009 quadratic'
cent_log10diversity*cent_log10diversity 1
cent_log10diversity*cent_log10diversity*site 0 1
cent_log10diversity*cent_log10diversity*year 0 1
cent_log10diversity*cent_log10diversity*site*year  0 0 0 1;
estimate 'vfanle diversity 2009 quadratic'
cent_log10diversity*cent_log10diversity 1
cent_log10diversity*cent_log10diversity*site 0 0 1
cent_log10diversity*cent_log10diversity*year 0 1
cent_log10diversity*cent_log10diversity*site*year 0 0 0 0 0 1;
ods output estimates=est_diversity; run;

proc mixed data=raw; class site year quadrat;
model log10anle=site|year
log10propp log10propp*site log10propp*year  log10propp*site*year;
repeated year/subject= quadrat(site) type=cs;
estimate 'rd100 propp 2008' log10propp 1 log10propp*site 1
log10propp*year 1 log10propp*site*year 1;
estimate 'suhi propp 2008' log10propp 1 log10propp*site 0 1
log10propp*year 1 log10propp*site*year 0 0 1;
estimate 'vfanle propp 2008' log10propp 1 log10propp*site 0 0 1
log10propp*year 1 log10propp*site*year 0 0 0 0 1;
estimate 'rd100 propp 2009' log10propp 1 log10propp*site 1
log10propp*year 0 1 log10propp*site*year 0 1;
estimate 'suhi propp 2009' log10propp 1 log10propp*site 0 1
log10propp*year 0 1 log10propp*site*year  0 0 0 1;
estimate 'vfanle propp 2009' log10propp 1 log10propp*site 0 0 1
log10propp*year 0 1 log10propp*site*year 0 0 0 0 0 1;
ods output estimates=est_propp; run;

proc mixed data=raw; class site year quadrat;
model log10anle=site|year
log10props log10props*site log10props*year  log10props*site*year;
repeated year/subject= quadrat(site) type=cs;
estimate 'rd100 props 2008' log10props 1 log10props*site 1
log10props*year 1 log10props*site*year 1;
estimate 'suhi props 2008' log10props 1 log10props*site 0 1
log10props*year 1 log10props*site*year 0 0 1;
estimate 'vfanle props 2008' log10props 1 log10props*site 0 0 1
log10props*year 1 log10props*site*year 0 0 0 0 1;
estimate 'rd100 props 2009' log10props 1 log10props*site 1
log10props*year 0 1 log10props*site*year 0 1;
estimate 'suhi props 2009' log10props 1 log10props*site 0 1
log10props*year 0 1 log10props*site*year  0 0 0 1;
estimate 'vfanle props 2009' log10props 1 log10props*site 0 0 1
log10props*year 0 1 log10props*site*year 0 0 0 0 0 1;
ods output estimates=est_props; run;
```

```
proc mixed data=raw; class site year quadrat;
model log10anle=site|year
log10total log10total*site log10total*year  log10total*site*year;
repeated year/subject= quadrat(site) type=cs;
estimate 'rd100 total 2008' log10total 1 log10total*site 1
log10total*year 1 log10total*site*year 1;
estimate 'suhi total 2008' log10total 1 log10total*site 0 1
log10total*year 1 log10total*site*year 0 0 1;
estimate 'vfanle total 2008' log10total 1 log10total*site 0 0 1
log10total*year 1 log10total*site*year 0 0 0 0 1;
estimate 'rd100 total 2009' log10total 1 log10total*site 1
log10total*year 0 1 log10total*site*year 0 1;
estimate 'suhi total 2009' log10total 1 log10total*site 0 1
log10total*year 0 1 log10total*site*year  0 0 0 1;
estimate 'vfanle total 2009' log10total 1 log10total*site 0 0 1
log10total*year 0 1 log10total*site*year 0 0 0 0 0 1;
ods output estimates=est_total; run;

*annual;
data raw09; set raw; if year=2008 then delete; run;
proc mixed data=raw09; class site quadrat;
model log10anle=site log10propa log10propa*site/solution;
repeated intercept/subject= quadrat(site) type=cs;
estimate 'rd100 proportion annuals 2009' log10propa 1 log10propa*site
1;
estimate 'suhi proportion annuals 2009' log10propa 1 log10propa*site 0
1;
estimate 'vfanle proportion annuals 2009' log10propa 1 log10propa*site
0 0 1;
ods output tests3=apropfullanva estimates=est_propa ;
run;


proc export data=afullanva replace
outfile="C:\Documents and Settings\cheryl vanier\My
Documents\UNLV\dianne\rare plant surveys\anle ancovas.xls";
proc export data=areducedanva replace
outfile="C:\Documents and Settings\cheryl vanier\My
Documents\UNLV\dianne\rare plant surveys\anle ancovas.xls";
proc export data=apropfullanva
outfile="C:\Documents and Settings\cheryl vanier\My
Documents\UNLV\dianne\rare plant surveys\anle ancovas.xls";
proc export data=est_total
outfile="C:\Documents and Settings\cheryl vanier\My
Documents\UNLV\dianne\rare plant surveys\anle ancovas.xls";
proc export data=est_props
outfile="C:\Documents and Settings\cheryl vanier\My
Documents\UNLV\dianne\rare plant surveys\anle ancovas.xls";
proc export data=est_propp
outfile="C:\Documents and Settings\cheryl vanier\My
Documents\UNLV\dianne\rare plant surveys\anle ancovas.xls";
proc export data=est_diversity
outfile="C:\Documents and Settings\cheryl vanier\My
Documents\UNLV\dianne\rare plant surveys\anle ancovas.xls";
proc export data=est_propa
```

```
outfile="C:\Documents and Settings\cheryl vanier\My
Documents\UNLV\dianne\rare plant surveys\anle ancovas.xls";
proc export data=est_richness
outfile="C:\Documents and Settings\cheryl vanier\My
Documents\UNLV\dianne\rare plant surveys\anle ancovas.xls";
run;
```

SIZE and BOLTING SUCCESS

```
proc sort data=bolt_stem; by site year stemgrp; run;
proc glimmix data=bolt_stem; by site year;
class stemgrp;
model sum_bolt/n_bolt=stemgrp /cl solution;
lsmeans stemgrp/pdiff  ilink;
ods output lsmeans=stemlsm ; run;

proc sort data=bolt_stem; by site year stemgrp; run;
proc glimmix data=bolt_stem; by site year;
class site stemgrp;
model sum_bolt/n_bolt=stemgrp /cl;
lsmeans stemgrp/pdiff  ilink;
ods output lsmeans=stemlsm; run;

proc glimmix data=bolt_stem; by site;
class stemgrp year;
model sum_bolt/n_bolt= year; run;

proc glimmix data=bolt_sum; by site;
class lvsgrp;
model sum_bolt/n_bolt= /intercept;
run;
```

```
#size variables;

raw1=read.delim("anle size for R.txt")

lfn.means=matrix(ncol=6,nrow=2)
lfn.resamp=matrix(nrow=10000,ncol=124)

for(l in 3:4){
lfn.means[l-
2,]=10^tapply(log10(raw1[,l]+1),(as.factor(paste(raw1$year,raw1$site))),mean)-1}

for(x in 1:6){
lfn.temp=subset(raw1,
as.factor(paste(raw1$year,raw1$site))==levels(as.factor(paste(raw1$year,raw1$site)))[x])
for(k in 1:10000){
for(l in 3:4){
xx=sample(log10(lfn.temp[,l]+1),length(lfn.temp[,l]),replace=TRUE)
lfn.resamp[k,((l-2)*10+x)]=10^mean(xx)-1
}}}
```

```
lfn.resamp.out=matrix(ncol=2,nrow=124)
for(y in 1:124){
lfn.resamp.out[y,]=quantile(lfn.resamp[,y],c(0.025,0.975),na.rm=TRUE)}

lfn.means

write.table(lfn.resamp.out,"anle size bootstrap output.txt",row.names=FALSE)
write.table(lfn.means,"anle size.txt",row.names=FALSE)
```

APPENDIX 8.

Rare Plant Survey analysis – sand species
1/18/2010
C. Vanier

General points of discussion:
- Species richness represents the average number of species found per quadrat. The diversity is actually the Hill's number, or species equivalents if all species were equally represented. It takes a maximum value of the species richness (when all species are equally represented) and a minimum value of approximately one (when one species strongly dominates all others). Details are available in Jost (2006).

Report

Climate variables

Rainfall, vapor density, and temperatures were quantified using monthly minima, maxima, mean, and interquartile range (iqr). Only months which had a complete set of data were used for a particular site.

ASTGEY

Total cover, richness, diversity, and the relative representation of life forms and native/non-native species were estimated by mean values. Diversity was expressed as the numbers equivalent (aka effective number of species), but calculations were done on the log transform of this value (Jost 2006) and back-transformed for reporting. All other values were log transformed prior to estimation of the mean and confidence intervals. Confidence intervals using the normal distribution tended to underestimate the 95% confidence interval, so quantile-based bootstrapped estimates from 10,000 resamples are reported. All analysis was completed in R 2.10.0 (R Development Core Team 2009), and diversity and species richness was estimated using the 'vegetarian' package (Jost 2006).

Only three sites were available for examining patterns with climate variables, so both the analysis and results are qualitative and preliminary. The ranks for each of the plant variables within the 2009 sites was computed, and this was compared with the climate variables for every month having a full monthly data set available. The relative representation of life forms and natives/non-natives was used to avoid confounding total cover with life form and native representation. Congruence of ranks was taken as a suggestion of an association for further study.

The potential relationships between quadrat-level species richness, species diversity, annual cover, perennial cover, shrub cover, native cover, and non-native cover (all except richness log10+1 transformed to meet model expectations) and the number of ASTGEY individuals (log10+1 transformed) within each site and year were fit using a mixed model ANOVA with grid as a random effect. The structure of the spatial covariance was chosen by comparing the Akaike information criterion corrected for small sample size (AICC) among alternatives. The best fit was a two-dimensional exponential geometrically anisotropic spatial covariance structure. The minimum adequate model was determined by comparing nested models using AICC. The model that optimized AICC is presented. This analysis was performed in SAS v9.1 (SAS Institute 2002-2003).

Results: Tables are located in ‘rare plant output-sand species.xls’. Full code and output are shown below. Sites were similar in total cover, although SACO had significantly less total cover in 2009 than in 2008 (Table 1). Native cover was high in these sites compared to non-native cover. Between sites, non-native cover was substantially higher in 2009 WEWA and slightly higher in 2009 EBCO than in SACO. SACO in both years had lower quadrat-level richness and diversity than EBCO and WEWA in 2009. On the whole-plot scale, SACO had greater species richness, but lower species evenness than EBCO and WEWA, suggesting stronger dominance by the most common species, particularly the top two species (Table 2).

Some potentially interesting relationships between monthly weather variables and plant presence were suggested by these data (Table 4). For example, total cover, diversity, and the proportion of non-natives was congruent with variation in temperature in the fall. Species richness and annual cover were congruent with rain and moisture in the air in September, while perennial cover was congruent with maximum temperature and variation in December. Shrub cover was congruent with minimum and average temperatures and vapor density in the fall.

The presence of ASTGEY was not significantly predicted by any of the independent variables in 2009 (Table 5). In 2008 SACO, ASTGEY was positively related to species richness and negatively related to non-native cover (w). A different set of predictors minimized the AICC for each site and year (Table 6). To ease interpretation of Tables 5 and 6, the correlation structure for the independent variables was calculated. Native cover and shrub cover were highly correlated (ρ=0.959; Spearman rank correlation), and both were correlated to total cover (ρ>0.926). Annual cover was moderately correlated with non-native cover (ρ=0.731) and diversity (ρ=0.675).

Table 1. Summary of mean and bootstrapped 95% confidence interval of quadrat-level measurements at sites containing ASTGEY. Diversity is back-transformed to Hill’s number, richness is average number of species, and all other values are expressed as percent cover in the plot. Top panel includes summary values, then second life forms, and the third information on nativity categories. Part ‘b’ denotes whole-site richness and diversity.

	total cover	95% CI		richness	95% CI		diversity	95% CI	
2008 SACO	23.51	20.68	26.45	12.97	11.89	14.06	5.48	4.99	6.01
2009 EBCO	21.76	19.85	23.86	20.41	18.80	21.98	10.03	8.96	11.18
2009 SACO	16.81	14.63	19.07	12.42	11.06	13.81	6.28	5.63	6.95
2009 WEWA	24.80	23.20	26.55	19.65	18.92	20.40	10.06	9.03	11.19

	a	95% CI		p	95% CI		s	95% CI	
2008 SACO	5.72	5.06	6.42	0.32	0.23	0.42	15.92	13.75	18.26
2009 EBCO	9.77	8.86	10.67	0.02	0.00	0.06	11.67	10.32	13.21
2009 SACO	5.88	5.22	6.59	0.23	0.17	0.31	9.74	8.22	11.45
2009 WEWA	9.31	8.63	10.12	2.59	2.35	2.84	11.89	10.20	13.78

	n	95% CI		w	95% CI	
2008 SACO	21.68	19.09	24.48	0.96	0.81	1.13
2009 EBCO	19.90	18.11	21.79	1.37	1.16	1.59
2009 SACO	15.28	13.35	17.40	1.08	0.93	1.25
2009 WEWA	18.76	17.06	20.62	4.90	4.27	5.67

	richness	diversity
2008 SACO	60	9.54
2009 EBCO	42	13.63
2009 SACO	55	11.61
2009 WEWA	49	12.90

Table 2. Top five species by cover for each ASTGEY site. Values are the sum of mid-points for each quadrat by site and year. The grand total is the total sum of mid-points for each site and year. The percentage of relative cover represented by the most common, the two most common, and the five most common species is provided in the 'top1', 'top2', and 'top5' rows.

2008 SACO		2009 EBCO		2009 SACO		2009 WEWA	
Ambdum	1541	Ambdum	324	Ambdum	1072	Ambdum	322
Kraere	112	Lartri	79	Kraere	83	Ephedra	67
Lartri	1072	Pecpla	23	Lartri	747	Kraere	39
Psofre	279	Psofre	29	Plaova	101	Lartri	42
Schismus	102	Schismus	43	Strlon	86	Schismus	142
Grand Tota	4117		815		3027		914
top1	37%		40%		35%		35%
top2	63%		49%		60%		51%
top5	75%		61%		69%		67%

Table 3. Proportional representation for each life form and nativity category as a function of total cover, computed from mean values. These were the values used for ranks in comparison with the climate data to avoid confounding total cover with individual categories' representation.

	a	p	s	n	w
2008 SACO	0.24	0.01	0.68	0.92	0.04
2009 EBCO	0.45	0.00	0.54	0.91	0.06
2009 SACO	0.35	0.01	0.58	0.91	0.06
2009 WEWA	0.38	0.10	0.48	0.76	0.20

Table 4. Congruent rankings between plant variables and climate variables by month. Only three sites were available for ranking (no data in 2008), and only complete months of data were included. 'Maxtemp'=maximum temperature, 'Mintemp'=minimum temperature, 'Meantemp'=mean temperature, 'iqrtemp'=interquartile range (75^{th}-25^{th} percentile; measure of variation). Same prefixes for 'vd' (vapor density, converted from relative humidity), and 'rain' is total monthly rainfall for the month.

Plant variables	Climate variable	Month
total cover, diversity, unk life form, non-native, nativity unk (231)	maxtemp	10
	iqrtemp	8
	iqrtemp	9
	iqrtemp	10
	iqrtemp	11
richness, annual cover (132)	rain	9
	iqrvd	9
perennial cover (321)	maxtemp	12
	iqrtemp	12
shrub cover (213)	mintemp	8
	mintemp	9
	mintemp	10
	mintemp	11
	mintemp	12
	maxtemp	9
	meantemp	8
	meantemp	9
	meantemp	10
	meantemp	11
	meantemp	12
	minvd	8
	minvd	9
	minvd	10
	maxvd	8
	maxvd	9
	maxvd	10
	maxvd	11
	maxvd	12
	meanvd	8
	meanvd	9
	meanvd	10
	meanvd	11

Table 5. Minimum adequate model for estimated intercepts and slopes predicting presence of ASTGEY (log10-transformed +1) for log10+1 transformed diversity, annual cover, perennial cover, native cover, and non-native cover. Model was fit within year and site, grid was the random effect, and a two-dimensional exponential geometrically anisotropic spatial covariance structure was also included (determined by AICC). Effects (species richness and shrub cover) were excluded from this model based on AICC.

yearsite	Effect	Estimate	StdErr	DF	tValue	Probt
2008SACO	Intercept	0.73	0.43	7	1.68	0.1378
2008SACO	asti_richness	0.06	0.01	121	4.44	**0.0000**
2008SACO	log10p	-0.19	0.21	121	-0.91	0.3627
2008SACO	log10diversity	-0.19	0.38	121	-0.49	0.6237
2008SACO	log10n	0.05	0.22	121	0.23	0.8205
2008SACO	log10w	-0.91	0.20	121	-4.62	**0.0000**
2009EBCO	Intercept	1.31	1.18	1	1.11	0.4663
2009EBCO	asti_richness	0.02	0.02	26	0.93	0.3608
2009EBCO	log10diversity	-0.13	0.64	26	-0.20	0.8430
2009EBCO	log10p	-0.09	0.66	26	-0.14	0.8881
2009EBCO	log10a	-0.98	0.81	26	-1.21	0.2369
2009EBCO	log10n	0.01	0.76	26	0.02	0.9872
2009SACO	Intercept	1.04	0.85	6	1.23	0.2658
2009SACO	asti_richness	-0.03	0.03	106	-0.98	0.3300
2009SACO	log10p	0.58	0.39	106	1.48	0.1418
2009SACO	log10diversity	0.23	0.68	106	0.34	0.7364
2009SACO	log10n	-0.07	0.48	106	-0.15	0.8837
2009SACO	log10w	0.57	0.31	106	1.82	0.0715
2009WEWA	Intercept	0.05	1.28	1	0.04	0.9734
2009WEWA	asti_richness	0.04	0.04	22	0.98	0.3379
2009WEWA	log10p	-0.01	0.50	22	-0.03	0.9782
2009WEWA	log10n	0.31	0.49	22	0.63	0.5331
2009WEWA	log10a	-1.46	2.12	22	-0.69	0.4997
2009WEWA	log10w	1.04	1.34	22	0.78	0.4445

*a was correlated with diversity and w, but the results were resistant to the inclusion of any, so all were included.
**s and n were highly correlated (r=0.95), so only n was included.

Table 6. Different view of ASTGEY regression results highlighting the differences in models among sites. The top table provides the p-values, while the lower table provides the intercept and slope values to aid interpretation.

yearsite	asti_richness	Intercept	log10a	log10diversity	log10n	log10p	log10w
2008SACO	0.0000	0.1378		0.6237	0.8205	0.3627	0.0000
2009EBCO	0.3608	0.4663	0.2369	0.8430	0.9872	0.8881	
2009SACO	0.3300	0.2658		0.7364	0.8837	0.1418	0.0715
2009WEWA	0.3379	0.9734	0.4997		0.5331	0.9782	0.4445

yearsite	asti_richness	Intercept	log10a	log10diversity	log10n	log10p	log10w
2008SACO	0.063	0.729		-0.186	0.050	-0.194	-0.908
2009EBCO	0.022	1.310	-0.983	-0.129	0.012	-0.094	
2009SACO	-0.027	1.042		0.229	-0.071	0.575	0.571
2009WEWA	0.037	0.053	-1.456		0.311	-0.014	1.043

ERVI:
The same procedure was used for ERVI that was described above for ASTGEY, with the following exceptions. For the quadrat-level analysis, the mid-points of cover classes for litter, sand, and rocks were log10+1 transformed and added. ‘Tracks’ was fit separately from the rest of the independent variables because of its effects on the residuals (Table 6). Only two sites were surveyed in 2009, so no relationships with environmental variables could be obtained.

Results: Sites were similar in total cover, perennial cover, and annual cover (Table 5). Shrub cover was significantly higher in the GLHO site compared to LICO. Native cover was low in these sites compared to non-native cover. Native and non-native cover was approximately equal in the LICO sites, while non-native cover was at least three-fold greater than native cover in GLHO. GLHO in 2008 had lower species richness than GLHO in 2009 or LICO in either year, but diversity was lower in 2009 GLHO, suggesting a few dominants rather than a community with high evenness. On the whole-plot scale, sites in 2009 had greater species richness, but lower species diversity, than in 2008. This pattern suggests stronger dominance by a few species in 2009 compared to 2008 (Table 7). The relative representation of the most common species confirms this supposition (Table 8), particularly for the most common species, which were all non-natives.

The presence of ERVI was positively related to native cover in LICO and negatively related to non-native cover in GLHO (where non-native cover dwarfed native cover; Tables 9, 10). Native cover and species richness were moderately correlated (ρ=0.610; Spearman rank correlation). Diversity and richness were correlated (ρ=0.677). Annual cover and non-native cover were positively correlated (ρ=0.691), and non-native cover was negatively correlated with diversity (ρ=-0.696).

Table 7. Summary of mean and bootstrapped 95% confidence interval of quadrat-level and whole-plot measurements at sites containing ERVI. Diversity is back-transformed to Hill's number, richness is average number of species, and all other values are expressed as percent cover in the plot. Top panel includes summary values, the second life forms, the third information on nativity categories, and fourth whole-plot values.

	total cover	95% CI		richness	95% CI		Hill diversity	95% CI	
2008 GLHO	22.11	18.88	25.93	8.53	7.63	9.46	4.62	3.99	5.34
2008 LICO	24.68	21.62	28.15	10.47	9.93	11.03	5.07	4.65	5.54
2009 GLHO	26.01	23.18	29.22	10.74	9.49	11.96	3.79	3.16	4.53
2009 LICO	24.26	20.56	28.59	11.54	10.91	12.19	4.56	4.02	5.14

	a	95% CI		p	95% CI		s	95% CI	
2008 GLHO	16.60	14.04	19.47	0.05	0.02	0.09	2.82	1.66	4.41
2008 LICO	22.81	20.02	25.98	0.03	0.01	0.07	0.35	0.09	0.83
2009 GLHO	19.57	17.15	22.20	0.05	0.02	0.11	2.19	1.03	3.83
2009 LICO	22.11	18.57	26.12	0.01	0.00	0.02	0.36	0.10	0.90

	n	95% CI		w	95% CI	
2008 GLHO	4.23	3.10	5.47	14.08	10.61	18.34
2008 LICO	11.32	9.69	13.19	11.42	8.92	14.18
2009 GLHO	4.75	3.45	6.27	17.91	14.57	21.63
2009 LICO	8.36	6.82	10.19	13.44	10.38	17.16

Whole-site

	richness	diversity
2008 GLHO	37	8.53
2008 LICO	40	8.97
2009 GLHO	47	7.05
2009 LICO	46	7.23

Table 8. Representation in the top five species for each site and year. Values provided are the sum of cover midpoints across all quadrats. The 'top1', 'top2', and 'top5' rows indicate the percent of total cover represented by the most common, two most common, and five most common species, respectively.

2008 GLHO		2008 LICO		2009 GLHO		2009 LICO	
Cryang	78	Cambre	177	Cryang	57	Cryang	65
Salsola	537	Erivis	329	Erivis	76	Erivis	348
Salsola-d	80	Salsola	123	Salsola	115	Salsola	126
Schismus	307	Schismus	716	Schismus	963	Schismus	895
Tamram	374	Tamram	114	Tamram	367	Tamram	119
Grand Total	1727		1872		1932		1877
top1	31%		38%		50%		48%
top2	53%		56%		69%		66%
top5	80%		78%		82%		83%

Table 9. Estimated intercepts and slopes predicting presence of ERVI (log10-transformed +1) for species richness and log10+1 transformed diversity, annual cover, perennial cover, shrub cover, native cover, and w (non-native cover?) by year and site. The model included transect as a random effect and a two-dimensional exponential geometrically anisotropic spatial covariance structure

(determined by AICC). The table provided is the minimum adequate model based on AICC. The full models are available in the Excel output file.

yearsite	Effect	Estimate	StdErr	DF	tValue	Probt
2008GLHO	Intercept	-0.45	0.67	9	-0.66	0.5241
2008GLHO	log10diversity	0.54	0.22	55	2.49	**0.0160**
2008GLHO	log10p	0.02	0.41	55	0.04	0.9673
2008GLHO	log10a	0.33	0.15	55	2.28	**0.0263**
2008GLHO	log10w	-0.49	0.12	55	-4.13	**0.0001**
2008GLHO	log10scovmid	0.22	0.35	55	0.64	0.5254
2009LICO	Intercept	-0.07	0.34	9	-0.20	0.8480
2009LICO	log10diversity	0.71	0.22	50	3.18	**0.0025**
2009LICO	log10p	-0.61	0.58	50	-1.07	0.2916
2009LICO	log10n	1.67	0.14	50	12.03	**0.0000**
2009LICO	log10scovmid	-0.16	0.14	50	-1.16	0.2521
2008LICO	Intercept	-0.94	0.97	9	-0.98	0.3548
2008LICO	ervi_richness	0.10	0.04	55	2.52	**0.0147**
2008LICO	log10diversity	1.09	0.64	55	1.71	0.0928
2008LICO	log10p	-1.45	0.80	55	-1.80	0.0772
2008LICO	log10n	1.18	0.32	55	3.69	**0.0005**
2008LICO	log10scovmid	-0.51	0.35	55	-1.43	0.1571
2009GLHO	Intercept	0.64	0.45	9	1.42	0.1903
2009GLHO	log10diversity	0.48	0.24	54	1.97	0.0540
2009GLHO	log10p	1.90	0.44	54	4.35	**0.0001**
2009GLHO	log10w	-0.41	0.18	54	-2.32	**0.0242**
2009GLHO	log10s	0.36	0.12	54	2.93	**0.0050**
2009GLHO	log10scovmid	-0.08	0.19	54	-0.44	0.6646
2009GLHO	log10lcovmid	-0.49	0.18	54	-2.80	**0.0070**

Table 10. Different view of ERVI regression results highlighting the differences in models among sites. The top table provides the p-values, while the lower table provides the intercept and slope values to aid interpretation.

P-values

yearsite	Intercept	ervi_richness	log10a	log10diversity	log10lcovmid	log10n	log10p	log10s	log10scovmid	log10w
2008GLHO	0.5241		**0.0263**	**0.0160**			0.9673		0.5254	**0.0001**
2008LICO	0.3548	**0.0147**		0.0928		**0.0005**	0.0772		0.1571	
2009GLHO	0.1903			0.0540	**0.0070**		**0.0001**	**0.0050**	0.6646	**0.0242**
2009LICO	0.8480			**0.0025**		**0.0000**	0.2916		0.2521	

Coefficients

yearsite	Intercept	ervi_richness	log10a	log10diversity	log10lcovmid	log10n	log10p	log10s	log10scovmid	log10w
2008GLHO	-0.447		0.333	0.543			0.017		0.223	-0.490
2008LICO	-0.945	0.103		1.092		1.185	-1.447		-0.509	
2009GLHO	0.642			0.478	-0.491		1.902	0.365	-0.083	-0.408
2009LICO	-0.068			0.711		1.668	-0.614		-0.158	

Literature cited

Jost, L. 2006. Entropy and diversity. Oikos 113(2): 363-375.

R Development Core Team. 2009. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

SAS Institute. 2002-2003. SAS v 9.1. Cary, NC.

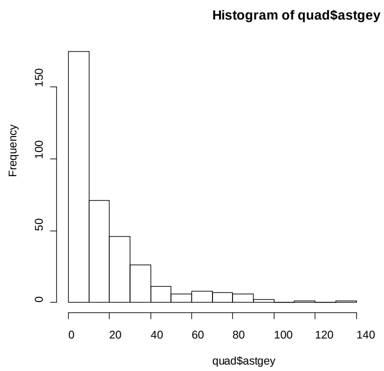
Analysis notes: Environmental variables

Relative humidity was converted to vapor density by using the following to estimate saturated vapor density:
$6.335 + 0.6718Tc - 0.020887Tc^2 + 0.00073095Tc^3$

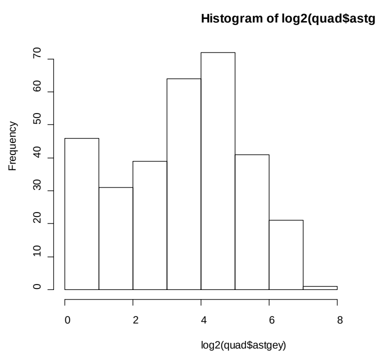
Where Tc=temperature in C, and

RH=VD/saturatedVD

Distribution:
```
> par(mfrow=c(1,1))
> hist(quad$astgey)
> mean(quad$astgey)
[1] 18.04722
> sum(quad$astgey)
[1] 6497
```



This distribution shows extreme clumping relative to Poisson with lambda=18 (not formally tested; available upon request).



These could possibly be modeled as normal after a log-transform, given the large sample size and range of possible values. Residual plots will tell.

Code and preparation:

```
#computed in Excel, then brought into R as text files:

fles=as.matrix(read.delim("rhtempfiles.txt",header=FALSE))
temp_rh=matrix(ncol=9)
```

```
for(k in 1:length(fles)){
temp=read.delim(fles[k,])
tt=cbind(levels(temp$Site),tapply(temp$Tc,temp$Month,min),
tapply(temp$Tc,temp$Month,max),tapply(temp$Tc,temp$Month,mean),
tapply(temp$Tc,temp$Month,IQR),tapply(temp$vd_mb,temp$Month,min),tapply(temp$
vd_mb,temp$Month,max),tapply(temp$vd_mb,temp$Month,mean),tapply(temp$vd_mb,t
emp$Month,IQR))
temp_rh=rbind(temp_rh,tt)}

temp_rh.df=data.frame(cbind(row.names(temp_rh),temp_rh),row.names=NULL)

names(temp_rh.df)=c("month","site","min_temp","max_temp","mean_temp","iqr_temp",
"min_vd","max_vd","mean_vd","iqr_vd")
write.table(temp_rh.df,"temperature rh fromR.txt",row.names=FALSE)
```

Used Pivot table in Excel to get final format.

ASTGEY Analysis notes:

<u>Relationship between quad-level variables and ASTGEY presence</u>

```
library(MASS)
raw=read.delim("asti quad level data.txt")
#removed 2008 because only one site was measured in this year
raw09=subset(raw,raw$year==2009)
attach(raw09)
cor(raw09[,5:14])
```

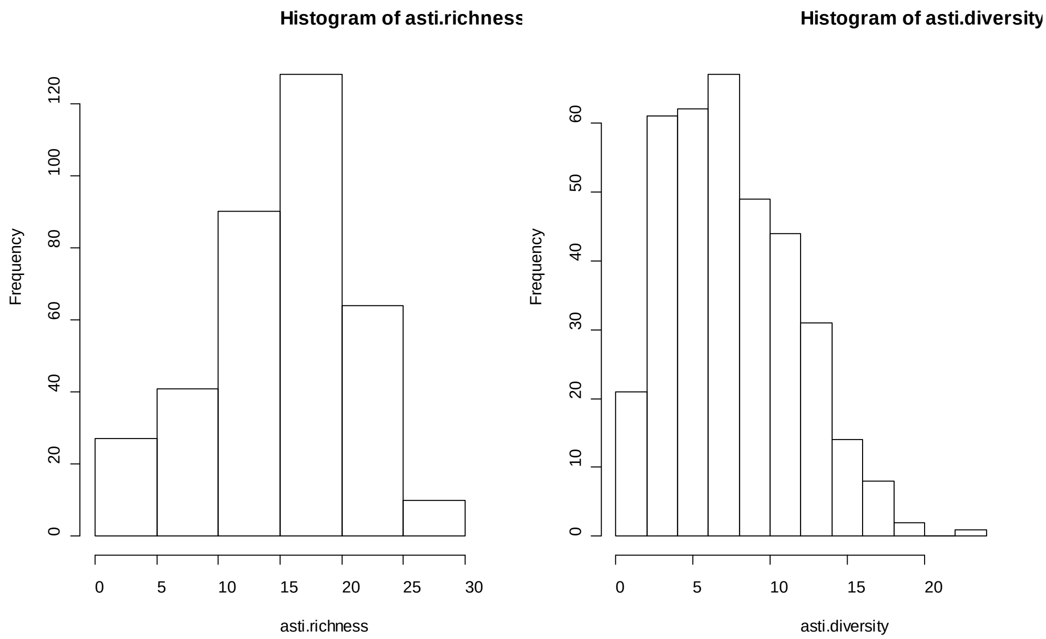
	asti_diversity	asti_richness	a	p	s	unk_life_form	n	w	unk_nativ	astgey
asti_diversity	1.00	**0.77**	**0.61**	0.23	-0.27	-0.01	-0.04	0.24	-0.01	-0.15
asti_richness	0.77	1.00	**0.82**	0.26	0.27	0.12	0.51	0.35	0.12	-0.22
a	0.61	0.82	1.00	0.14	0.20	0.02	0.44	0.59	0.02	-0.17
p	0.23	0.26	0.14	1.00	-0.01	0.10	0.04	0.55	0.10	-0.25
s	-0.27	0.27	0.20	-0.01	1.00	0.16	0.95	0.04	0.16	-0.01
unk_life_form	-0.01	0.12	0.02	0.10	0.16	1.00	0.14	0.06	1.00	-0.11
n	-0.04	0.51	0.44	0.04	0.95	0.14	1.00	0.10	0.14	-0.05
w	0.24	0.35	0.59	0.55	0.04	0.06	0.10	1.00	0.06	-0.25
unk_nativ	-0.01	0.12	0.02	0.10	0.16	1.00	0.14	0.06	1.00	-0.11
astgey	-0.15	-0.22	-0.17	-0.25	-0.01	-0.11	-0.05	-0.25	-0.11	1.00

Diversity, richness and annual cover may be highly correlated; need to interpret output carefully.

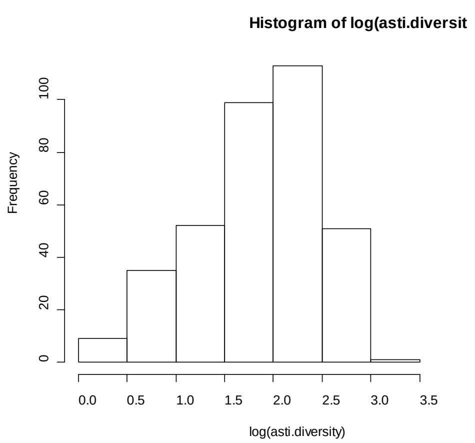
```
#created diversity and species richness data sets for each site
asti.quad=read.delim("asti community quad.txt")
asti.richness=matrix(ncol=1,nrow=length(asti.quad[,1]))
asti.diversity=matrix(ncol=1,nrow=length(asti.quad[,1]))

for(j in 1:length(asti.quad[,1])){
asti.richness[j]=d(asti.quad[j,5:99],q=0)
asti.diversity[j]=d(asti.quad[j,5:99],q=1)}
```

```
> par(mfrow=c(1,2))
> hist(asti.richness)
> hist(asti.diversity)
```



As anticipated, richness is OK, while diversity (Hill number) should probably be log transformed;



Mean and bootstrapped 95% CI for log(diversity) and species richness for each site/year.

```
> tapply(asti.richness,paste(asti.quad$Year,asti.quad$Site),mean)
2008 SACO 2009 EBCO 2009 SACO 2009 WEWA
 14.21528  20.91667  14.54167  19.77778

> 2^(tapply(log2(asti.diversity), paste(asti.quad$Year,asti.quad$Site),mean))
2008 SACO 2009 EBCO 2009 SACO 2009 WEWA
 5.310768  9.975806  6.056876 10.011273
```

#95% CI- these values were larger than the parametric CI, so I used the bootstrapped ones.

```
tapply(asti.richness,paste(asti.quad$Year,asti.quad$Site),mean)+(qnorm(0.975)*tapply(asti.richness,paste(asti.quad$Year,asti.quad$Site),sd)/tapply(asti.richness,paste(asti.quad$Year,asti.quad$Site),length))

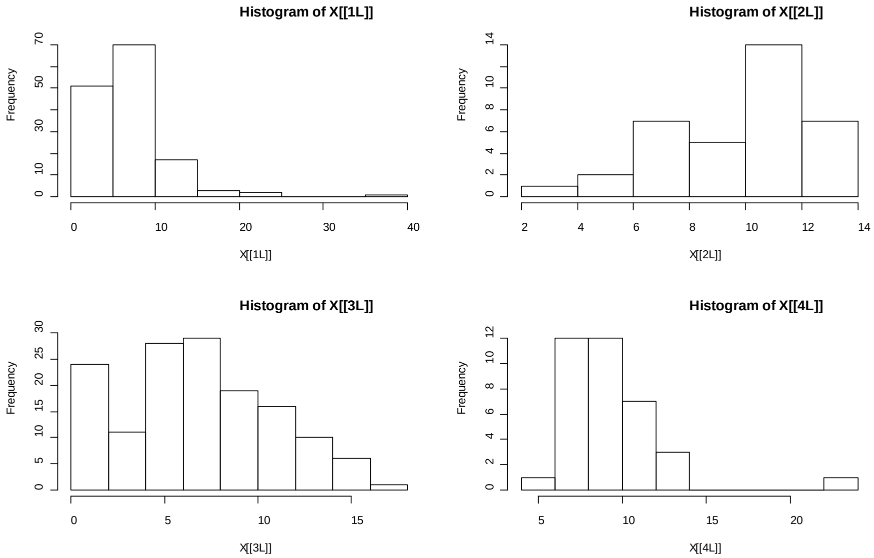
rich.resamp=matrix(nrow=10000,ncol=4)
div.resamp=matrix(nrow=10000,ncol=4)
for(x in 1:4){
div.temp=subset(asti.diversity,
as.factor(paste(asti.quad$Year,asti.quad$Site))==levels(as.factor(paste(asti.quad$Year,asti.quad$Site)))[x])
rich.temp=subset(asti.richness,
as.factor(paste(asti.quad$Year,asti.quad$Site))==levels(as.factor(paste(asti.quad$Year,asti.quad$Site)))[x])
for(k in 1:10000){
xx=sample(rich.temp,length(rich.temp),replace=TRUE)
rich.resamp[k,x]=mean(xx)
xy=sample(log2(div.temp),length(div.temp),replace=TRUE)
div.resamp[k,x]=2^mean(xy)}}

resamp.out=matrix(ncol=4,nrow=4)
for(y in 1:4){
resamp.out[y,1:2]=(quantile(div.resamp[,y],c(0.025,0.975)))
resamp.out[y,3:4]=(quantile(rich.resamp[,y],c(0.025,0.975)))}

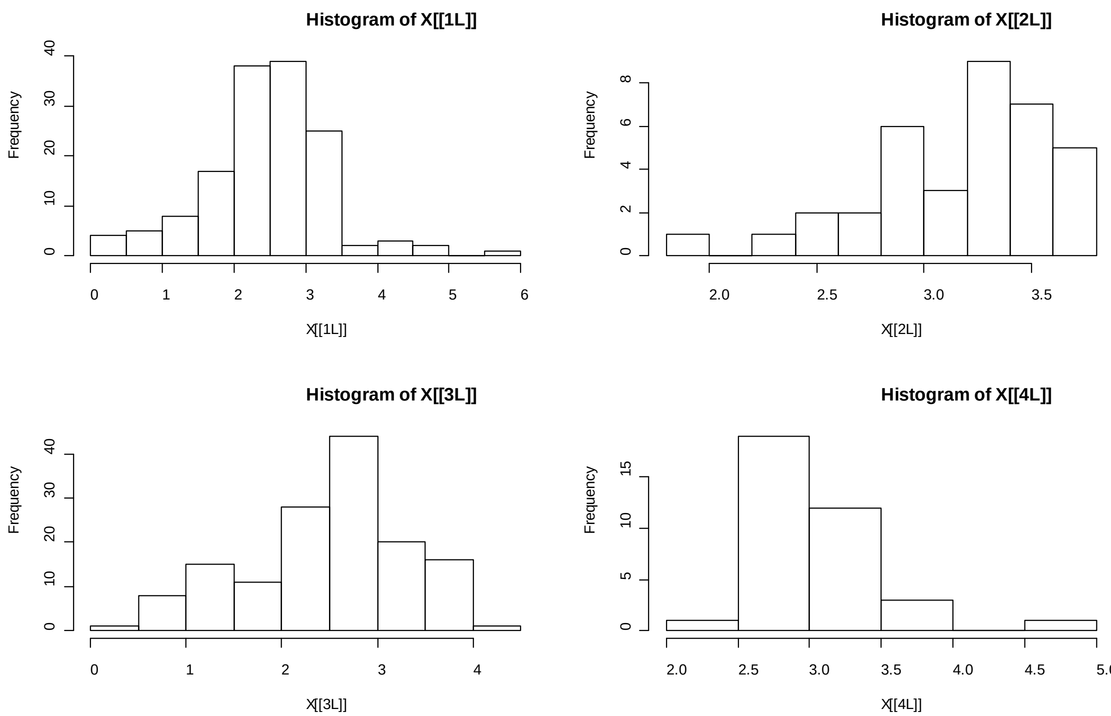
> resamp.out
         [,1]      [,2]     [,3]     [,4]
[1,] 4.803486  5.854793 13.34722 15.07639
[2,] 8.871639 11.087288 19.47222 22.36111
[3,] 5.419474  6.757900 13.45122 15.59028
[4,] 8.993239 11.132783 19.02778 20.50000

asti.out=as.data.frame(cbind(asti.quad[,1:4],asti.diversity,asti.richness,asti.lfn[,5:8],asti.lfn[,10:12]))

par(mfrow=c(2,2))
tapply((asti.lfn$a),paste(asti.lfn$Year,asti.lfn$Site),hist)
```




```
par(mfrow=c(2,2))
tapply(sqrt(asti.lfn$a),paste(asti.lfn$Year,asti.lfn$Site),hist)
```



#as for the above, the distribution was much more symmetrical with a sqrt transform, so I transformed prior to getting the means, then reported back-transformed values.
#95% CI- these values were larger than the parametric CI, so I used the bootstrapped ones.

```
lfn.means=matrix(ncol=4,nrow=12)
lfn.resamp=matrix(nrow=10000,ncol=124)
```

```
for(l in c(5:8,10:12)){
lfn.means[l,]=tapply(sqrt(asti.lfn[,l]),(as.factor(paste(asti.lfn$Year,asti.lfn$Site))),mean)^
2}

for(x in 1:4){
lfn.temp=subset(asti.lfn,
as.factor(paste(asti.lfn$Year,asti.lfn$Site))==levels(as.factor(paste(asti.lfn$Year,asti.lfn$
Site)))[x])
for(k in 1:10000){
for(l in c(5:8,10:12)){
xx=sample(sqrt(lfn.temp[,l]),length(lfn.temp[,l]),replace=TRUE)
lfn.resamp[k,(l*10+x)]=mean(xx)^2
}}}

lfn.resamp.out=matrix(ncol=2,nrow=124)
for(y in 1:124){
lfn.resamp.out[y,]=quantile(lfn.resamp[,y],c(0.025,0.975),na.rm=TRUE)}

lfn.means
            [,1]        [,2]         [,3]         [,4]
 [1,]          NA          NA           NA           NA
 [2,]          NA          NA           NA           NA
 [3,]          NA          NA           NA           NA
 [4,]          NA          NA           NA           NA
 [5,]  6.16273799  9.92953595 6.352583e+00  9.431080937
 [6,]  0.15820472  0.00154321 9.721405e-02  2.611945690
 [7,] 18.30978747 12.02276663 1.138667e+01 12.412058527
 [8,]  0.03450496  0.00154321 6.028164e-04  0.009645062
 [9,]          NA          NA           NA           NA
[10,] 24.11009159 20.27367628 1.726088e+01 19.124074958
[11,]  0.89842794  1.37430260 1.001190e+00  5.068449208
[12,]  0.03450496  0.00154321 6.028164e-04  0.009645062

write.table(lfn.resamp.out,"asti lfn bootstrap output.txt",row.names=FALSE)
write.table(asti.out,"asti quad level data.txt",row.names=FALSE)

    #Total cover

tapply(sqrt(asti.quad$total),paste(asti.quad$Year,asti.quad$Site),mean)^2

2008 SACO 2009 EBCO 2009 SACO 2009 WEWA

 26.31119  22.19203  18.97077  25.11043

#95% CI- these values were larger than the parametric CI, so I used the bootstrapped
ones.
```

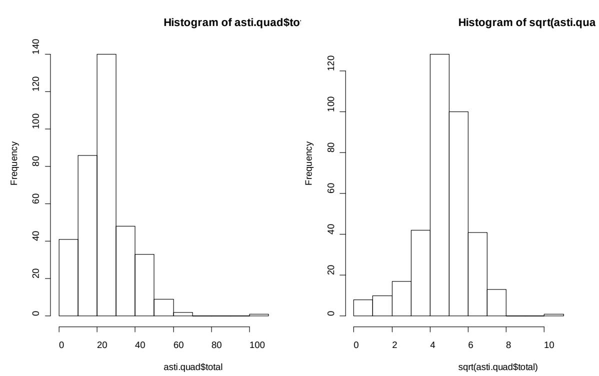
```
tapply(asti.quad$total,paste(asti.quad$Year,asti.quad$Site),mean)+(qnorm(0.975)*tapply
(asti.quad$total,paste(asti.quad$Year,asti.quad$Site),sd)/tapply(asti.quad$total,paste(asti.
quad$Year,asti.quad$Site),length))
2008 SACO 2009 EBCO 2009 SACO 2009 WEWA
 28.79489  22.99676  21.17721  25.68788

tot.resamp=matrix(nrow=10000,ncol=4)
for(x in 1:4){
tot.temp=subset(asti.quad$total,
as.factor(paste(asti.quad$Year,asti.quad$Site))==levels(as.factor(paste(asti.quad$Year,as
ti.quad$Site)))[x])
for(k in 1:10000){
xx=sample(sqrt(tot.temp),length(tot.temp),replace=TRUE)
tot.resamp[k,x]=mean(xx)^2
}}

tot.resamp.out=matrix(ncol=2,nrow=4)
for(y in 1:4){
tot.resamp.out[y,1:2]=(quantile(tot.resamp[,y],c(0.025,0.975)))}

    > tot.resamp.out
          [,1]     [,2]
    [1,] 23.84082 28.97493
    [2,] 20.24860 24.30453
    [3,] 16.96229 21.01857
    [4,] 23.40459 26.93035

    #Below shows why the sqrt transform
    for(i in 1:360){asti.quad$total[i]=sum(asti.quad[i,5:99])}
    par(mfrow=c(1,2))
    hist(asti.quad$total)
    hist(sqrt(asti.quad$total))
```



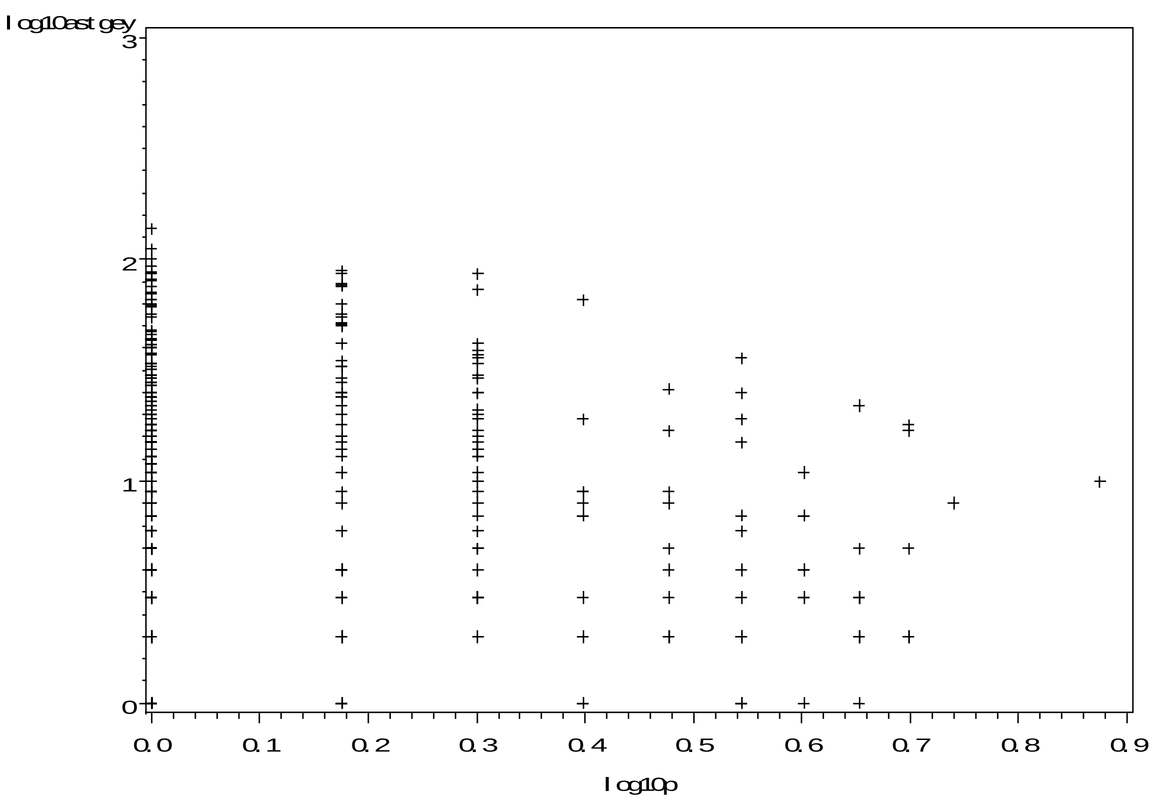

```
    #whole-site level diversity and richness
asge.gamma=matrix(nrow=4,ncol=95)
```

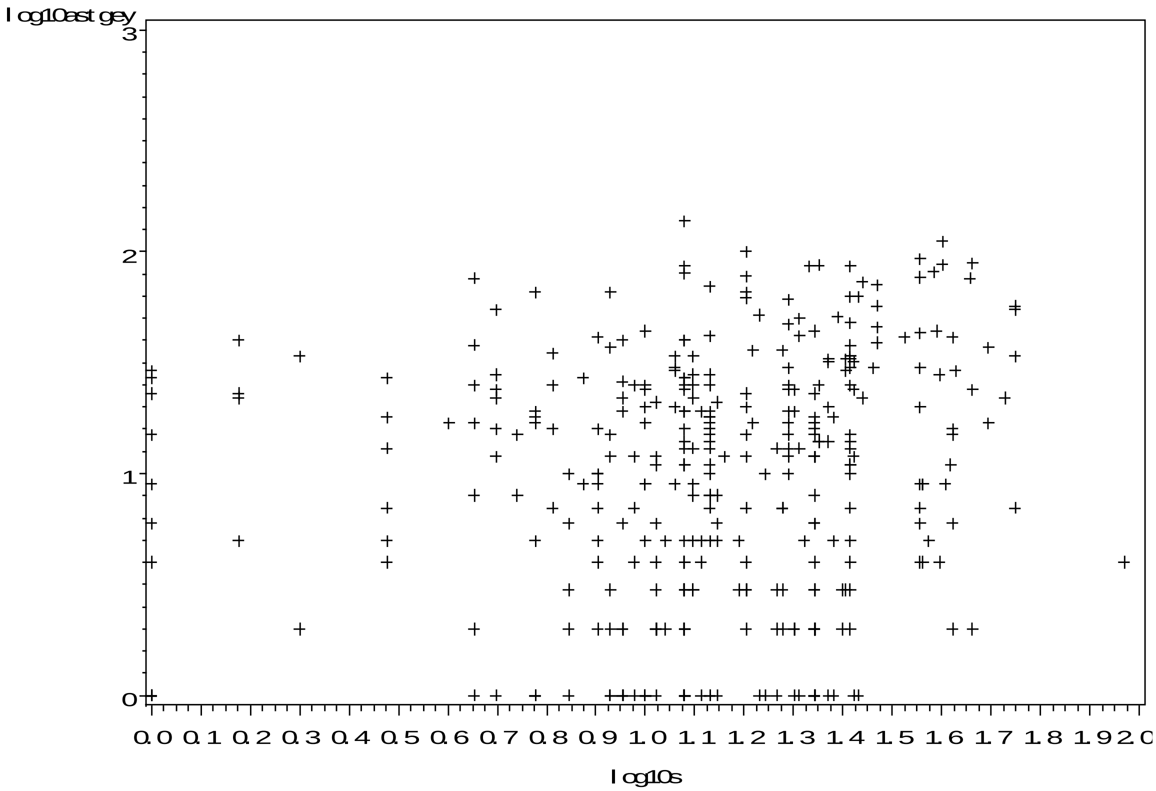
```
for(i in 3:97){asge.gamma[,i-
2]=tapply(raw[,i],(as.factor(paste(raw$Year,raw$Site))),sum)}

rich.div=matrix(nrow=4,ncol=2)
for(x in 1:4){
rich.div[x,1]=d(asge.gamma[x,],q=0)
rich.div[x,2]=d(asge.gamma[x,],q=1)}
```

##########Relationships Among Variables for ASTGEY (SAS)

NAME	log10a	log10p	log10s	log10w	log10n	log10astgey	log10diversity	log10totcov
log10a	1.000	0.056	0.105	0.731	0.292	-0.101	0.675	0.375
log10p	0.056	1.000	0.059	0.114	0.074	-0.130	0.189	0.128
log10s	0.105	0.059	1.000	0.086	0.959	0.192	-0.345	0.926
log10w	**0.731**	0.114	0.086	1.000	0.167	-0.218	0.534	0.298
log10n	0.292	0.074	**0.959**	0.167	1.000	0.162	-0.205	0.975
log10astgey	-0.101	-0.130	0.192	-0.218	0.162	1.000	-0.114	0.128
log10diversity	**0.675**	0.189	-0.345	0.534	-0.205	-0.114	1.000	-0.166
log10totcov	0.375	0.128	**0.926**	0.298	**0.975**	0.128	-0.166	1.000




log10astgey
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2
1
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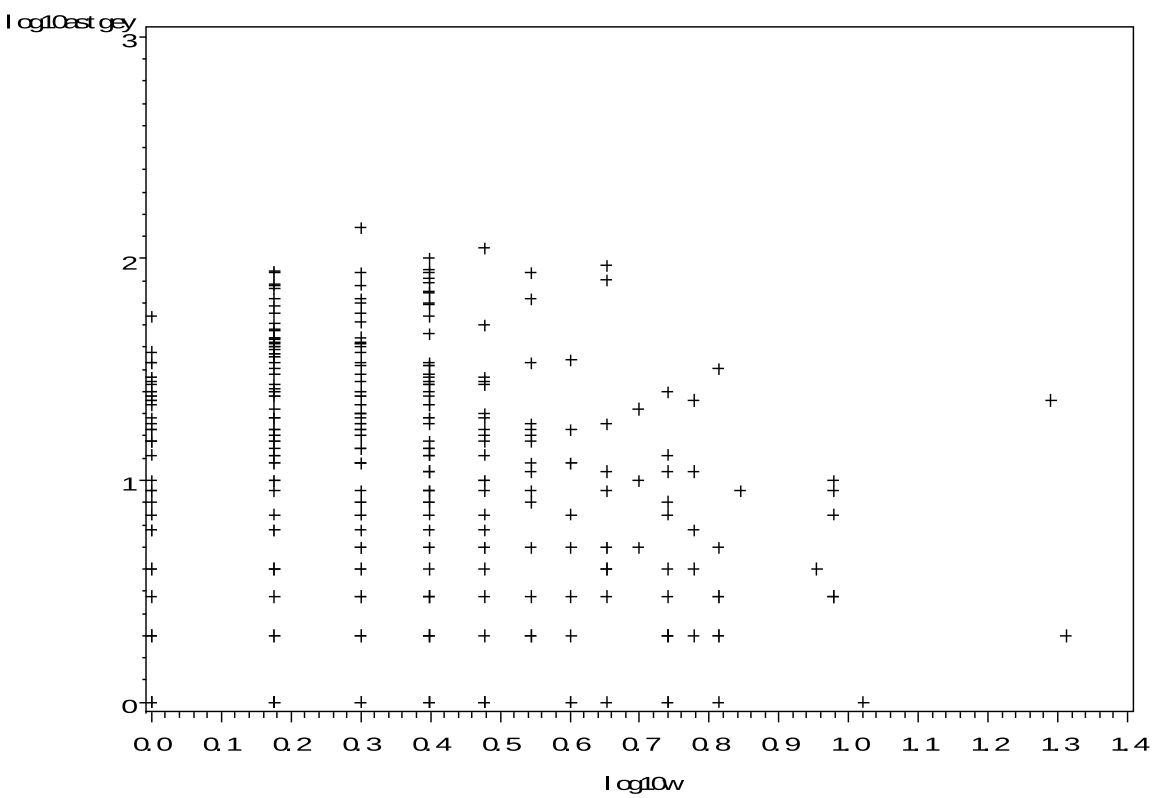
log10s


log10astgey
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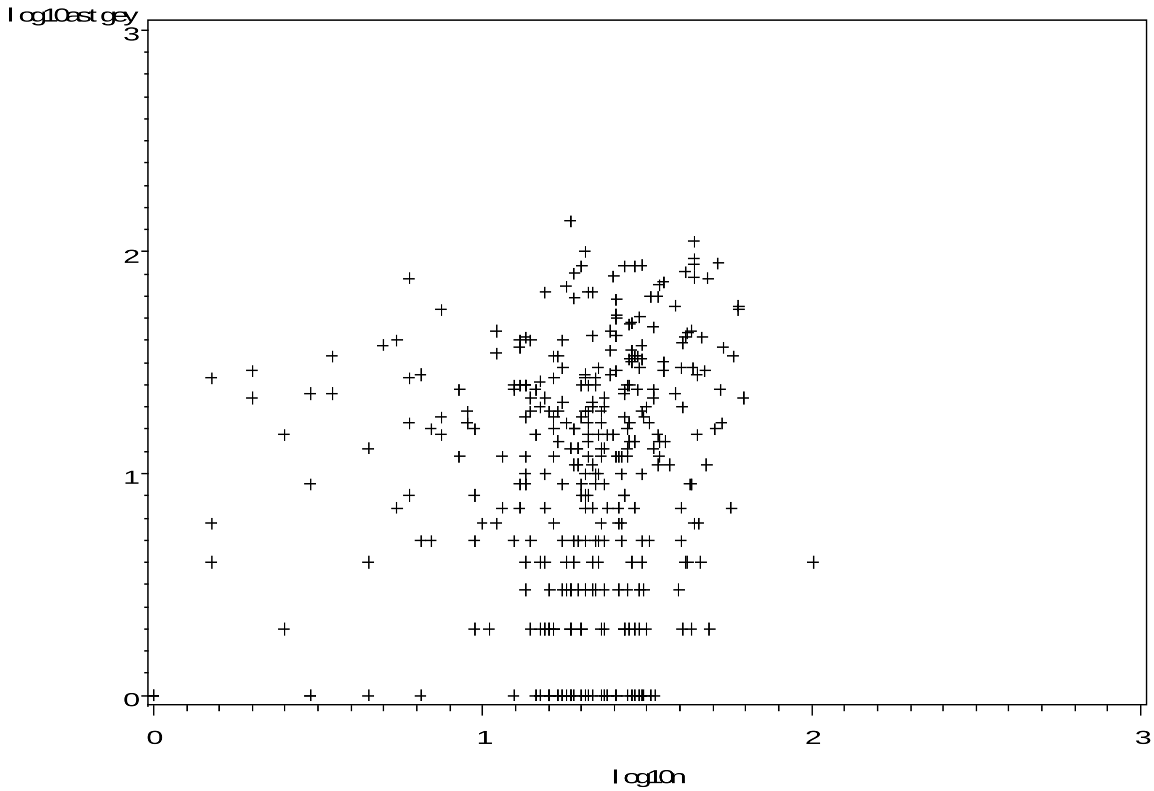
log10w


log10astgey
log10n

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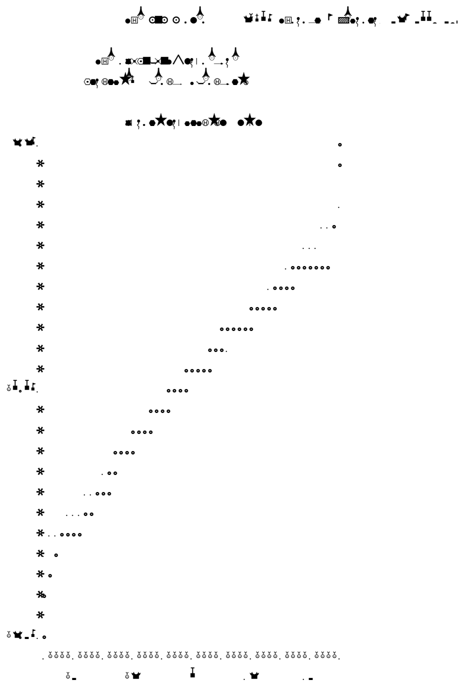

ERVI Analysis notes

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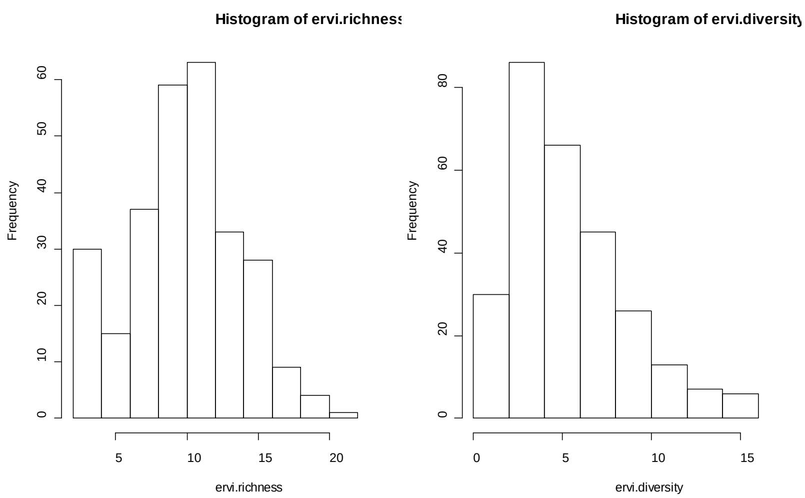
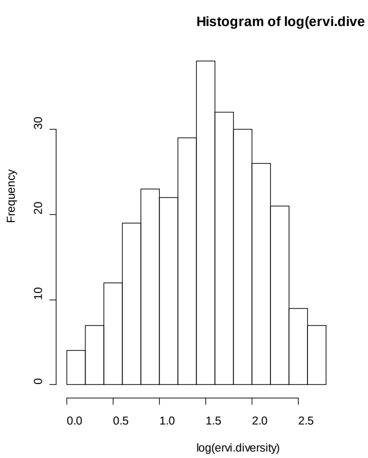
#created diversity and species richness data sets for each site
ervi.quad=read.delim("ervi community quad.txt")
ervi.richness=matrix(ncol=1,nrow=length(ervi.quad[,1]))
ervi.diversity=matrix(ncol=1,nrow=length(ervi.quad[,1]))

library(vegetarian)
for(j in 1:length(ervi.quad[,1])){
ervi.richness[j]=d(ervi.quad[j,5:69],q=0)
ervi.diversity[j]=d(ervi.quad[j,5:69],q=1)}

par(mfrow=c(1,2))
hist(ervi.richness)
hist(ervi.diversity)
```

Distributions of richness and diversity by quadrat.





We'll again work with Shannon index rather than Hill's number.

Mean and bootstrapped 95% CI for log(diversity) and species richness for each site/year.

```
tapply(ervi.richness,paste(ervi.quad$Year,ervi.quad$Site),mean)
2^(tapply(log2(ervi.diversity), paste(ervi.quad$Year,ervi.quad$Site),mean))

> tapply(ervi.richness,paste(ervi.quad$Year,ervi.quad$Site),mean)
2008 GLHO 2008 LICO 2009 GAHI 2009 LICO
 8.528571 10.471429 10.742857 11.536232

> 2^(tapply(log2(ervi.diversity), paste(ervi.quad$Year,ervi.quad$Site),mean))
2008 GLHO 2008 LICO 2009 GAHI 2009 LICO
 4.620743  5.073182  3.786854  4.555518
```

```
#95% CI- these values were larger than the parametric CI, so I used the bootstrapped ones.
tapply(ervi.richness,paste(ervi.quad$Year,ervi.quad$Site),mean)+(qnorm(0.975)*tapply(ervi.richness,paste(ervi.quad$Year,ervi.quad$Site),sd)/tapply(ervi.richness,paste(ervi.quad$Year,ervi.quad$Site),length))

rich.resamp=matrix(nrow=10000,ncol=4)
div.resamp=matrix(nrow=10000,ncol=4)
for(x in 1:4){
div.temp=subset(ervi.diversity,
as.factor(paste(ervi.quad$Year,ervi.quad$Site))==levels(as.factor(paste(ervi.quad$Year,ervi.quad$Site)))[x])
rich.temp=subset(ervi.richness,
as.factor(paste(ervi.quad$Year,ervi.quad$Site))==levels(as.factor(paste(ervi.quad$Year,ervi.quad$Site)))[x])
for(k in 1:10000){
xx=sample(rich.temp,length(rich.temp),replace=TRUE)
rich.resamp[k,x]=mean(xx)
xy=sample(log2(div.temp),length(div.temp),replace=TRUE)
div.resamp[k,x]=2^mean(xy)}}

resamp.out=matrix(ncol=4,nrow=4)
for(y in 1:4){
resamp.out[y,1:2]=(quantile(div.resamp[,y],c(0.025,0.975)))
resamp.out[y,3:4]=(quantile(rich.resamp[,y],c(0.025,0.975)))}

resamp.out
         [,1]     [,2]      [,3]      [,4]
[1,] 3.988131 5.337561  7.628571  9.457143
[2,] 4.647667 5.536185  9.928571 11.028571
[3,] 3.163681 4.533526  9.485714 11.957143
[4,] 4.018278 5.143287 10.913043 12.188406
```

#as for the above, the distribution was much more symmetrical with a sqrt transform, so I transformed prior to getting the means, then reported back-transformed values.
#95% CI- these values were larger than the parametric CI, so I used the bootstrapped ones.

```
ervi.lfn=read.delim("ervi life form nativity.txt")

lfn.means=matrix(ncol=4,nrow=12)
lfn.resamp=matrix(nrow=10000,ncol=124)

for(l in c(5:9)){
lfn.means[l,]=tapply(sqrt(ervi.lfn[,l]),(as.factor(paste(ervi.lfn$Year,ervi.lfn$Site))),mean)
^2}

for(x in 1:4){
lfn.temp=subset(ervi.lfn,
as.factor(paste(ervi.lfn$Year,ervi.lfn$Site))==levels(as.factor(paste(ervi.lfn$Year,ervi.lfn
$Site)))[x])
for(k in 1:10000){
for(l in c(5:9)){
xx=sample(sqrt(lfn.temp[,l]),length(lfn.temp[,l]),replace=TRUE)
lfn.resamp[k,(l*10+x)]=mean(xx)^2
}}}

lfn.resamp.out=matrix(ncol=2,nrow=124)
for(y in 1:124){
lfn.resamp.out[y,]=quantile(lfn.resamp[,y],c(0.025,0.975),na.rm=TRUE)}

lfn.means
[5,] 16.59914312 22.81246534 19.57179587 22.108178660
 [6,]  0.04819204  0.03112192  0.05340993  0.005145978
 [7,]  2.82254445  0.34779337  2.18584727  0.361064315
 [8,]  4.23045636 11.32217399  4.75008078  8.360824699
 [9,] 14.07911810 11.41682627 17.90860308 13.435701067
[10,] 22.11449829 24.67813779 26.00530868 24.259188095
```

#Total cover

```
tapply(sqrt(ervi.lfn$total),paste(ervi.lfn$Year,ervi.lfn$Site),mean)^2
2008 GLHO 2008 LICO 2009 GAHI 2009 LICO
 22.11450  24.67814  26.00531  24.25919
```

#95% CI- these values were larger than the parametric CI, so I used the bootstrapped ones.

```
tapply(ervi.lfn$total,paste(ervi.quad$Year,ervi.quad$Site),mean)+(qnorm(0.975)*tapply(
ervi.lfn$total,paste(ervi.quad$Year,ervi.quad$Site),sd)/tapply(ervi.lfn$total,paste(ervi.qu
ad$Year,ervi.quad$Site),length))
2008 GLHO 2008 LICO 2009 GAHI 2009 LICO
 25.19909  27.19056  27.99389  27.77533

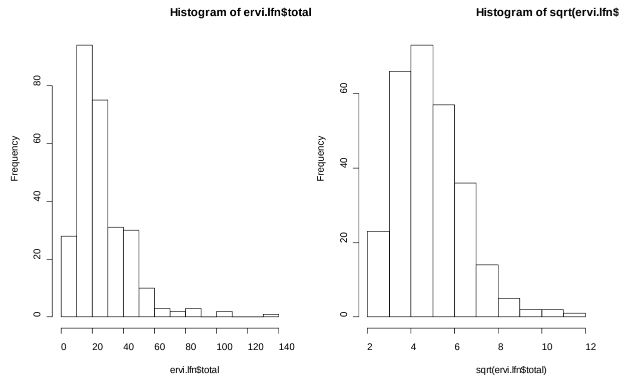
tot.resamp=matrix(nrow=10000,ncol=4)
for(x in 1:4){
tot.temp=subset(ervi.lfn$total,
as.factor(paste(ervi.quad$Year,ervi.quad$Site))==levels(as.factor(paste(ervi.quad$Year,e
rvi.quad$Site)))[x])
for(k in 1:10000){
xx=sample(sqrt(tot.temp),length(tot.temp),replace=TRUE)
tot.resamp[k,x]=mean(xx)^2
}}

tot.resamp.out=matrix(ncol=2,nrow=4)
for(y in 1:4){
tot.resamp.out[y,1:2]=(quantile(tot.resamp[,y],c(0.025,0.975)))}

tot.resamp.out

         [,1]     [,2]
[1,] 18.88018 25.93029
[2,] 21.61996 28.14841
[3,] 23.17538 29.22097
[4,] 20.55843 28.58658

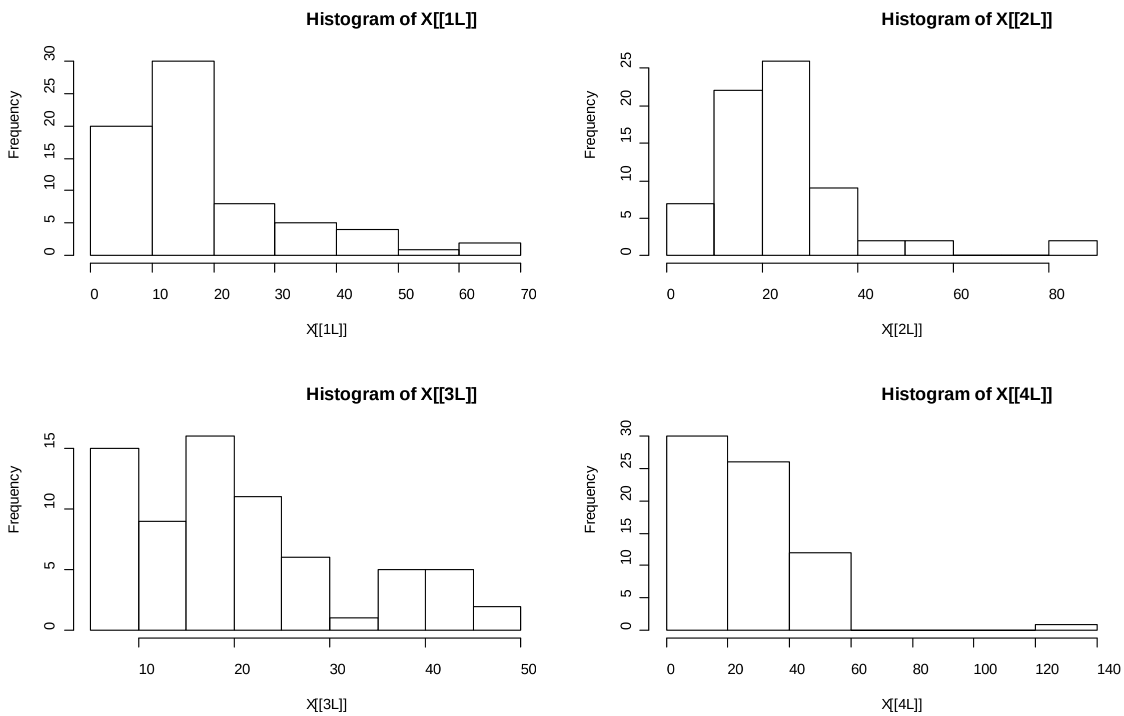
#Below shows why the sqrt transform
for(i in 1:360){ervi.lfn$total[i]=sum(ervi.quad[i,5:99])}
par(mfrow=c(1,2))
hist(ervi.lfn$total)
hist(sqrt(ervi.lfn$total))
```



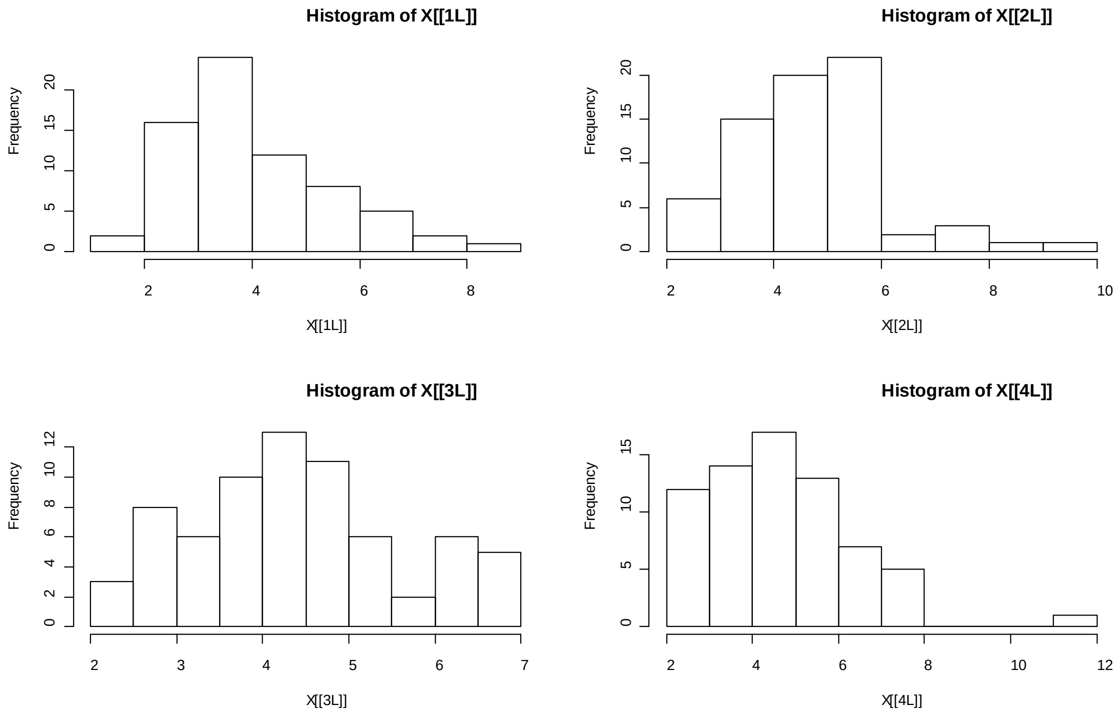
```
#whole-site level diversity and richness
ervi.gamma=matrix(nrow=4,ncol=95)
for(i in 5:69){ervi.gamma[,i-2]=tapply(raw[,i],(as.factor(paste(raw$Year,raw$Site))),sum)}

rich.div=matrix(nrow=4,ncol=2)
for(x in 1:4){
rich.div[x,1]=d(ervi.gamma[x,],q=0)
rich.div[x,2]=d(ervi.gamma[x,],q=1)}

par(mfrow=c(2,2))
tapply((ervi.lfn$a),paste(ervi.lfn$Year,ervi.lfn$Site),hist)
#Annuals
```




```
par(mfrow=c(2,2))
tapply(sqrt(ervi.lfn$p),paste(ervi.lfn$Year,ervi.lfn$Site),hist)
#perennials
```




```
ervi.out=as.data.frame(cbind(ervi.quad[,1:4],ervi.diversity,ervi.richness,ervi.lfn[,5:9]))
write.table(lfn.resamp.out,"ervi lfn bootstrap output.txt",row.names=FALSE)
write.table(ervi.out,"ervi quad level data.txt",row.names=FALSE)
```

```
##########Relationships with quadrat-level habitat variables and ERVI presence###
 *ERVI*******************************;
proc import datafile="C:\Documents and Settings\cheryl vanier\My
Documents\UNLV\dianne\rare plant surveys\sand species\ervi files.xls"
out=erviraw replace; sheet="ervi quad level data"; run;
proc import datafile="C:\Documents and Settings\cheryl vanier\My
Documents\UNLV\dianne\rare plant surveys\Data to
Cheryl_Finals\xycoord.xls"
out=xy replace; sheet="xyervi"; run;

data xy; set xy; coord=1;  run;
proc sort data=xy nodupkey; by year site transect quadrat;
proc sort data=erviraw; by year site transect quadrat;
data ervixy; merge erviraw xy; by year site transect quadrat;
run;

data ervixy; set ervixy; yearsite=year||site; log10ervi=log10(ervi+1);
log10diversity=log10(ervi_diversity+1); log10a=log10(a+1);
log10p=log10(p+1); log10s=log10(s+1);
log10n=log10(n+1); log10w=log10(w+1); log10totcov=log10(a+p+s+1);
log10lcovmid=log10(lcovmid+1);
log10rcovmid=log10(rcovmid+1);
log10scovmid=log10(scovmid+1);run;
proc gplot data=erviraw; plot log10ervi*log10diversity;
```

```
plot log10ervi*ervi_richness;
plot log10ervi*log10a;
plot log10ervi*log10p;
plot log10ervi*log10s;
plot log10ervi*log10w;
plot log10ervi*log10n;
plot log10ervi*log10lcovmid;
plot log10ervi*log10rcovmid;
plot log10ervi*log10scovmid;
plot log10ervi*tracks01;
run;
proc gplot data=erviraw; plot ervi*log10n; run;
proc univariate plot normal data=erviraw; var log10ervi log10n; run;

*full model; *some missing values for lcov, so not included in overall
model;
proc sort data=ervixy; by yearsite transect;
proc corr spearman data=ervixy outs=ervicorr; run;
proc mixed data=ervixy; by yearsite; class transect;
model log10ervi=ervi_richness log10diversity log10a log10p log10s
log10n log10w
rcovmid log10scovmid log10lcovmid/outp=res solution; *log10lcovmid ;
random transect;
repeated/ type=sp(expga)(xcoord ycoord);
ods output solutionf=anva_out2;
run;
proc univariate plot normal data=res; var resid; run;
proc mixed data=ervixy; by yearsite; class transect;
model log10ervi=log10diversity  log10p  log10w log10s
log10scovmid log10lcovmid /outp=res solution; * ;
random transect;
repeated/ type=sp(expga)(xcoord ycoord);
ods output solutionf=glho09_out;
run;

proc mixed data=ervixy; by yearsite; class transect;
model log10ervi=log10diversity  log10p  log10n
log10scovmid /outp=res solution; * ;
random transect;
repeated/ type=sp(expga)(xcoord ycoord);
ods output solutionf=lico09_out;
run;

proc mixed data=ervixy; by yearsite; class transect;
model log10ervi=ervi_richness log10diversity  log10p  log10n
log10scovmid /outp=res solution; * ;
random transect;
repeated/ type=sp(expga)(xcoord ycoord);
ods output solutionf=lico08_out;
run;

proc mixed data=ervixy; by yearsite; class transect;
model log10ervi= log10diversity  log10p   log10a log10w
log10scovmid /outp=res solution; * ;
random transect;
repeated/ type=sp(expga)(xcoord ycoord);
ods output solutionf=glho08_out;
```

```
run;

proc export data=glho09_out outfile="C:\Documents and Settings\cheryl
vanier\My Documents\UNLV\dianne\rare plant surveys\sand species\ervi
regressions.xls" replace;
proc export data=glho08_out outfile="C:\Documents and Settings\cheryl
vanier\My Documents\UNLV\dianne\rare plant surveys\sand species\ervi
regressions.xls";
proc export data=lico09_out outfile="C:\Documents and Settings\cheryl
vanier\My Documents\UNLV\dianne\rare plant surveys\sand species\ervi
regressions.xls";
proc export data=lico08_out outfile="C:\Documents and Settings\cheryl
vanier\My Documents\UNLV\dianne\rare plant surveys\sand species\ervi
regressions.xls";
proc export data=anva_out outfile="C:\Documents and Settings\cheryl
vanier\My Documents\UNLV\dianne\rare plant surveys\sand species\ervi
regressions.xls";
proc export data=anva_out2 outfile="C:\Documents and Settings\cheryl
vanier\My Documents\UNLV\dianne\rare plant surveys\sand species\ervi
regressions.xls";
run;
```