Sediment Transport to White-Margined

Penstemon Habitat (*Penstemon albomarginatus*)

2005-NSHE-502A-P

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EXECUTIVE SUMMARY

Rapid growth in the Las Vegas metro area is driving development southward into the Ivanpah Valley and has generated demand to build a new relief airport for McCarran International Airport. Growing near the area of the planned airport site (near Primm, NV) is the white-margined penstemon, or beardtongue (*Penstemon albomarginatus*), a rare perennial forb occurring in only four known general locations: two in the Mojave Desert of Southern Nevada, one in the Mojave Desert of southeast California, and one in the Sonoran Desert of northwest Arizona (F.J. Smith, 2001).

This report summarizes the findings from a two-year field study conducted in Southern Nevada between October 1, 2007 and September 30, 2009. Framed through a series of objectives, the overall goal was to better understand factors that affect the suitability of certain areas for *P. albomarginatus* habitats. Several objectives were specifically aimed at identifying relationships between the presence of *P. albomarginatus* and the extent of eolian sediment transport of sand and dust from upwind dry lake beds. This was motivated by the hypothesis that development of large areas of the Roach Lake basin for the planned Ivanpah Valley Airport may adversely affect *P. albomarginatus* populations around Roach Lake by impacting the eolian mobility of sediment through *P. albomarginatus* habitat areas.

Field measurements were targeted at characterizing climatic parameters, characteristics of *P. albomarginatus* habitat areas, and soil properties. The study relied on comparing characteristics of sites with *P. albomarginatus* populations to sites that are nearby and appear quite similar, but do not have *P. albomarginatus* plants. Seven sites were selected, five in Clark County (four *P. albomarginatus* and one comparison) and two in Nye County (one *P. albomarginatus* and one comparison). From south to north, the Clark County field study sites were the Roach Lake South penstemon site (RLS, just northeast of Roach Lake Playa), the Roach Lake comparison site (RLC, 3.5 km north of RLS), the Roach Lake North penstemon site (RLN, 5 km north of RLS), the Jean Lake Exclosure site (JLE, east of Jean Dry Lake), and Hidden Valley penstemon (HV). The Nye County sites were located along Hwy 95, just west of Death Valley Junction (Hwy 160) about 300 m south of the highway. The Nye County comparison site (NCC) was about 500 meters east and slightly south of the Nye County penstemon site (NCP).

Each study site was instrumented with a 6-meter high meteorological tower equipped with instruments for measuring temperature, relative humidity, solar radiation, barometric pressure, wind speed at five heights, wind direction (top), and rainfall. Additionally, two sets of soil moisture probes were installed at three ranges of depths (0-30 cm, 15-45 cm, and 45-60 cm), one set in the under canopy of a large perennial plant and one in the inter-spaces between large perennial plants.

Sand flux was measured with three arrays of sediment traps, one at each vertex of a triangle around the meteorological tower (about 15 meters apart). Each array consisted of four traps, with the lowest trap at a height of 5 cm and the highest at a height of 105 cm. The traps were mounted on a swiveling post so that they would orient themselves into the wind during high-wind events. Sediment traps were emptied and weighed eight times over the course of the study. Adjacent to the traps, real-time sand movement counters were installed with the sensing area of the instrument at a height of 10 cm above the soil surface. These sensors were intended to provide a temporal trace of eolian sediment transport events.

Atmospheric dust deposition was measured with a combination of both wet and dry deposition in modified United States Geological Survey (USGS) traps (Reheis and Kihl, 1995) once per year. Two replicate deposition traps, shaped like Bundt cake pans (outer diameter = 24.1 cm, inner diameter = 1.9 cm), were mounted at a height of 1.8 m and filled with clean-washed glass marbles. The traps were exposed for two periods over the course of the project.

Soils were sampled at several depths over the range 0–60 cm, both in areas under the canopies of large perennial plants and in the inter-spaces between such plants. Soil samples, sediment collected in eolian traps, and dust deposition samples were subjected to textural and chemical analysis (pH, electrical conductivity, phosphorous, ammonium, nitrate, organic carbon, and calcium carbonate) using standard procedures.

Soil saturated hydraulic conductivity was measured with a disc tension infiltrometer. Four-to-seven replicate measurements were completed at each site in the under canopy of large perennial plants and the inter-spaces between them. The USGS KINematic runoff and EROSion (KINEROS2) model was used in conjunction with field measured hydraulic conductivity (K_{sat}) to estimate overland runoff and sediment transport.

Plant community structure at each of the five penstemon sites and the two comparisons sites was characterized by measuring individual plant canopy heights, widths, and rectangular coordinates to the nearest cm for all live and dead perennial plant species in 50 m x 2.5 m transects. Twenty-two transects were measured in penstemon sites and eleven transects were measured in comparison sites. Plant species identifications were based on the *Jepson Manual of Higher Plants of California* (Hickman, 1993). Mean distances from *P. albomarginatus* plants to the nearest dominant species were also compared with a general linear model to evaluate potential facilitation or competition within the community. Results from a cluster analysis of our study sites were evaluated using non-metric multidimensional scaling based on perennial plant species densities (McCune and Grace, 2002).

All Nevada penstemon sites previously documented were resurveyed and *P. albomarginatus* densities and global positioning system (GPS) coordinates within 10-m wide continuous transects within and adjacent to the 1997-1998 estimated population boundaries (F.J. Smith, 2001) were recorded.

In April 2008, 30 *P. albomarginatus* plants within 100 m of the meteorological and sediment transport instruments at the Clark County penstemon sites (RLN, RLS, JLE, HV) were flagged and 60 plants were flagged and measured at the Nye County Penstemon (NCP) site. For each plant, the number of shoots, median shoot height, canopy widths, number of shoots with flowers, number of shoots with fruits, and number of shoots impacted by herbivores were counted. These data were collected again in May 2008 and March, April, and May 2009.

In October 2009, the root systems of five *P. albomarginatus* plants at the Hidden Valley (HV) study site and five *P. albomarginatus* plants at the Roach Lake North (RLN) study site were excavated and data for rooting depth and structure were measured. Whole root systems were collected and examined for potential root parasitism with adjacent perennial shrubs and grasses. Cross-sections of the root crowns were examined under a dissecting microscope and potential ages were estimated by counting annual xylem increments. Root tissue was also examined for ectomycorrhizal symbioses but not for endomycorrhizal symbioses.

P. albomarginatus recruitment, longevity, and mortality in relation to precipitation were also evaluated for the Jean Lake (JLE) population utilizing data collected by Bureau of Land Management (BLM) botanists from 1996 to 2006. The presence, location, canopy area, and fruiting status of all *P. albomarginatus* plants in eight 50 x 5 m transects were recorded each year in May.

Data from this study were examined and used to address several specific questions:

What are the characteristics of *P. albomarginatus* habitats?

All 12 *P. albomarginatus* populations documented during 1997-8 surveys (F.J. Smith, 2001) were resurveyed in 2008-9. Our surveys documented live *P. albomarginatus* plants within and adjacent to the 1997-8 estimated population boundaries. Based on 2008-9 field surveys of all known populations of *P. albomarginatus* in Clark and Nye Counties, we estimated that there are approximately 125,825 *P. albomarginatus* plants in Clark County and 78,954 plants in Nye County. These estimates are almost five times greater than the 1997-8 estimates of 25,964 for Clark County and two times greater than the 42,200 plants estimated for Nye County. Furthermore, our results are based on below-average precipitation years, so that the actual size of the *P. albomarginatus* population could be even greater than our estimate. However, owing to variations between the two methods used (ours and Smith's), it remains unclear if the differences between the two surveys are due to a real increase in *P. albomarginatus* population or simply a result of the approximate nature of the Smith (2001) surveys.

The age structure of *P. albomarginatus* populations could not be determined based on the above-ground growth characteristics we measured. However, there were significant differences in mean *P. albomarginatus* canopy height and area among the five populations we measured, but these differences were not consistent when the 2008 growth data are compared to the 2009 data. The root length, biomass, and xylem ring count data indicate that annual above-ground plant biomass production is not significantly correlated with plant age or reproductive potential. If xylem ring counts for root collars do represent annual growth increments – a reasonable but untested hypothesis – then the ages of the ten root systems we excavated ranged from approximately 5 to 35 years. During the study the percent of shoots with flowers varied from 3 to 56, while the number of shoots with fruits varied from 0 to 33 percent. The Nye County plants produced essentially no fruits in both study years and the Jean Lake Exclosure (JLE) population also did not produce fruits in 2009. Drought and insect herbivory were the causes for the lack of reproductive success at the Nye County penstemon (NCP) and JLE sites. Among the other sites, actual seed dispersal was only observed for the Hidden Valley (HV) population in 2009 and dispersal distances ranged from 1 to 15 cm.

Plant community structure for *P. albomarginatus* populations differed more between counties than between penstemon and comparison sites. Results of a cluster analysis of the study sites indicated that for Clark County, the native perennial grass, *P. rigida*, and the native shrubs, *K. lanata* and *Acamptopappus shockleyi*, are the most likely indicator species for the presence of *P. albomarginatus*. *A. dumosa*, *L. tridentata,* and *Krameria erecta* are relatively ubiquitous and apparently unrelated to the presence of *P. albomarginatus*.

Within each population, 66 to 94 percent of the *P. albomarginatus* plants occurred in the canopy inter-spaces. For the small number of *P. albomarginatus* that occurred in under canopy locations, the overstory species was equally likely to be *A. dumosa* or *P. rigida* (only in Clark County), but never *L. tridentata*. *P. albomarginatus* establishment is much more likely in canopy inter-spaces than under plant canopies, but our data could not determine whether this simply reflects the relative abundance of inter-space areas compared to under canopy areas. Our results indicate that, similar to most Mojave Desert perennial plant species, *P. albomarginatus* recruitment events are rare and episodic and may require a combination of successive wet years that favor seed production, seed germination, and seedling growth.

What are the ranges of soils, geomorphology, and climatic properties supporting *P. albomarginatus* populations?

All of the study sites where *P. albomarginatus* was present can be characterized as sandy (>80 percent sand, >85 percent at surface) to a depth of at least 60 cm, having slopes in the range of 1.8-4.6 percent with aspects (facing direction) in the range of 174-309 degrees from north. Due to their texture, soils were all very well-drained with measured saturated hydraulic conductivities in excess of 50 mm/hr. Soil moisture content was typically low, with annual average volumetric water content generally less than 5 percent, but with peak months approaching 8-10 percent. Precipitation was below average during the 2008-9 study years, with measured rainfall in Clark County and Nye County averaging about 80 mm/year and about 50 mm/year, respectively, over the two-year period. Long-term monitoring data collected by the Bureau of Land Management at the Jean Lake Exclosure (JLE) site suggest that plant emergence can occur in years with as little as 10 mm of precipitation (rainfall measured only from January through June).

In comparing the five sites with *P. albomarginatus* populations to the two comparison sites (no *P. albomarginatus*), it was found that the soil and climatic parameters mentioned above varied more between sites in different counties than between penstemon and comparison sites. This was also true for average and extreme values for temperature, relative humidity, solar radiation, and wind speeds. Small differences between counties notwithstanding, overall, these climatic variables were very similar across all sites and exhibited typical ranges for Mojave Desert basins. Therefore, these parameters may be part of a range of conditions that are suitable for *P. albomarginatus*, but there was no evidence that the comparison sites had critically different conditions than the penstemon sites in the context of these parameters.

There were some other parameters that were different between soils at penstemon and comparison sites. The soil acidity measured from 0 to a depth of 2.5 cm was slightly higher at penstemon sites, although the difference probably is not meaningful (near neutral in any case). At penstemon sites, the profile with depth of clay content exhibited a peak in the 5-30 cm depth, changing in value from about 4 to about 7 percent. This appeared to coincide with a peak in carbonate content (up to about 18 percent carbonate in the vegetation inter-space region) over the 5-15 cm depth. Both of these peaks were muted or altogether absent from the soil profiles at the comparison sites.

A common attribute of soils at penstemon sites was that the soils were mapped as formed in alluvium and covered by eolian sand. According to Natural Resources Conservation Service (NRCS) soil maps, all of the penstemon sites from this study as well as previously documented penstemon sites not instrumented in this study shared a few common soil series. Even though eolian sediment transport rates recorded during our study were relatively low, it is probably the eolian nature of the soils for most of the known *P. albomarginatus* populations in Nevada that results in the lack of significant cryptobiotic crust development in the *P. albomarginatus* habitats.

In summary, sandy soils with shrub covers of less than 20 percent and an accumulation of surface carbonates in the canopy inter-spaces appear to provide the best habitats for sustainable *P. albomarginatus* populations based on the persistence and/or expansion of the population size and extent of the estimates from the 1997-8 surveys. Furthermore, based on *P. albomarginatus* densities, the Bluepoint and Arizo soil series supported the largest *P. albomarginatus* populations in both Clark and Nye Counties, and wherever these soils occur the possibility of discovering new *P. albomarginatus* populations exists. It is not clear if the higher carbonate content near the surface of the soil is of importance to *P. albomarginatus* habitat or if it is only an incidental consequence of the types of soils that the *P. albomarginatus* occur in.

To what extent does eolian transport of sand occur?

The five sites where *P. albomarginatus* was present were clearly shaped by eolian transport of sand and the presence of this sand appears to be an important factor in *P. albomarginatus* habitat areas. However, the eolian deposits in *P. albomarginatus* sites were formed over geological time scales. On-site measurements of sand transport indicated that present-day rates for eolian sediment transport are in line with the low end of the range of other measurements reported for desert regions vegetated with creosote and tarbush (Bergammetti and Gillette, in press). At these rates – on the order of 2.5-10 kg soil/meter/year – it would take centuries for new sediment deposits to add 1 cm of soil.

The vegetation density at the seven study sites is the primary reason for the low sediment transport rates. Estimates based on measured densities indicate that about 80 percent of the wind's momentum is extracted by the vegetation, with the remainder available to initiate sediment transport. A lag cover at most sites that is composed of small pebbles and gravel further reduces the wind's momentum and provides additional stability to the soil surface. Furthermore, sand saltation, the dominant mechanism for eolian transport, is attenuated by the presence of vegetation which removes sand grains and prohibits the full-blown mobilization of surface sediment. Under these conditions sediment transport occurs in short fits and starts, often resulting in a reshuffling of surface sand within a site rather than robust sand transport through the site.

The sediment collected in the sand traps was also examined for chemical content. Overall, the chemical composition of the material was similar to the native soil, suggesting that present-day sand transport does not serve to replenish nutrients at *P. albomarginatus* sites.

Based on these findings, despite the strong association between the presence of *P. albomarginatus* and well-drained sandy soils of eolian origin, it is unlikely that present-day eolian sand transport processes have any appreciable effect on *P. albomarginatus* habitat areas. Permanent changes in surface cover notwithstanding (e.g. vegetation changes due to climate change, land use), the density of present-day vegetation at the study sites greatly reduces the extent of eolian sand transport.

To what extent does eolian transport of dust occur?

Deposition of dust varied in magnitude more by county than between penstemon and comparison sites, with deposition rates to Clark County sites (1.1-24 g/m^2/year) about five times those to Nye County sites (1.3-1.4 g/m^2/year) on average. Enrichment factors of deposited dust with respect to the surface soil material for phosphorous (P), ammonium (NH_4), and organic carbon were all significantly greater than unity, indicating that deposition is a net source of these materials to the soil. In all cases, dust was a larger source of these materials than eolian sand, with annual mass deposition rates that were comparable to a small fraction (few percent) of the amount of material in the top 1 cm of soil. Nitrate deposition represented a very significant source of nitrate for the soil, with annual mass deposition rates equal to as much as 60 percent of the nitrate present in the top 1 cm of soil.

Although we were not able to determine if the material deposited to the sites is of importance in the context of maintaining sustainable *P. albomarginatus* populations, patterns of deposition rates, with significant obvious differences between Clark and Nye County, clearly indicate that the material deposited is dominated by regional-scale (10-100s of kilometers) sources rather than local (10-1000s meters) basin sources. This is most clearly illustrated by the enhanced nitrate deposition in Clark County (due to proximity to Los Angeles basin and high levels of nitrate air pollution) as compared to Nye County.

To what extent do fluvial processes that push sediment downslope counteract eolian processes?

The results of KINEROS2 modeling indicate that even when exceptional events were considered (e.g., 100-year rainfall), the amount of sediment transport through overland runoff is very small – smaller even than the eolian transport rates. Admittedly a simplistic representation of basin hydrology, the model did underscore the exceptional drainability of the surface soils at our study sites and reinforced the descriptions of drainability based on the soil mapping units.

Channels were a dominant feature of the landscape, both at penstemon and comparison sites, and it is likely that channel flow is the primary pathway for fluvial sediment transport downslope. In fact, consistent with expectation for the Mojave's basin and range topography, it appears that channel flow is the dominant present-day geomorphic process, with eolian transport and overland runoff occurring at much lower rates – at least at sites suitable for *P. albomarginatus* habitat.

Study shortcomings

In aspects related to *P. albomarginatus* habitat, density, and community characterization, as well as climatic, environmental, and sediment transport measurements, the major shortcoming of this study is that it took place over a relatively short two-year period and at a limited number of locations. Furthermore, the survey methods used were not designed for long-term trends assessment, but rather were intended to provide a snapshot in time. The establishment of one or more long-term monitoring sites is suggested. Ideally, these sites would focus on measurement of environmental parameters as well as the health of *P. albomarginatus* populations. Additional deposition and sand flux measurement instrumentation would not further impact costs or labor requirements and may yield useful longer-term information. Perhaps existing BLM monitoring locations such as the Jean Lake Exclosure (JLE) or the Hidden Valley (HV) *P. albomarginatus* population monitoring area would be suitable for this purpose.

This study focused on *P. albomarginatus* in Southern Nevada sites. *P. albomarginatus* is also documented to occur in the Mojave Desert of southeast California and the Sonoran Desert of northwest Arizona (F.J. Smith, 2001). The soils, climatic properties, and habitat characteristics at those two locations could further our understanding of the range of conditions that are suitable for *P. albomarginatus* habitat. Therefore, we recommend that those populations be better characterized and the results of that work be compared to those of the present study.

Related to spatial representativeness, it is also recommended that a genetic analysis of existing *P. albomarginatus* populations be conducted to better understand the impact of the reproductive isolation of the Clark and Nye County populations (as well as the California and Arizona populations) and to assess the overall genetic diversity within the species.

Management considerations

Historical development patterns suggest that the Clark County populations of *P. albomarginatus* are more likely than the Nye County populations to be negatively impacted by land use. Due to the large, deep root system of *P. albomarginatus*, it is not practical to transplant *P. albomarginatus* from threatened populations to suitable sites. Possibly, *P. albomarginatus* seed could be used to establish new populations at suitable sites.

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1 Introduction

The corridor between Las Vegas and the California border, along I-15, has been a focus of future urban planning in the last few years. In 1998, Congress approved a land withdrawal near Primm, Nevada, for the purposes of an airport and associated industrial and commercial development (Ivanpah Valley Airport Public Lands Transfer Act, H.R. 3705). The majority of the airport development would occur on Roach Lake. In the Clark County Conservation of Public Land and Natural Resources Act of 2002, an undetermined number of acres were identified along the I-15 corridor to support utility development for the airport. As growth in Las Vegas continues, new opportunities for development will be sought. Particularly for the cities of Henderson and Las Vegas, a new airport near Primm will drive a desire to expand south.

One of the plants growing in this area is the white-margined penstemon or beardtongue (*Penstemon albomarginatus*), a rare perennial forb (Figure 1-1) occurring in only four known general locations: two in the Mojave Desert of Southern Nevada, one in the Mojave Desert of southeast California, and one in the Sonoran Desert of northwest Arizona (F.J. Smith, 2001).

a. b.

Figure 1-1. *Penstemon albomarginatus* growing in eolian sand (a) and alluvial sand and gravel (b), Clark County, Nevada (May 2006).

This study was motivated by the need to better understand the potential interactions between *P. albomarginatus* habitat and possible future development activities at Roach Lake or near other known *P. albomarginatus* populations and the subsequent need for mitigation to prevent *P. albomarginatus* from being added to the United States Fish and Wildlife Service Endangered Species list. Broadly, the project goals were to better characterize the existing populations and habitat characteristics of *P. albomarginatus* in Southern Nevada, determine whether transport of sediment into or out of habitat areas has a dominant role in maintaining populations, and, if possible, identify factors that determine where and why *P. albomarginatus* populations currently occur. These findings could then be used as a basis for development and implementation of sustainable land management practices.

1.1 Report organization

Study objectives and background concepts are provided in the remainder of this section. Methods used in conducting measurement, data analysis, and modeling are described in detail in Chapter 2. The results of these efforts are summarized in Chapter 3. In Chapter 4, the results are discussed and analyzed in the context of the below stated objectives. A summary of the conclusions drawn is provided in Chapter 5.

1.2 Objectives

Specifically, the questions we sought to answer were:

1) **What are the characteristics of *P. albomarginatus* habitats?**

    a. Determine the areal extent, density, spatial patterns, age structure, seed production viability and dispersal, and rooting depths and distributions for *P. albomarginatus* populations.

    b. Determine the range in plant community structures supporting existing populations of *P. albomarginatus*: Species composition including non-vascular plants (cryptobiotic crusts and mycorrhizal associations), density (plants/m^2), spatial patterns, and age (size) structure.

2) **What are the ranges in soils, geomorphology, and climatic properties supporting *P. albomarginatus* populations?**

    a. Determine ranges in properties including texture, structure, chemistry, hydraulic conductivity, and moisture, as well as other environmental parameters such as slope, aspect, rainfall, temperature, wind, and solar radiation.

3) **To what extent does eolian transport of sand occur?**

    a. Determine the scales of sand transport: Is sand transported from distances of kilometers upwind or is it redistributed within an area?

    b. Determine to what degree vegetation structure affects sand transport and to what degree *P. albomarginatus* populations rely on such sand transport.

4) **To what extent does eolian transport of dust occur?**

    a. Determine how prevalent dry deposition of dust-sized particles is and to what degree those particles originate from upwind playas.

    b. Determine if such particles carry specific nutrients or appear to cause conditions that are essential for *P. albomarginatus* populations.

5) **To what extent do fluvial processes that push sediment downslope counteract eolian processes?**

a. Determine if the balance or difference in sediment transport through fluvial and eolian processes is relevant to survival of *P. albomarginatus* populations?

To achieve the above objectives, a 2-year field measurement campaign was started on October 1, 2007, and ended on September 30, 2009. Seven sites were selected for in-depth characterization. Two sites were located in Nye County, Nevada, and five sites were located in Clark County, Nevada. Five of the sites corresponded to locations where *P. albomarginatus* populations were documented in the past ("penstemon sites"), while two "comparison sites" without *P. albomarginatus* were used for identifying possible limiting environmental factors. All sites were instrumented with meteorological towers, sand traps, dust deposition traps, and automated sand motion sensors. *P. albomarginatus* phenology, density, community structure, and rooting depths were characterized at the five penstemon sites. Density and areal extent were also determined for other locations in Southern Nevada where *P. albomarginatus* plants were found during 1997-8 field surveys. Commonalities and differences among penstemon and comparison sites as well as among Clark County and Nye County sites were used in conjunction with biotic and abiotic characteristics to determine which, if any, measured environmental parameters could have a limiting influence on where *P. albomarginatus* occurs.

1.3 Background

The penstemon genus is endemic to North America, containing approximately 250 species in the Scrophulariaceae, or figwort, family. It was first discovered in 1884 by Marcus Jones near Yucca, Arizona. Twenty-one years later, in 1905, M. Jones discovered a second population in Clark County, Nevada, and *P. albomarginatus* was formally described as a species in 1908 (Jones, 1908). The San Bernardino County, California, populations were discovered in 1920 and 1941 and the populations in Nye County, Nevada, were discovered in 1970 and 1997. The taxonomic status of *P. albomarginatus* is unique and it has never been confused with any other species of penstemon nor is it believed to hybridize with other species in the genus, though *P. palmeri* and *P. bicolor* are known to occur in or adjacent to *P. albomarginatus* populations. *P. albomarginatus* populations in Nevada were most recently surveyed in 1997 and 1998 (F.J. Smith, 2001). However, although that report provides the most complete picture of the known locations, population size, and biology of *P. albomarginatus*, variation in the density of *P. albomarginatus* within the reported boundaries of these populations was not documented nor was that report able to determine whether populations were increasing or declining. Currently *P. albomarginatus* is considered to be rare because of its limited geographic distribution, but where it does occur there may be more than 1,000 plants per acre.

The major hypothesis for this study is: Are the white-margined penstemon populations located east of Interstate 15 maintained by the movement of local source materials within the valleys where the plants reside? A corollary to the main hypothesis is: Would the development of playa basins as part of construction projects, such as the planned Ivanpah airport, impact the availability of these source materials to *P. albomarginatus* habitat areas? Specifically, two types of transport are evaluated in this study as possible sources of the material required to maintain *P. albomarginatus* habitat. First, sand transport along corridors of prevailing wind and downslope of habitat areas may be the dominant mechanism and source by which the sandy soils where *P. albomarginatus* generally occurs are maintained. Here, it is important to consider the competing effect of hydrologic processes where sediment may be transported downslope by surface runoff. Second, playa sediments upwind of *P. albomarginatus* habitat areas may serve as sources of limiting nutrients through the emission of suspendable dust during wind events and the subsequent transport and deposition of that dust into *P. albomarginatus* habitat areas.

Eolian sediment transport (i.e., transport of sediment by wind) can occur by three processes: creep, saltation, and suspension (Bagnold, 1941). Transport by creep is limited to coarse sand-sized particles and larger through a series of short burst of movement from one-to-five times the diameter of the particle per jump. Creep accounts for a proportionally small amount of net transport mainly because of the long time scales required to have any movement at all by this process. Saltation occurs for all sand-sized particles and is the distinct hopping-like motion of sediment that generally results in the formation of ripples. Saltating particles move by either aerodynamic entrainment or by being ejected into the air stream by other particles hitting the surface. Saltating particles account for the majority of net movement of sand-sized particles at scales of a few meters to thousands of meters, but are also responsible for a large proportion of the movement of finer dust particles (Shao et al., 1993). Dust or silt and clay-sized particles are also moved by the processes of suspension. Suspended particles are carried on the scale of kilometers to thousands of kilometers depending on both the energy of the wind and the size of the particles.

The vertical wind speed profile has a characteristic form over a roughened surface that can be described by the "law of the wall":

$$\frac{u_z}{u_*} = \frac{1}{\kappa}\ln\left(\frac{z}{z_o}\right) \quad (1)$$

where u_z (m/s) is the wind speed at a height z (m), κ is a constant of 0.4, z_o (m) is the roughness length, and u_* is the shear velocity (m/s). The shear velocity describes the transfer of time-averaged momentum in a turbulent, uniform, and steady flow over the surface. The force from the wind creates drag and lift forces on the sediment at the surface. If these combined forces exceed the gravity and binding energy forces acting on the surface particles, then it is said that the threshold for sediment transport has been achieved and entrainment and subsequent transport will occur. The threshold wind speed (or shear velocity) at which a soil surface will begin to erode depends on many time and location-dependent variables including height, width and spacing of vegetation, soil particle size, moisture content, and crust development (Wolfe and Nickling, 1993). Disturbance of native desert surfaces has a large effect on reducing the binding forces that protect the surface from wind erosion. Neff et al. (2008) attribute a current dust load increase of 500 percent from late Holocene average dust levels to anthropogenic disturbances in the western U.S. including construction from urban expansion, grazing, and other anthropogenic sources.

Vegetation or non-erodible elements (i.e., gravel or cryptobiotic crusts) on a surface reduce the amount of overall soil loss by wind. Vegetation acts to physically block moving sediment, covers a portion of the surface, and because of its porous and flexible properties extracts momentum from the wind reducing its effect at the soil surface (Gillies et al., 2002). The amount of momentum the vegetation can extract from the wind can be estimated from the roughness density, which is a measure that incorporates the frontal area and density of the vegetation (e.g., Gillies et al., 2006) as follows

$$\lambda = n\, b\, h \,/\, S \qquad (2)$$

with λ as the roughness density, *n* as the number of plants, *b* and *h* as the average width and height of the plants, and *S* as the total area of the surveyed plot. Using the roughness density the Raupach et al. (1993) model partitions the total shear stress (u_{*tR}) between the stress on the erodible surface (u_{*tS}) and the vegetation, expressing the sheltering capacity of vegetated surfaces as a ratio (R_t) for a given roughness density with the equation:

$$R_t = \frac{u_{*tS}}{u_{*tR}} = \frac{1}{(1-\sigma\lambda)^{0.5}\,(1+\beta\lambda)^{0.5}} \qquad (3)$$

with the subscript S and R representing the shear stress at the soil surface and as measured above the vegetation canopy, respectively, σ as the ratio of the basal (plan view) to frontal area and β as the ratio of the element drag coefficient to the surface drag coefficient. The dynamics of surface shear stress reduction by vegetation have been shown to be adequately predicted by the Raupach et al. (1993) drag partition model (King et al., 2005).

2 Methods

2.1 Site descriptions

The monitoring sites included in this report are enumerated in Table 2-1. They represent five areas where the *P. albomarginatus* population has been previously identified, plus two comparison sites, one at Roach Lake and one in Nye County, that are near the other locations but that do not currently support *P. albomarginatus* populations. The Universal Transverse Mercator (UTM) locations in Table 2-1 are for the specific location of the meteorological tower at each study site. Maps of the Clark County and Nye County sites are provided in Figure 2-1 and Figure 2-2, respectively.

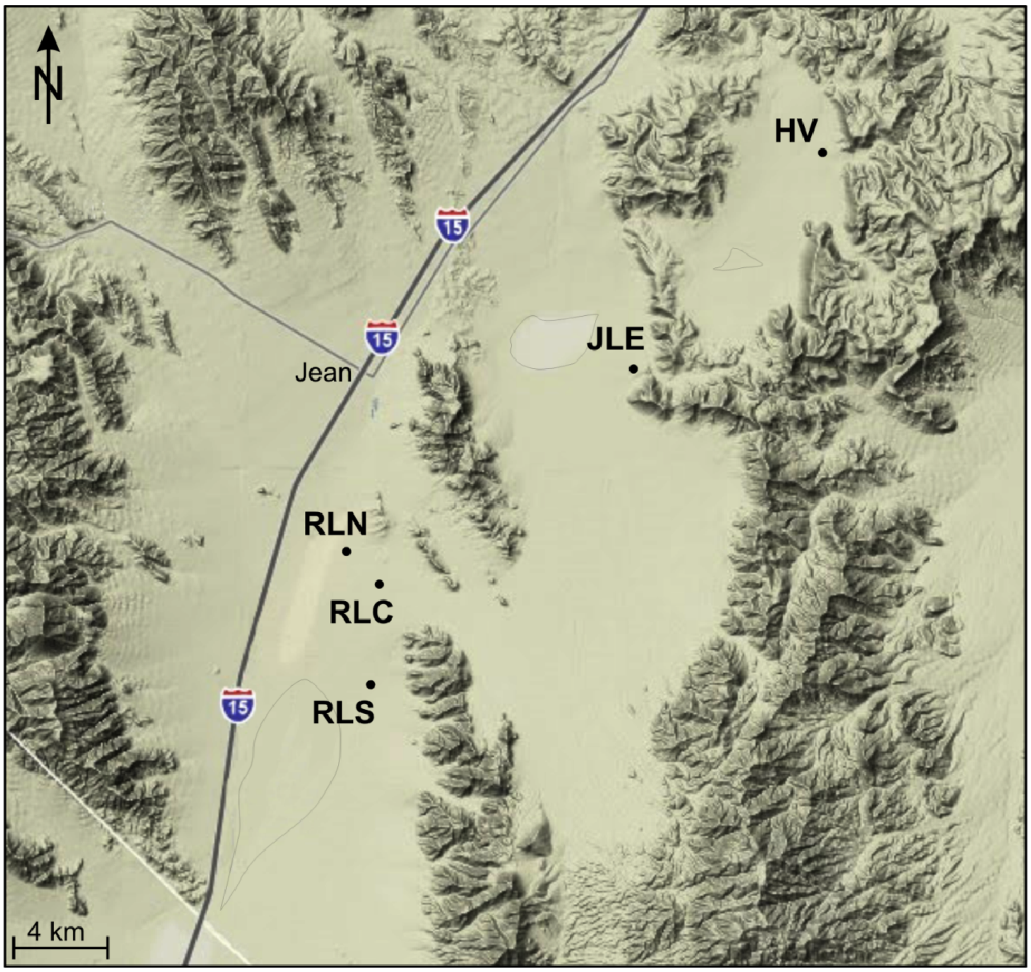


Figure 2-1. Plan view of Clark County study sites.

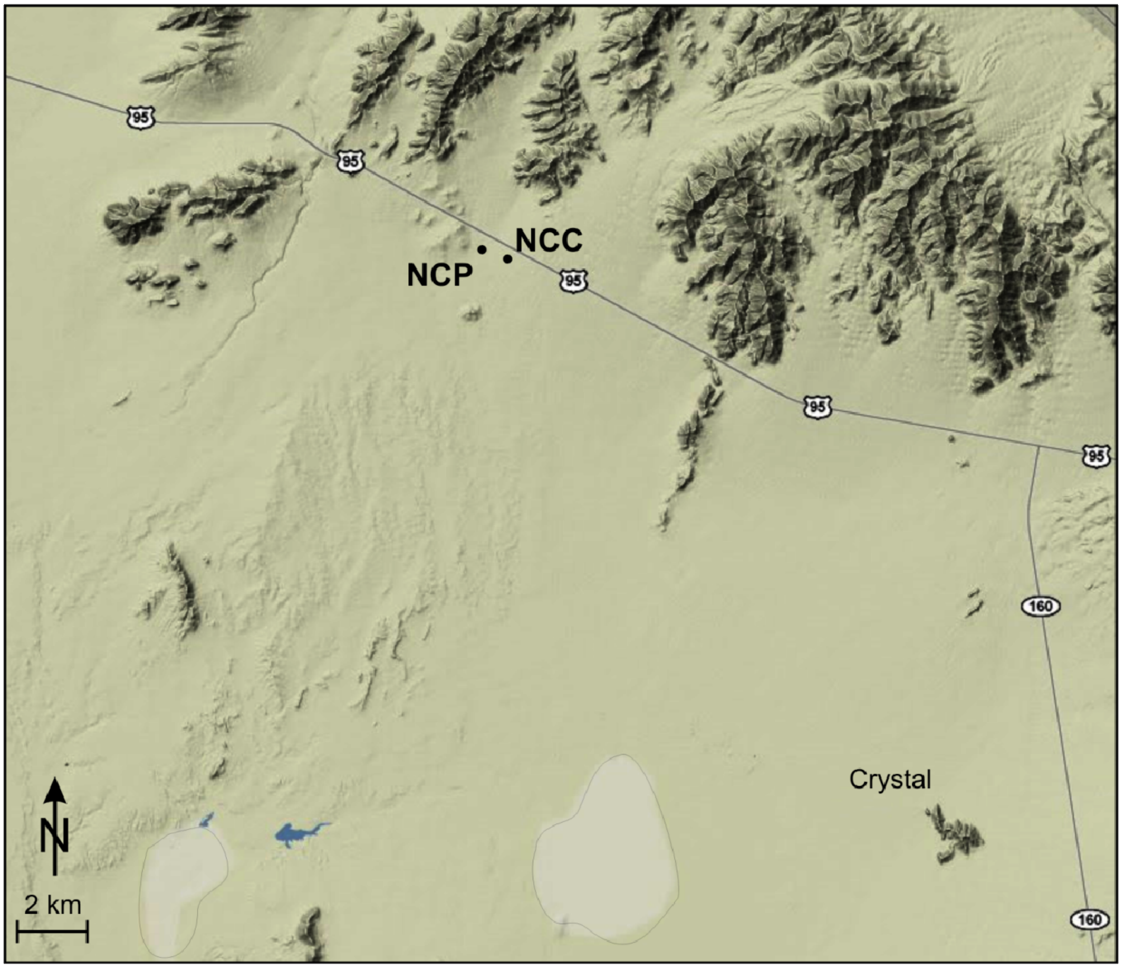


Figure 2-2. Plan View of Nye County study sites.

Table 2-1. Site locations given in UTM coordinates (NAD27 CONUS) and elevation in feet.

Site Name	Site	Nearest Town	Tower Locations East	Tower Locations North	Aspect (deg)	Slope (%)	Elevation (feet)
Roach Lake South	RLS	Jean, NV	651843	3950267	239	4.6	2688
Roach Lake Comparison	RLC	Jean, NV	652625	3953574	292	2.7	2885
Roach Lake North	RLN	Jean, NV	651055	3954932	244	1.8	2735
Jean Lake Exclosure	JLE	Jean, NV	660718	3960742	309	2.0	2880
Hidden Valley	HV	Jean, NV	667136	3968901	239	2.0	3136
Nye County Penstemon	NCP	Beatty, NV	565394	4051402	174	1.9	2739
Nye County Comparison	NCC	Beatty, NV	565885	4051207	226	1.2	2745

2.2 Soil properties

At each of the sites, soil samples were taken from two locations at each of the inter-spaces (between plants) and from the under canopy (under plants) at depth intervals of 0-2.5 cm, 2.5-5.0 cm, 5-10 cm, 10-20 cm, 20-30 cm, 30-50 cm, and 50-70 cm. This produced a total of 196 soil samples, which were analyzed for texture (sand, silt, and clay contents), pH, electric conductivity (EC), phosphorous (P), ammonium (NH_4), and nitrate (NO_3) content, and carbonate ($CaCO_3$) concentration and organic carbon (C) by mass. Soil samples were sieved using a 2mm sieve before each of the following analyses was performed. These pre-treatments were performed to determine pH/EC, organic matter content, percent soluble salts, percent $CaCO_3$, and texture of the non-soluble fraction. Both pH and EC measurements were acquired with a 1:1 saturated paste using NRCS Soil Survey Laboratory methods 4F2 (Saturated Paste), 4C1a2a1 (pH), 4F2c (EC extraction), and 4F2b1 (EC measurement) (Soil Survey Staff 2004). Organic material was removed by combustion in a 400˚ C muffle furnace. Percent organic matter was calculated from pre- and post-combustion sample weights. Percent carbonate was determined by gravimetric loss after dissolution with a sodium acetate buffer solution according to the methods in Soukup et al (2008) and Kunze and Dixon (1986). Soil texture was determined using the hydrometer method (modified from Gee and Bauder (1986)).

2.3 Climatology

A 6-meter high meteorological tower was installed and instrumented with sensors at each of the seven study sites. The following equipment was used for sampling at each monitoring site:

Table 2-2. Variables recorded and their associated instruments and units.

	Variable	Instrument	Recording Units
1	Date	Campbell CR1000 with GPS	Year, Julian Day
2	Time	Campbell CR1000 with GPS	HH:MM:SS
3	Wind Speed	NRG #40 Cup Anemometer	m/s
4	Wind Direction	NRG #200P Wind Vane	Degrees from North
5	Temperature and Relative Humidity	Vaisala HMP50 Temperature and RH probe	^{o}C / %
6	Temperature	CS107 Temperature probe	^{o}C
7	Atmospheric Pressure	Vaisala CS105 Barometric Pressure Sensor	hPa (mb)
8	Solar Radiation	Apogee CS300 Pyranometer	Wm^{-2}
9	Soil Moisture	CS616 Water Content Reflectometer	Volumetric Water Content (%)
10	Rainfall	Texas Electronics Tipping Bucket Rain Gage	mm
11	Eolian Sediment Intensity	Sabatech Inc. Safire saltation activity sensor	g/m/s
12	Eolian Sediment Transport	BSNE self-aligning sand traps	g/m/s
13	Overland Flow	Tension Infiltrometer	L/s
14	Plant Community Structure	GPS, meter tape	plants/m^2
15	Penstemon Phenology	GPS, meter tape	plants/m^2

Data from sensors labeled #1-11 within Table 2-2 were stored on-site on a Campbell CR1000 data logger. Data were recorded at 1-minute averaging times based on a 1-second sampling frequency. Eolian sediment intensity was sampled and recorded at a higher frequency (24 Hz) during eolian sediment transport events in a separate final storage area.

The wind speed was measured by a vertical profile of 5 NRG #40 3-cup anemometers at each site. These anemometers have an accuracy of 0.1 m/s, a stall speed of 0.78 m/s, and a distance constant of 3.0 m. They were mounted on 1.0 m booms at increasing logarithmic spacing on a 6.0 m tower. The wind direction was measured by a NRG #200P wind vane located on top of the 6.0 m tower. The soil moisture was measured by six CS616 water content reflectometers inserted to measure two profiles of three sensors each per site, one profile in a vegetation inter-space area and one profile in an under canopy area. Three probes integrate the soil moisture (calibrated to volumetric water content) and were buried at depths of 0-30 cm, 15-45 cm, and 40-70 cm. The CS616 probes have an accuracy of ±2.5 percent volumetric water content (VDC) and a resolution of 0.1 percent VDC.

All climatic data underwent several levels of quality assurance checks before use in further analysis.

2.4 Sediment transport

The time-resolved sediment transport by eolian processes was measured using a Sabatech Inc. Safire. A Safire contains a 0.02 m wide piezoelectric sensor around its 0.06 m circumference located 0.12 m from the tip. It is mounted with the sensor located at 0.10 m so that it will measure sediment transport of significant strength. It outputs an analog signal that is calibrated to the sediment transport rate of sand-sized particles. Three modified Big Springs Number Eight (BSNE)-type traps were constructed to measure the height-integrated sediment transport by wind at each site. These traps consisted of four separate heads spaced at heights at 0.05, 0.25, 0.42, and 1.0 m. Each head has a 0.05 m by 0.02 m opening that is directed into the wind by an attached vane and a fine mesh screen on the rear to allow near- isokinetic flow through it. The traps physically remove sediment from the air stream, allowing for further mineralogical analysis on the samples captured. Mass flux (g/m/day) was calculated by fitting a curve to each profile of the mass of sediment collected divided by the area of the trap inlet (for each collection period) and then integrating over the height of the traps. The equation used to fit the curve comes from the empirical formula of Shao and Raupach (1992):

$$y = c(e^{-az^2} + e^{-bz^2}) \tag{4}$$

where *y* is the mass of sediment caught in each trap divided by the area of the trap inlet (g/m^2) at the height *z* (m) above the ground, and *a*, *b*, and *c* are constants. The integrated form from zero to infinity is:

$$\int_0^\infty y\,dz = \int_0^\infty c(e^{-az^2} + e^{-bz^2})\,dz = \frac{c\sqrt{\pi}}{2}\left(\frac{1}{\sqrt{a}} + \frac{1}{\sqrt{b}}\right) \tag{5}$$

This solution resolves a mass flux per unit width for each of the three sediment traps at each site which were then averaged together and divided by the number of days since the last collection time.

Dust deposition was collected as a combination of both wet and dry deposition in modified USGS traps (Reheis and Kihl, 1995) once per year. Two replicate deposition traps, shaped like Bundt cake pans (OD = 24.1 cm, ID = 1.9 cm), were mounted at a height of 1.8 m and filled with clean-washed glass marbles. The traps were exposed for two periods over the course of the project. All of the traps were collected within a 2 day window of one another and were returned to the field after extracting the trapped particles. The sediment was removed with reagent-grade ethyl alcohol. The marbles were washed in situ and then removed from the dust pans. The pan was then rinsed into a small propylene container and left exposed in a fume hood to evaporate any extra liquid. The traps were then reassembled and put back into the field. Samples were weighed and then sent to University of Nevada Las Vegas (UNLV) Geosciences laboratory for texture and chemical (pH, EC, NO_3, NH_4, Cl, P, C, SO_4) analysis. To estimate the rate of deposition in units of material per area per time, the total mass of material collected (or specific chemical species) was divided by the exposure period and the exposed area of the deposition sampler (0.0456 m^2).

Runoff potential at the penstemon and comparison sites was investigated using the KINematic runoff and EROSion model KINEROS2 (Smith et al., 1995), (Woolhiser et al., 1990) software developed by USDA-ARS to describe the process of interception, infiltration, surface runoff, and erosion from small watersheds. KINEROS2 processes input from two files as well as receive interactive input from the user. A parameter file describes the watershed geometric, hydraulic, and infiltration characteristics. A rainfall file supplies breakpoint data from one or more rain gauges. Fluvial transport and its potential for sediment transport were estimated from rainfall, hydraulic conductivity, and site characteristics.

Hydraulic conductivity is a soil property that describes the speed with which the soil pores permit water movement through the soil matrix. Water can flow through soil as saturated, unsaturated, or vapor flow. The hydraulic conductivity depends on the type of soil, porosity, and configuration of the soil pores. In water-saturated soils, the hydraulic conductivity is represented as Ksat. To measure the hydraulic properties of the soil, infiltration experiments were conducted with a tension disc infiltrometer (TI) (Young et al., 2004; Ankeny et al., 1991). The infiltrometer consists of a 20 cm diameter disc covered by a fabric mesh with an air-entry value of approximately -20 to -30 cm, a reservoir tube, and a mariotte tube to maintain a constant tension at the fabric mesh. The tension infiltrometer supplies water to the surface at a user-defined tension or negative pressure (-15 cm and -10 cm of water column were used). An experiment consists of two different pressure steps, beginning with the highest tension (~-15 cm of water) and ending with a lower tension (~-10 cm of water).

Prior to each experiment the ground surface was cleared of clasts and other material, exposing the soil. A thin layer of moist contact sand was then applied to the soil surface to ensure good hydraulic contact between the ground and the disc. The water level in the reservoir was monitored using electronic pressure transducers. Thus, the dataset includes the volume outflow as a function of time for each pressure step.

The method based on Wooding (1968) work was used to calculate the hydraulic conductivity versus infiltration rate for unconfined infiltration. Wooding (1968) proposed the following algebraic approximation (Equation 6) of steady-state unconfined infiltration rates into soil from a circular source of radius r (cm), where Q is the volume of water entering the soil per unit time (cm^3 hr^{-1}), K(cm hr^{-1}) is the hydraulic conductivity, and h (cm) is the matric potential or tension at the source. The value of h will normally be negative corresponding to a tension at the water source; however, it can also be zero. It is assumed that the unsaturated hydraulic conductivity of soil varies with matric potential h(cm) (Equation 7) as proposed by Gardner (1958), where Ksat is the saturated hydraulic conductivity.

$$Q = \pi r^2 K \left[1 + \frac{4}{\pi r \alpha} \right] \quad (6)$$

$$K(h) = K_{sat} e^{\alpha h} \quad (7)$$

Knowing the infiltration rate (Q) entering the soil per unit time through the porous membrane at a minimum of two tensions, i.e., h1 and h2, we can derive Equation (8) by replacing K in Equation (6) with K_{sat} exp (α h) in Equation(7).

$$Q(h) = \pi r^2 K_{sat} e^{\alpha h} \left[1 + \frac{4}{\pi r \alpha} \right] \quad (8)$$

With measurements completed at two different tensions (h1 and h2), we can solve for α using

$$\alpha = \frac{\ln[Q(h1)/Q(h2)]}{h2 - h1} \quad (9)$$

Figure 2-3. Tension infiltrometer measurement in plant under canopy.

2.5 Penstemon community structure

Plant community structure at each of the five penstemon sites and the two comparisons sites was characterized by measuring individual plant canopy heights and widths and rectangular coordinates to the nearest cm for all live and dead perennial plant species in 50 m x 2.5 m transects. Transects were located between 50 and 1000 m of the on-site meteorological tower. In Clark County four transects were measured for each of the penstemon sites (RLN, RLS, JLE, HV), five transects were measured for the Nye County Penstemon (NCP) site, and at least one *P. albomarginatus* occurred in each of the penstemon transects. In order to increase the sample size for the comparison sites, six transects were measured in Clark County and five transects were measured in Nye County. Plant species identifications were based on the *Jepson Manual of Higher Plants of California* (Hickman, 1993). Cluster analysis of our study sites was evaluated using non-metric multidimensional scaling based on perennial plant species densities (McCune and Grace 2002).

2.6 Penstemon population size, areal extent, and density

Nevada *P. albomarginatus* population size, areal extent, and density were previously estimated based on field surveys conducted between 1997 and 1998 (F.J. Smith 2001). However, those estimates did not detail the variations of *P. albomarginatus* density within the boundaries of the 12 documented sites and did not include standard deviations for the density estimates. Consequently, all Nevada penstemon sites previously documented were resurveyed. It was discovered that several of the Nye County populations that were previously mapped as non-overlapping populations should probably be considered as contiguous populations. We estimated *P. albomarginatus* density by counting *P. albomarginatus* plants in 10m wide continuous transects that varied in length from 5 to 500 m depending on the density of plants, i.e., high densities were correlated with short transect length. In general, transects ended after counting 25 to 30 plants and we measured more than 3,500 transects. Most surveys included two surveyors, often walking in parallel. Not all of the areas within the boundaries determined by the 1997-8 surveys were covered. Areas outside the 1997-8 boundaries were also surveyed because of similarity in soils and the obvious presence of *P. albomarginatus* plants. To estimate the population size, we multiplied the number of acres estimated by Smith (2001) plus the area of the new acres we found by the density estimates we determined based on linear transect data, which was weighted by the percent of each transect relative to the total length of all transects within a population. NAD27 conus UTMs were used so that our data could be overlaid on the USGS maps used to designate the 1997-1998 *P. albomarginatus* population boundaries.

2.7 Penstemon growth, phenology, and age structure

In April 2008 30 *P. albomarginatus* plants within 100 m of the meteorological and sediment transport instruments were flagged and UTMs (NAD27 conus) recorded at each of the Clark County penstemon sites (RLN, RLS, JLE, HV) and 60 plants were flagged and measured at the Nye County Penstemon (NCP) site. For each plant, the number of shoots, median shoot height, canopy widths, number of shoots with flowers, number of shoots with fruits, and number of shoots impacted by herbivores were counted. These data were collected again in May 2008. To obtain a better temporal understanding of *P. albomarginatus* phenology, plant data were collected more intensively in March, April, and May 2009.

In October 2009 the root systems of five *P. albomarginatus* plants at the Hidden Valley (HV) study site and five *P. albomarginatus* plants at the Roach Lake North (RLN) study site were excavated and data for rooting depth, biomass, and structure were collected. The plants sampled included the range of canopy areas documented in order to test the hypothesis that rooting depth and/or biomass is correlated with aboveground growth. Based on recommendations from BLM, only ten plants at these two sites were sampled because the sampling technique was destructive. Whole root systems were collected and examined for potential root parasitism with adjacent perennial shrubs and grasses. Cross-sections of the root crowns were examined under a dissecting microscope and potential ages were estimated by counting xylem increments. Root tissue was also examined for ectomycorrhizal symbioses but not for endomycorrhizal symbioses.

P. albomarginatus recruitment, longevity, and mortality in relation to precipitation were also evaluated for the Jean Lake population utilizing data collected by BLM botanists from 1996 to 2006. The presence, location, canopy area, and fruiting status of all *P. albomarginatus* plants in eight 50 x 5 m transects were recorded each year in May.

3 Results

3.1 Ranges in soil and climatic properties supporting *P. albomarginatus* populations

3.1.1 Soil properties: texture and chemistry

Soil profiles sampled in the vegetation under canopy areas and inter-spaces were examined for variations with depth and in the context of identifying differences between penstemon and comparison sites. Parameters profiled include sand, silt, and clay content, pH, electrical conductivity, and phosphorous, ammonium, nitrate, calcium carbonate, and organic carbon content. Full site by site profiles are provided in Appendix D. Here, we provide an overview of the results and identify notable trends. We note that at the Roach Lake Comparison (RLC) site, the first soil profile sample obtained in the plant under canopy area was apparently tainted by recent animal urine as indicated by very high surface nitrate and ammonium levels. Two additional independent under canopy samples were obtained from that site and re-analyzed. Re-analysis confirmed that the first sample was not representative of nitrate and ammonium levels. Interestingly, the two re-analyzed soil samples did exhibit a very high degree of variability with respect to electrical conductivity at varying depths. This variability is evident in the figures that separate penstemon sites from comparison sites.

All of the study sites had considerable sand content in the top layer of the soil, and in most cases the sand content continued to be high to a depth of 60 cm. The highest surface sand content (average of the inter-space and under canopy) was at Roach Lake North (RLN) (92.0 percent) whereas the lowest was at Roach Lake Comparison (RLC) (86.1 percent) and the second lowest was at Roach Lake South (RLS) (87.5 percent). Sand contents at the other sites were between 88.4 and 91.4 percent.

Textural compositions at the Roach Lake sites (RLS, RLC, and RLN) and the Hidden Valley (HV) site were fairly uniform with depth. At Jean Lake Exclosure (JLE), silt content began to increase from a value of about 5 percent to about 8 percent, starting at a depth of 25 cm, with clay content showing a similar, but more muted trend. At the Nye County Penstemon (NCP) site, there was a pronounced silt/clay-rich layer between 7 and 20 cm below the surface. Below 25 cm, the soil was extremely sandy (>95 percent). The Nye County Comparison (NCC) site had a comparatively modest silt/clay-rich layer at a depth of 10 cm. In contrast to the penstemon site, at depths greater than 25 cm the comparison site exhibited a significant reduction in sand content (~80 percent for inter-space).

Soil average pH was slightly alkaline and ranged from 7.9 (RLS) to 8.4 (NCC). Phosphorous and ammonium content were highest at the soil surface for all sites and were comparable in magnitude among sites (8-11 mg/kg for phosphorous and 7-12 mg/kg for ammonium). There were no clear differences between the penstemon and comparison sites. Nitrate and organic carbon were generally higher at the soil surface in the under canopy than in the inter-space. In the inter-space, where *P. albomarginatus* are usually found, there were no clear differences between the comparison and penstemon sites for either nitrate or organic carbon profiles with depth.

Overall soil acidity increased with depth for both comparison and *P. albomarginatus* sites (Figure 3-1) and was also slightly greater in *P. albomarginatus* sites for the 0-2.5 cm soil depth and the 5-10 cm depth. However, it is doubtful that these differences in soil acidity have any impact on limiting the establishment of *P. albomarginatus* or distribution of *P. albomarginatus* habitat. Both acidity and soil electrical conductivity, an indirect measure of soil salinity, were significantly greater in the under canopy than in inter-space regions (Figure 3-2).

There is a slight but significant increase in clay content in the 5-30 cm depths for the penstemon inter-space samples as compared to the comparison inter-space samples (Figure 3-3). The pattern of changes in soil chemistry (phosphorus, nitrate, ammonium, and organic carbon) with depth were similar for penstemon and comparison sites, all decreased significantly with depth. However, carbonate levels in penstemon soils, for both inter-space and under canopy, were significantly greater than in comparison soils (Figure 3-4) and appear to coincide with the depths at which clay content is elevated in the 0-30 cm range. Neither the two-fold or greater difference in soil carbonate levels between the penstemon and comparison under canopy samples (below 5 cm) nor the high carbonate content in the surface (top 10 cm) inter-space soil at penstemon sites (Figure 3-4b) is reflected by the soil pH profile (Figure 3-1).

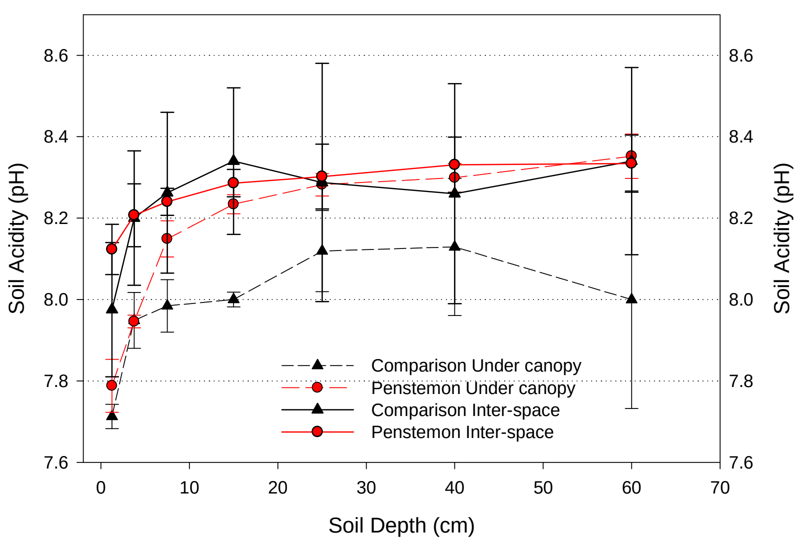


Figure 3-1. Relationship of *P. albomarginatus* presence, shrub canopies, and soil depth with soil pH. Error bars represent the standard error of the mean.

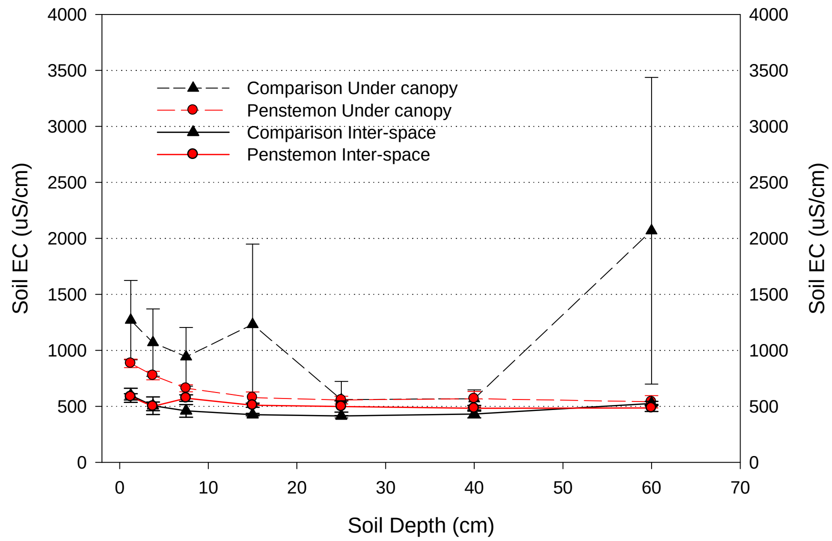


Figure 3-2. Soil electrical conductivity patterns for penstemon and comparison sites. Error bars represent the standard error of the mean.

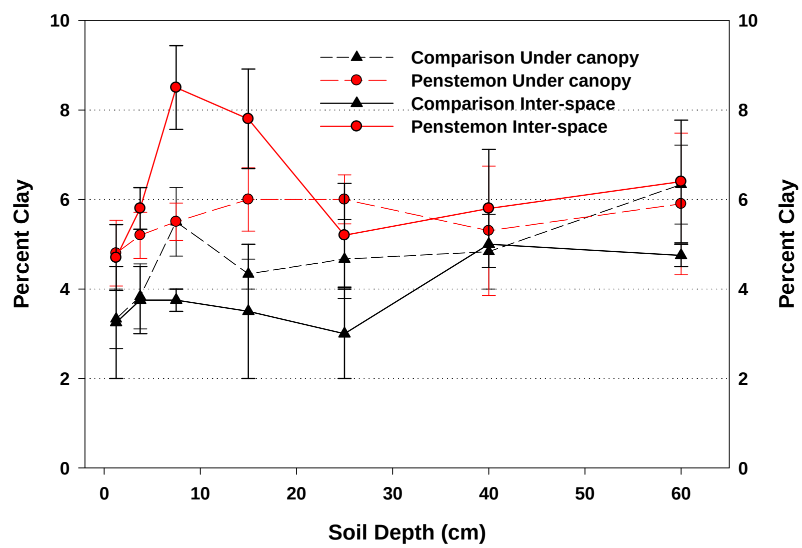
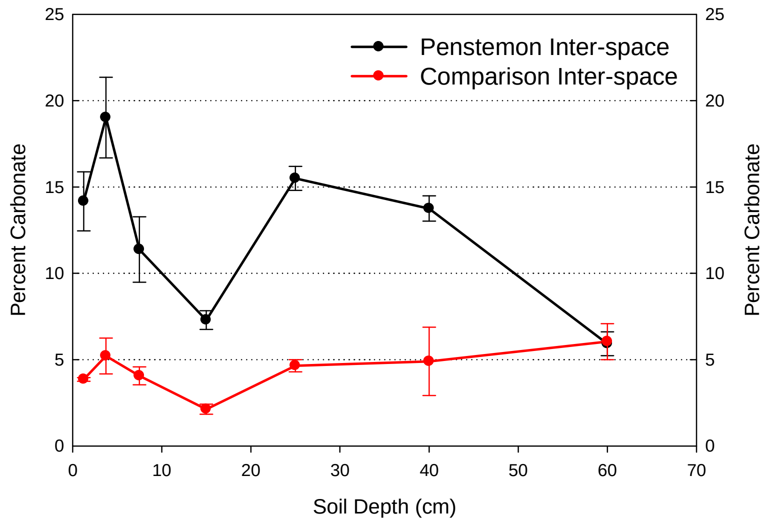
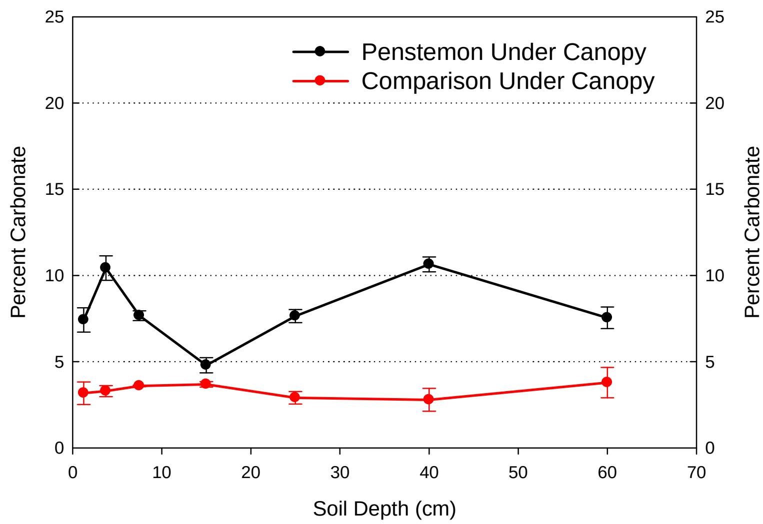


Figure 3-3. Variation of clay content (%) with depth for penstemon and comparison sites. Error bars represent the standard error of the mean.



a. Inter-space only



b. Under canopy only

Figure 3-4. Patterns of soil carbonate levels for whole sites and for inter-space (a) and under canopy (b) microsites. Error bars represent the standard error of the mean.

3.1.2 Soil cryptobiotic crusts

Representative photos of the soil surface and cryptobiotic crust development from each of the study sites are shown in Figure 3-5 through Figure 3-11. On penstemon site soils, cryptobiotic crust development was poor to non-existent. On the comparison site soils there was approximately 0-10 percent cover by crusts, but there was also a large amount of spatial heterogeneity. Consequently, the presence of cryptobiotic crusts does not seem to have a significant role in defining what constitutes a sustainable penstemon site. Other non-vascular plants, including the moss *Syntrichia caninervis,* were also absent or rare from penstemon sites. Nevertheless, there certainly is an important soil microbial community that is an essential component of all sustainable penstemon sites, but our study did not specifically investigate this component.

3.1.3 Soil classification

Soil parent materials mapped by the National Resource Conservation Service (Borup, 2004) (Lato, 2006) were eolian for all the penstemon study sites and mixed alluvium for the comparison study sites (Table 3-1, Table 3-2). Study sites overlaid on soil mapping units and detailed descriptions of the soil series are provided in Appendix B.

The Prisonear fine sand soil mapping unit encompasses most of the Roach Lake South (RLS) site (southern most site in Ivanpah Valley) and the Roach Lake North (RLN) penstemon sites in Clark County. However, 85 percent of this mapping unit consists of the Prisonear soil series (sandy, mixed, thermic Calcic Petrocalcid), which is described as having a petrocalcid subsoil horizon (Bkqm1) at a depth of 89 cm (35 in). We excavated soils to a depth of about 100 cm (40 in) during installation of soil moisture probes and collection of soil samples for chemical and textural analysis at all the study sites. We also excavated five individual root systems from each of the RLN and HV penstemon sites to depths of 150 cm (60 in). During our soil excavations we did not encounter a petrocalcid subsoil at the RLN site, and the soil chemical data for carbonates for the RLN site do not have an abrupt increase in carbonates in the 50-70 cm depth. However, the Prisonear fine sand mapping unit also includes up to 6 percent Arizo soils (sandy-skeletal, mixed, thermic Typic Torriorthent) which are deep sandy soils without a subsoil accumulation of carbonates. It therefore seems probable that Arizo soils were the dominant soil series at the RLN site and probably dominated the upper slope of the RLS site.

The southern portion of the RLS *P. albomarginatus* population extended into the Tipnat-Bluepoint-Hypoint mapping unit, approximately 300 m northeast of the Roach Lake playa and approximately 2.5 km southwest of the location of the RLS instruments. The Tipnat series (fine-loamy, mixed, superactive, thermic Typic Natrargid) is finer textured than the other penstemon sites, higher in sodium, with cattle saltbush (*Atriplex polycarpa*) as the dominant shrub.

The RLC site is encompassed by the Tonopah-Arizo mapping unit, with the Tonopah soil series (sandy-skeletal, mixed, thermic Typic Haplocalcid) representing 45 percent of the mapping unit and the Arizo series representing 40 percent. Consequently, it is unlikely that the RLC site included the Tonopah soil series because carbonates did not increase significantly with soil depth.

Figure 3-5. Soil surface lag and minimal cryptobiotic crust development at the Roach Lake South (RLS) study site (March 2009).

Figure 3-6. Soil surface lag and cryptobiotic crust development at the Roach Lake Comparison (RLC) study site (October 2009).

Figure 3-7. Soil surface lag with minimal cryptobiotic crust development at Roach Lake North (RLN) study site (April 2009).

Figure 3-8. Soil surface lag with minimal cryptobiotic crust development at Jean Lake Exclosure (JLE) study site (March 2009).

Figure 3-9. Soil surface lag with minimal cryptobiotic crust development at Hidden Valley (HV) study site (June 2009).

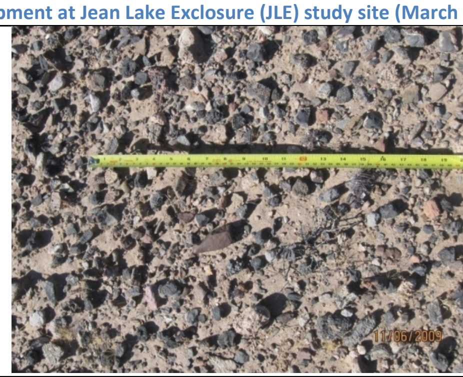


Figure 3-10. Soil surface lag with minimal cryptobiotic crust development at Nye County Comparison (NCC, November 2009).

Figure 3-11. Soil surface lag with minimal cryptobiotic crust development at Nye County Penstemon (NCP, November 2009).

The soil mapping units for JLE and HV penstemon sites, 192-Bluepoint and 192-Bluepoint-Grapevine associations, respectively, were dominated by the eolian Bluepoint series (mixed, thermic Typic Torripsamment).

The 2151-Arizo-Bluepoint mapping unit encompassed the NCP site, which includes the eolian Arizo and Bluepoint soils that were also dominant at the JLE and HV sites. The NCC site was mapped as 2020-Weiser-Canoto Association with Weiser soil series (loamy-skeletal, carbonatic, thermic Typic Haplocalcid) comprising 70 percent of the unit, which has a significant carbonate accumulation below 20 cm. However, we did not observe an increase in carbonates with depth at the NCC site, indicating that the soil at the NCC site was more Bluepoint/Arizo-like than Weiser-like. For comparison, we note that the other *P. albomarginatus* populations at sites in Nye County surveyed by Smith (2001) but not instrumented in our study were on soils that included the St Thomas-Rock outcrop-Commski, Commski-Arizo association, Arizo-Bluepoint association, and Bluepoint series.

Table 3-1. Soil mapping units, series, and taxonomic classes for the Clark County penstemon and comparison study sites.

Study Site	Mapping Unit*	Soil Series	Parent Material	Taxonomic class
Roach Lake South (RLS)	780-Prisonear fine sand, 2 to 8 percent slopes	Prisonear	Eolian sands over limestone alluvium	Sandy, mixed, thermic Calcic Petrocalcid
	391-Tipnat-Bluepoint-Hypoint association	Tipnat-	Mixed Alluvium	Fine-loamy, mixed, superactive, thermic Typic Natrargid
		Bluepoint-	Eolian sands	Mixed, thermic Typic Torripsamment
		Hypoint	Mixed Alluvium	Sandy, mixed, thermic Typic Torriorthent
Roach Lake Comparison (RLC)	380—Tonopah-Arizo association	Tonopah	Mixed Alluvium	Sandy-skeletal, mixed, thermic Typic Haplocalcid
		Arizo	Mixed Alluvium	Sandy-skeletal, mixed, thermic Typic Torriorthent
Roach Lake North (RLN)	780-Prisonear fine sand, 2 to 8 percent slopes	Prisonear	Eolian sands over limestone alluvium	Sandy, mixed, thermic Calcic Petrocalcid
Jean Lake Exclosure (JLE)	192—Bluepoint association	Bluepoint	Eolian sands	Mixed, thermic Typic Torripsamment
	450—Arizo association	Arizo	Mixed alluvium	Sandy-skeletal, mixed, thermic Typic Torriorthent
Hidden Valley (HV)	191—Bluepoint-Grapevine association	Bluepoint	Eolian sands	Mixed, thermic Typic Torripsamment
		Grapevine	Mixed Alluvium with some gypsum	Coarse-loamy, mixed, superactive, thermic Typic Haplocalcid
	450—Arizo association	Arizo	Mixed alluvium	Sandy-skeletal, mixed, thermic Typic Torriorthent
Nye County Comparison (NCC)	2020-Weiser-Canoto association	Weiser	Limestone alluvium	Loamy-skeletal, carbonatic, thermic Typic Haplocalcid
		Canoto	Mixed Alluvium	Loamy-skeletal, mixed, superactive, calcareous, thermic Typic Torriorthent
Nye County Penstemon (NCP)	2151-Arizo-Bluepoint	Arizo	Mixed alluvium	Sandy-skeletal, mixed, thermic Typic Torriorthent
	2121-Commski-Arizo	Bluepoint	Eolian sands	Mixed, thermic Typic Torripsamment
	2270-Bluepoint fine sand	Commski	Mixed alluvium	Loamy-skeletal, carbonatic, thermic, Typic Haplocalcid
	2080-St Thomas rock outcrop-Commski			

*(2004 and 2006 Natural Resources Conservation Service)

Table 3-2. Soil association and geophysical characteristics.

Study Site	Soil Association	Landscape Type	Landform	Surface rock (%)	Slope	Runoff	Drainage class	Permeability class	Ksat range (inch/hour)
Roach Lake South (RLS)	Prisonear	Fan piedmont	Sand sheet, fan remnants	10	2-8	High	Well	Rapid	6-20
	Tipnat-Bluepoint-Hypoint	Bolson	Alluvial flats	25	0-4	Low	Well	Moderately Slow	0.2-0.6
Roach Lake Comparison (RLC)	Tonopah-Arizo	Fan piedmont	Fan remnant	45	2-8	Low	Excessively	Rapid	6-20
Roach Lake North (RLN)	Prisonear	Fan piedmont	Sand sheet, fan remnants	10	2-8	High	Well	Rapid	6-20
Jean Lake Exclosure (JLE)	Bluepoint	Basin floor	Sand sheets	0	0-8	Very Low	Somewhat excessively	Rapid	6-20
	Arizo	Fan piedmont	Fan apron	50	2-8	Low	Excessively	Rapid	6-20
Hidden Valley (HV)	Bluepoint-Grapevine	Basin floor	Sand sheets	0	0-8	Very Low	Somewhat excessively	Rapid	6-20
	Arizo	Fan piedmont	Fan apron	50	2-8	Low	Excessively	Rapid	6-20
Nye County Comparison (NCC)	Weiser Canoto	Piedmont Fan	Fan remnant	65	2-4	Very Low	Well	Moderate	0.6-2.0
Nye County Penstemon (NCP)	Bluepoint Arizo Commski	Basin floor Fan piedmont	Sand sheets Fan apron Fan remnant	0 50 58	0-8 2-8 0-4	Very Low Low	Somewhat excessively Well	Rapid Rapid Moderate	6-20 6-20 0.6-2.0

3.1.4 Precipitation, soil moisture, and hydraulic conductivity

Detailed, site by site monthly average climatic data and hydraulic conductivity data are provided in Appendix C. Here, we summarize pertinent trends and observations.

Precipitation patterns for Clark and Nye Counties over the past 14 years are shown in Figure 3-12. Nye County mean annual precipitation (recorded at Beatty, Nevada, located approximately 30 miles northwest of the NCP study site) for 1995 to 2006 (167 ± 21.8 mm) was not significantly greater than mean annual precipitation in Las Vegas, Clark County (113 ± 16.6 mm) for the same time interval. Despite 32 percent less mean annual precipitation in Clark County than Nye County between 1995 and 2006, this difference was not significant because of the high variation between years. Clark County precipitation ranged from 42 to 187 mm and Nye County precipitation ranged from 12 to 320 mm. The annual mean precipitation for Clark County of 85.7 mm during our two-year study was only 75 percent of the previous 10-year mean. Similarly, the mean for Nye County from 1995 to 2006 (167 mm) was not significantly greater than the 2-year study mean (51.7 mm), even though it was only 31 percent of the mean for the previous ten years.

In contrast to the long-term precipitation pattern, which indicates that Clark County is 32 percent drier than Nye County, mean total precipitation during our study (October 2007 through September 2009) for the five Clark County study sites (171.4 mm) was 66 percent greater than the mean total (86.2 mm) for the two Nye County study sites (Figure 3-13). Furthermore, the Clark County sites were wetter in 2008 (89.1 mm) than in 2009 (81.5), while Nye County was drier in 2008 (34.1 mm) compared to 2009 (51.7 mm).

The relationship of total daily precipitation with soil volumetric water contents for the Roach Lake South (RLS) penstemon site (Figure 3-14) illustrates a typical pattern for a sandy Mojave Desert soil. During winter (December - February), precipitation events result in the greatest soil moisture levels for the top 45 cm of soil. Beginning in early spring (March - April) the top 45 cm of soil begins drying more rapidly due to higher air temperatures. Soil water content remains low for all depths throughout the summer and fall, except for occasional summer monsoon events that typically do not replenish the soil below 50 cm, but result in significant increase in the 0-30 cm depth, especially for under canopy soils. Consequently, the response in soil volumetric water to precipitation events for the under canopy microsites was markedly different than for the inter-space soils (Figure 3-15). In general, there tended to be more soil water in inter-spaces than for under canopy soils (Figure 3-16), but the magnitude of the effect varied by site and was reversed for the Nye County Comparison (NCC) site.

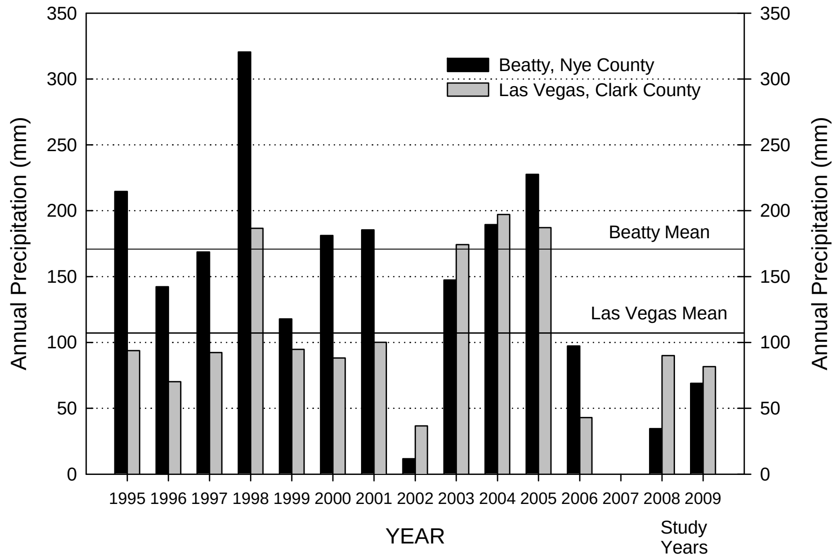


Figure 3-12. Annual precipitation totals for Las Vegas, Nevada, and Beatty, Nevada, from 1995 through 2009.

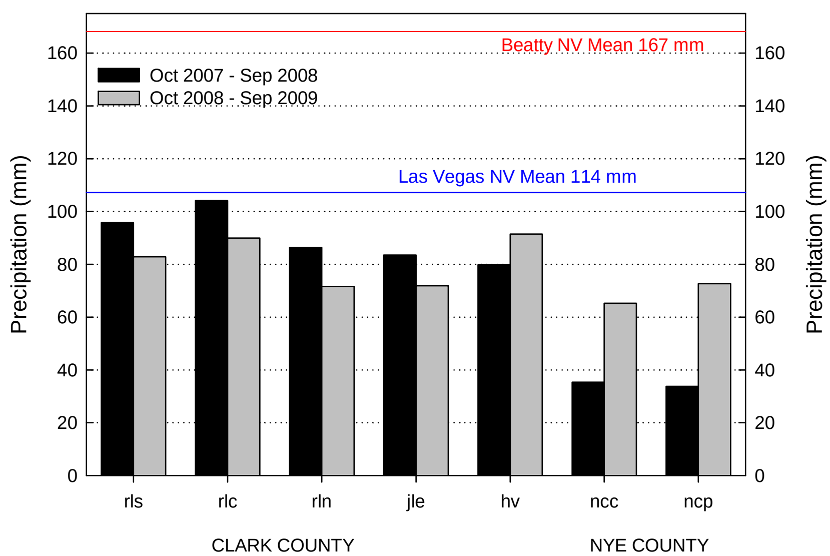


Figure 3-13. Comparison of total annual precipitation among study sites for October 2007 through September 2009.

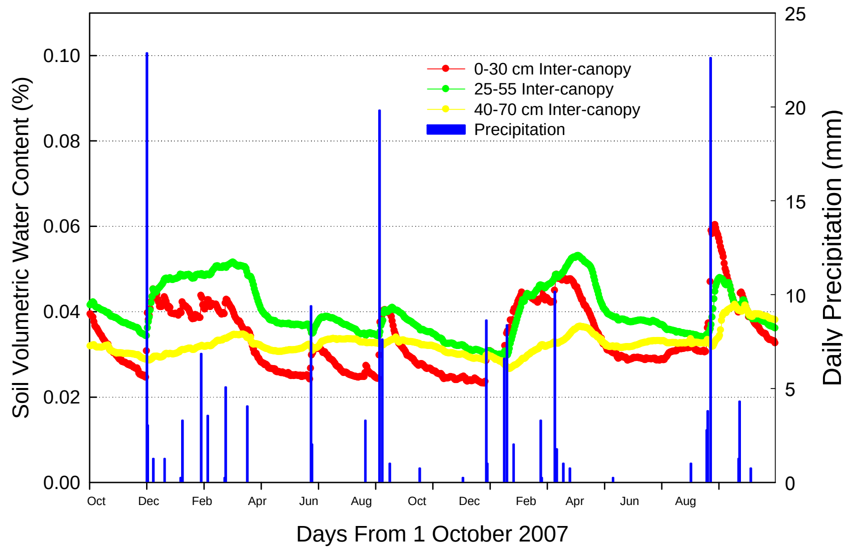


Figure 3-14. Daily variations in soil volumetric water content for inter-spaces at the Roach Lake South (RLS) penstemon site in response to precipitation events.

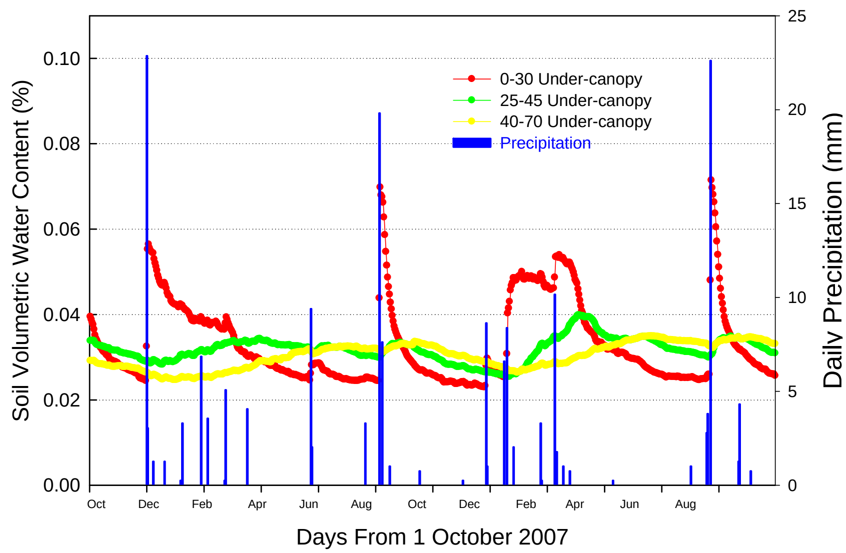


Figure 3-15. Daily variations in soil volumetric water content under shrub canopies at the Roach Lake South (RLS) penstemon site in response to precipitation events.

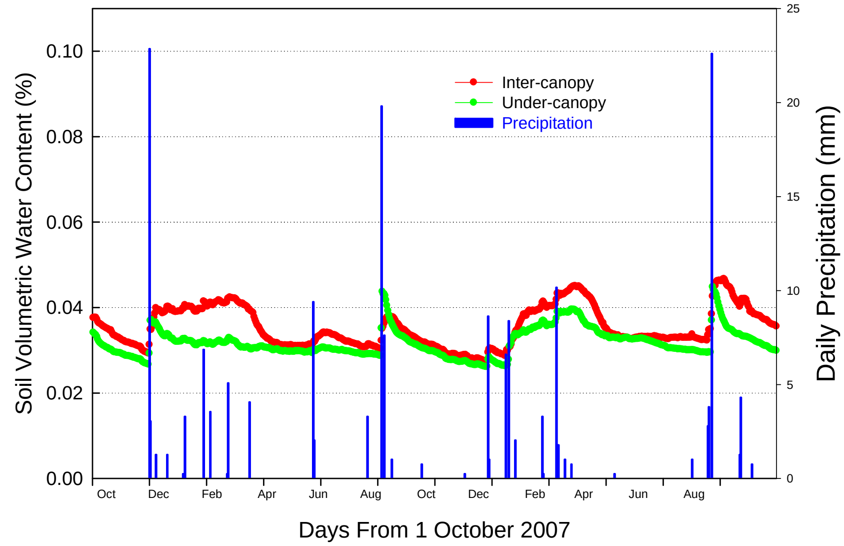


Figure 3-16. Mean soil volumetric water content for under canopy probes and inter-canopy probes.

With some site-to-site variability, Clark County sites had monthly rainfall totals that were greater than 15 mm in November 2007, January 2008, May 2008, August 2008, December 2008, February 2009, and July 2009. Overall, this is consistent with the expected trend for the region for late fall and winter rains (October – March) and monsoonal summer rain events (July and August). Differences in monthly rainfall totals among the three Roach Lake sites underscore how spatially variable Mojave rain events can be, especially those during the summer monsoon season. For example, in August 2008, the Roach Lake South (RLS) and Roach Lake Comparison (RLC) sites registered 28.4 mm and 29.2 mm of rainfall, respectively, while the Roach Lake North (RLN) site registered only 8.1 mm of rain. Over the 2-year monitoring period, rainfall at the Nye County sites occurred primarily from October – February; summertime rain events and rainfall totals over the whole study period were much smaller than those at Clark County sites (Figure 3-17). At the Clark County sites, average monthly rainfall over the study period ranged from 6.6 mm (RLN) to 8.1 mm (RLC), whereas at the Nye County sites average monthly rainfall ranged from 4.2 to 4.4 mm. The difference in precipitation observed over the 2-year study period is not supported by historical and modeled rainfall data, which suggest (though not with statistical significance due to very high inter-annual variability) that the Nye County sites should receive higher annual rainfall than Clark County sites.

Measurements of the soil-saturated hydraulic conductivity (K_{sat}) across all study sites are summarized in Figure 3-18. Site averaged hydraulic conductivities were calculated were calculated from the under canopy and inter-space averages using the plant cover as a weighting factor as follows

$$K_{sat,agg} = K_{sat,under} \times plant\% + K_{sat,iner} \times (1 - plant\%)$$

where *plant%* corresponds to the fraction of the surface that is covered by vegetation and is based on field measurements of plant density and distributions.

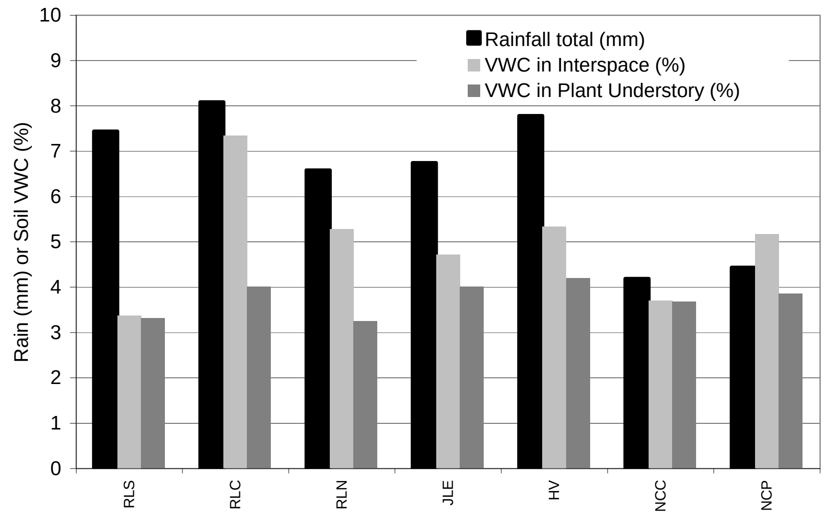


Figure 3-17. Monthly rainfall totals and soil moisture averages for the entire 2-year study period. Missing data from the JLE and HV sites were substituted with monthly totals from RLN and missing data from the NCC site were substituted with monthly totals from NCP.

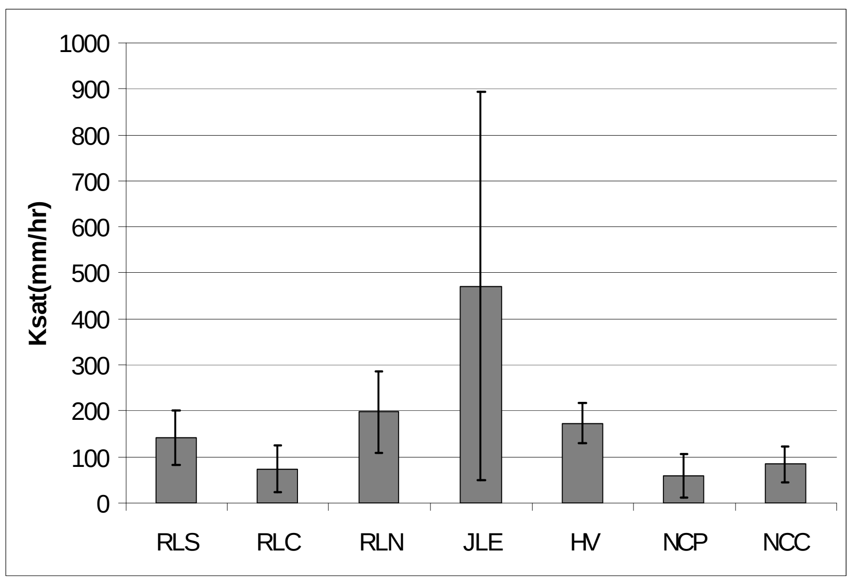


Figure 3-18. Saturated hydraulic conductivity as measured by tension infiltrometer for under canopy and inter-space. Error bars represent the standard error of the mean.

At all sites, the hydraulic conductivity was lower in the under canopy than in the vegetation inter-space, in some cases by an order of magnitude or more. This is probably because litter can accumulate and compact in the under canopy and reduce infiltration. However, the effect of the comparatively low hydraulic conductivity in the under canopy on the site aggregate $K_{sat,agg}$ was fairly minimal at all sites since the plant cover accounted for less than 25 percent of the surface area in all cases. Aggregate $K_{sat,agg}$ value was highest at Jean Lake Exclosure (JLE) (471 mm/hr), although the average was associated with very high variability – i.e., JLE $K_{sat,agg}$ was not statistically different than other sites. The lowest K_{sat} value (59.3 mm/hr) was measured at the Nye County Penstemon site (NCP). However, the hydraulic conductivities at all of the sites are indicative of a very well-drained soil. This is consistent with the very sandy character of these soils as well as with their NRCS classification.

3.1.5 Other environmental aspects: temperature, humidity, radiation, and wind speed

Among the Clark County sites, mean monthly temperatures and minimum and maximum 1-minute temperatures were nearly identical, with very little site-to-site variation (Figure 3-19). The highest monthly average temperature was 31.9 C and the highest 1-minute temperature was 42.0 C, both occurring at Roach Lake South (RLS) during the month of July 2008. The lowest average monthly temperature was measured at the Jean Lake Exclosure (JLE) in December 2008 (5.2 C), although the lowest 1-minute temperature was measured at Hidden Valley (HV) during the same month (-11.75 C). The next lowest 1-minute temperature was measured at Jean Lake Exclosure (JLE) (-7.4 C). The Nye County sites were, on average, warmer than the Clark County sites, with the highest monthly average temperature recorded at the Nye County Comparison (NCC) site (32.2 C) and the highest 1-minute temperature at the Nye County Penstemon (NCP) site (43.7 C), both in July 2008. The minimum 1-minute temperature was -3.6 C at the Nye County Comparison (NCC) site. Temperature minima and maxima do not explain why *P. albomarginatus* are not found at the comparison sites. Both the highest temperatures and the lowest temperatures occur at penstemon sites. Although small in absolute terms, differences in temperature profiles were greater between Clark and Nye County sites than between comparison and penstemon sites within the same county.

The reasoning presented above can also be applied to relative humidity (Figure 3-20) and solar radiation (Figure 3-21). That is, differences, where they do exist, in relative humidity and solar radiation monthly averages and extrema are greater between counties than they are between penstemon and comparison sites within the same county.

There were some differences in wind speed between sites (Figure 3-22), although, here again, there was no apparent relationship between these differences and whether the site was a penstemon site or a comparison site. April (2008 and 2009) was the windiest month of the year for all sites. Overall, the windiest sites (highest average maximum wind speed) were Jean Lake Enclosure (JLE), Nye County Comparison (NCC), and Nye County Penstemon (NCP). The least windy site was Roach Lake North (RLN), probably because the site is located about 500 m south of a hill, which may act as a wind shelter. The highest 1-minute wind speed (22.1 m/s) was measured at Jean Lake Exclosure (JLE) in February 2008. Wind speeds of 20 m/s or higher were recorded at every site.

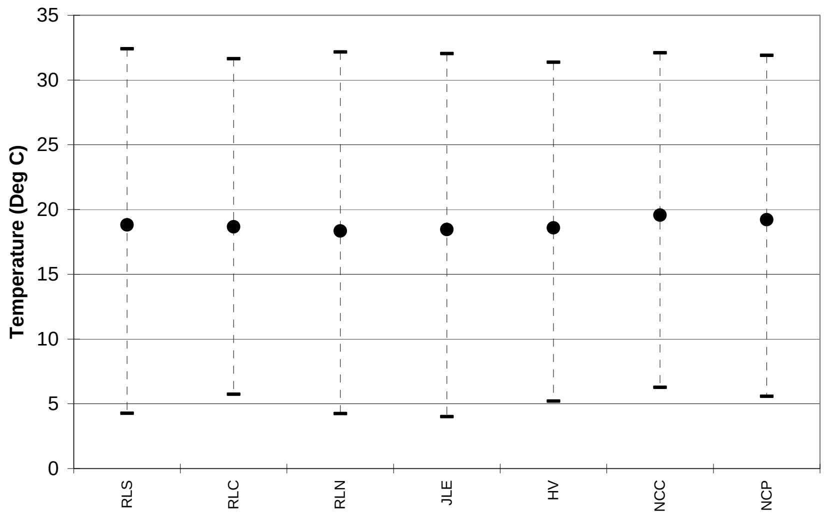


Figure 3-19. Study average temperature, average monthly maximum, and average monthly minimum.

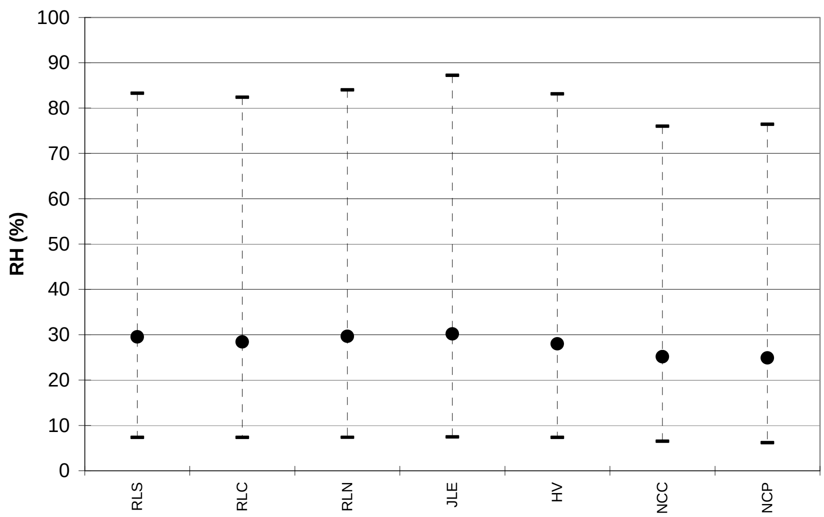


Figure 3-20. Study average relative humidity, average monthly maximum, and average monthly minimum.

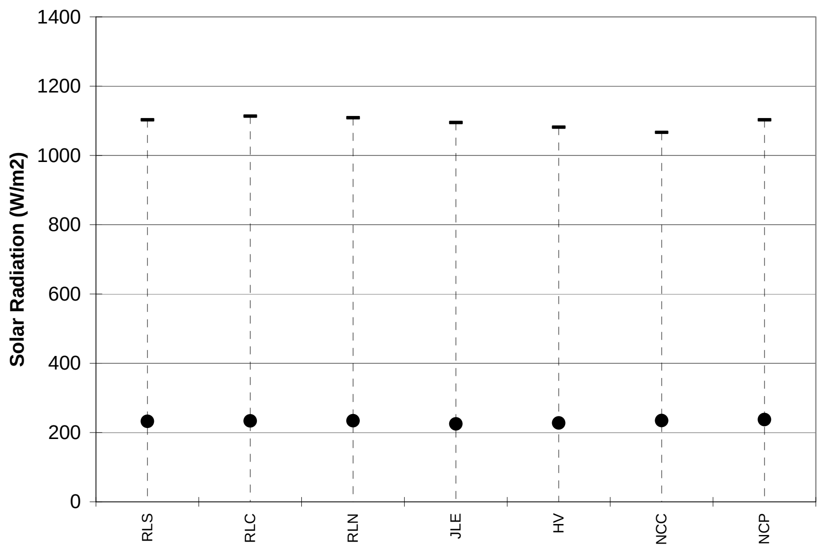


Figure 3-21. Study average solar radiation, average monthly maximum, and average monthly minimum.

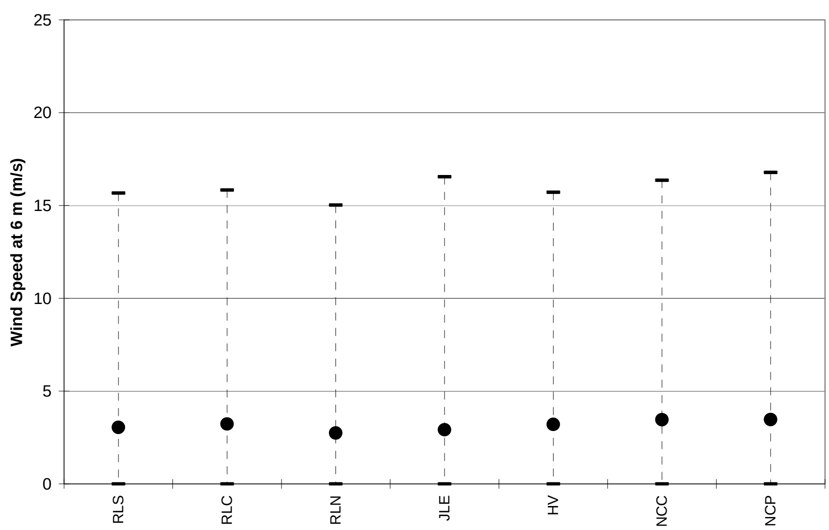


Figure 3-22. Study average wind speed, average monthly maximum, and average monthly minimum.

For comparing wind directions, 1-minute wind speed and direction data are presented in Figure 3-23 as wind roses. In the figure, all available wind data for a site are shown in the left panel while only those data associated with wind speeds greater than 8 m/s are shown in the right panel. At all sites, high winds are associated with relatively narrow bands of wind directions as compared with average winds. For example, at Roach Lake South (RLS) and Roach Lake Comparison (RLC), the wind rose that includes all valid wind measurements (left panels) has components associated with all cardinal directions. In contrast, when only winds greater than 8 m/s are considered, the associated wind directions are confined to a narrow band that centers around south (SSE to SSW) and a very narrow band that centers around north. The same is true for Roach Lake North (RLN), although we note that high winds are much less frequent there when compared to RLS and RLC. At Jean Lake Exclosure (JLE), high winds are generally from a narrow band around the southwest direction. The same is true for Hidden Valley (HV), although at HV, some high winds are associated with a northerly direction. The two Nye County sites (NCP, NCC) exhibit very similar high wind frequencies and directions. Among all seven study sites, the Nye County sites had the greatest proportion of high winds associated with a northerly direction. As with some of the other parameters examined in this section, the wind roses for sites within a county (e.g., RLS and RLC or NCC and NCP) have more in common with one another than the penstemon sites as a group (i.e., RLS, RLN, JLE, HV, and NCP) or the comparison sites as a group (i.e., RLC and NCC). The interaction of wind with sediment is explored for these different locations in a later section.

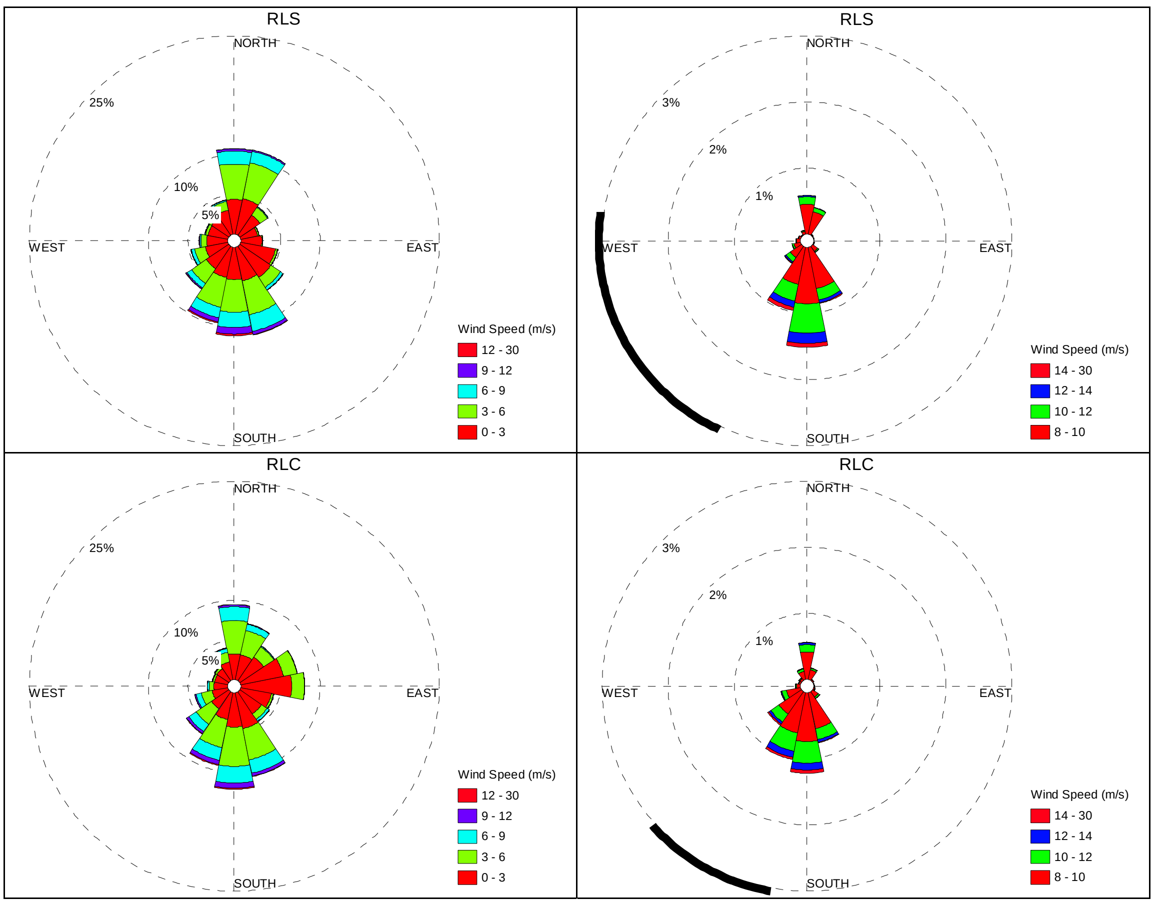


Figure 3-23. Wind roses by site for all 1-minute wind speeds (left panels) and for periods when the wind speed was greater than 8 m/s (right panels). Thick black trace in panels on the right side of the figure indicate the angle extent of nearby playa (s) as viewed from the meteorological tower at the site.

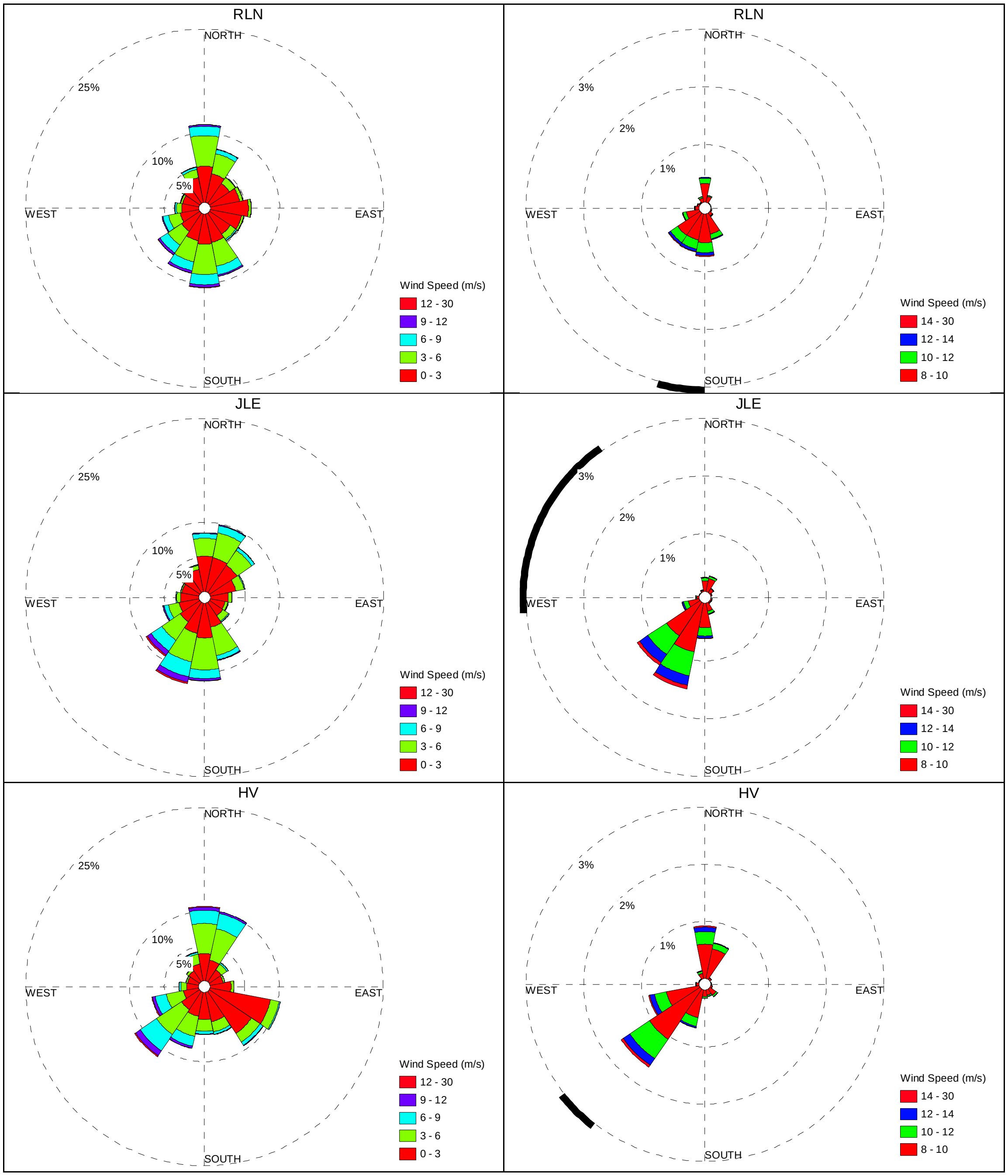


Figure 3-23. (Continued from previous page). Wind roses by site for all 1-minute wind speeds (left panels) and for periods when the wind speed was greater than 8 m/s (right panels). Thick black trace in panels on the right side of the figure indicate the angle extent of nearby playa (s) as viewed from the meteorological tower at the site.

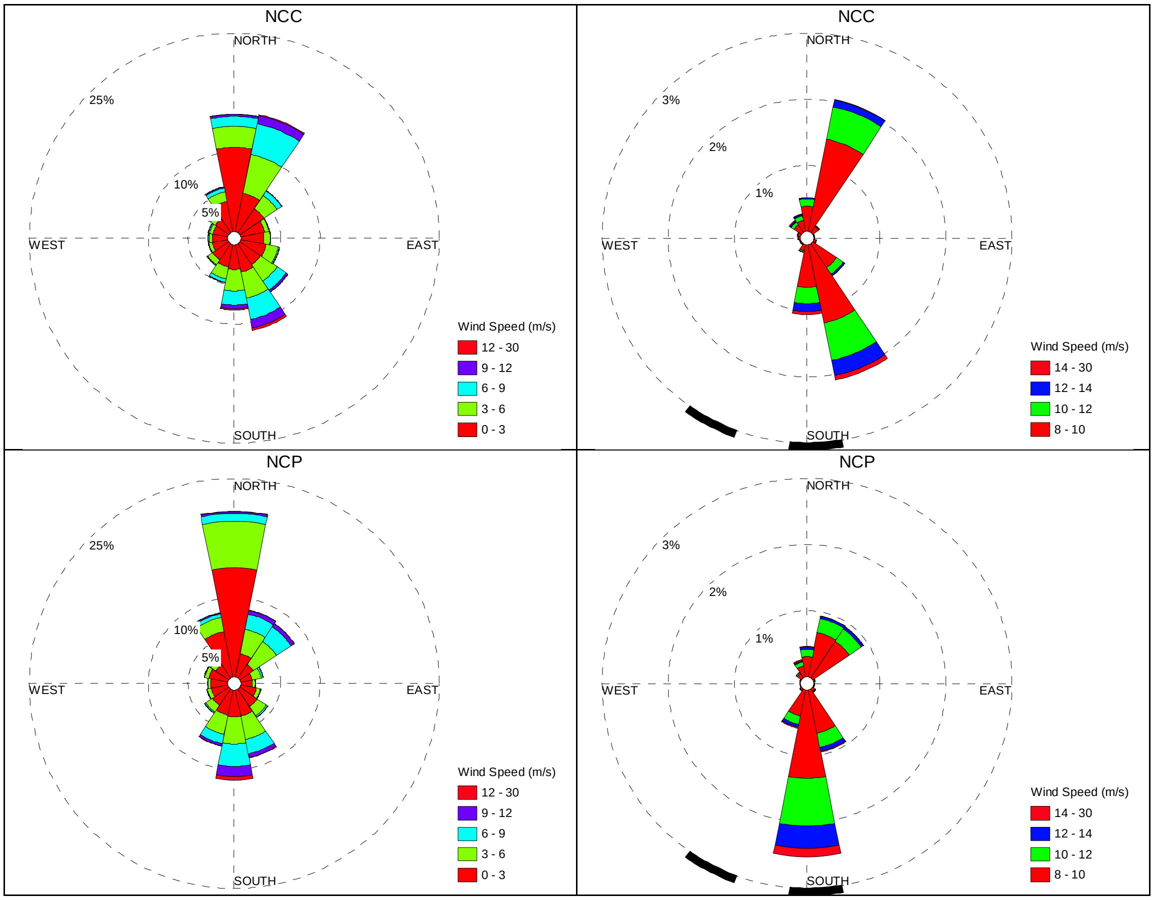


Figure 3-23. (Continued from previous page). Wind roses by site for all 1-minute wind speeds (left panels) and for periods when the wind speed was greater than 8 m/s (right panels). Thick black trace in panels on the right side of the figure indicate the angle extent of nearby playa (s) as viewed from the meteorological tower at the site.

3.2 Sediment transport

3.2.1 Sediment trap and instantaneous sediment flux measurements

The modified integrated sediment samplers were collected a total of eight times over the duration of the project. Hidden Valley (HV) was only collected seven times because of damage to the sampling equipment by cattle at the site during the spring of 2009 and was re-assembled in its original location at the start of the April 2009 collection period. The fluxes calculated from each site are based on an average of each of the three traps from the sites and the duration that the traps were left to accumulate sediment (Figure 3-24). Sediment fluxes were elevated at all sites in the spring of 2008 and spring of 2009. The sediment flux measured at Hidden Valley (HV) in early summer 2009 (period 7) was much higher than at any of the other sites. For all other periods, the Hidden Valley site more or less tracks the temporal trend of Jean Lake Exclosure (JLE). As mentioned previously, the spring 2009 sample at Hidden Valley was lost when cattle trampled over the study site, knocking over all sediment traps. It is possible that the disturbance caused by the presence of cattle rendered the soil surface much more susceptible to wind erosion at the Hidden Valley site. This would explain the comparatively very high sediment fluxes measured during period 7 at that site. Consistent with this hypothesis is the very low rainfall amounts in April, May, and June of 2009, followed by higher rainfall in July 2009. The relatively dry interval in spring 2009 would have kept the disturbed, loosened soil surface from establishing a natural crust. Rainfall in July of 2009 would have stabilized the disturbance somewhat and would explain why sediment transport rates measured in the late summer/early fall of 2009 at Hidden Valley are in line with those measured at the other Clark County sites.

Overall, Nye County Comparison (NCC) had the lowest annualized sediment transport rate (2.5 $\pm$ 0.5 kg/m/yr). This was not significantly different (α = 0.05) from the sediment transport at the Nye County Penstemon site (NCP, 4.0 $\pm$ 1.4 kg/m/yr). The sediment transport at the Clark County penstemon sites (7.0 $\pm$ 1.1 kg/m/yr), which include RLS, RLN, JLE, and HV, was different from that at the Clark County comparison site (RLC, 3.8 $\pm$ 0.3 kg/m/yr). Considering only the Roach Lake penstemon sites (RLN and RLS), there was still a statistical difference as compared to the Roach Lake Comparison (RLC) site. Importantly, the Clark County comparison site (RLC) had significantly higher sediment transport rates than the Nye County Penstemon (NCP) site. This suggests that the magnitude of present-day sediment transport rates through an area is not what encourages or prevents *P. albomarginatus* from establishing in a particular area. This is discussed in greater detail in Section 5.

Interestingly, regression analysis of the amount of material collected in the sediment traps for each collection period against the wind conditions measured at the site for that collection period did not uncover any statistically significant relationships between high winds and sediment transport. These regressions were tried using numerous combinations of only high wind events, winds from specific directions (i.e., north or south only), winds during periods when the soil moisture was above a certain threshold, and/or during periods when the relative humidity was below a threshold. In all cases, wind conditions were unable to explain the variance in the collected sediment samples (R^2 values well below 0.1, p values well above 0.5). There is no question that the little sediment that was found in the sand traps was transported by wind. However, the absence of any clear relationship between wind and sediment mass transported suggests strongly that while wind drives sediment transport under certain conditions, the combination of parameters that controls sediment transport is complex and time-dependent. That is, simply applying a set of static environmental criteria such as maximum soil moisture, relative humidity, days since rain, temperature, and/or wind conditions is not sufficient to identify periods when sediment transport occurs. What is needed is knowledge of the soil's potential for windblown transport at any given time in combination with wind conditions at that time.

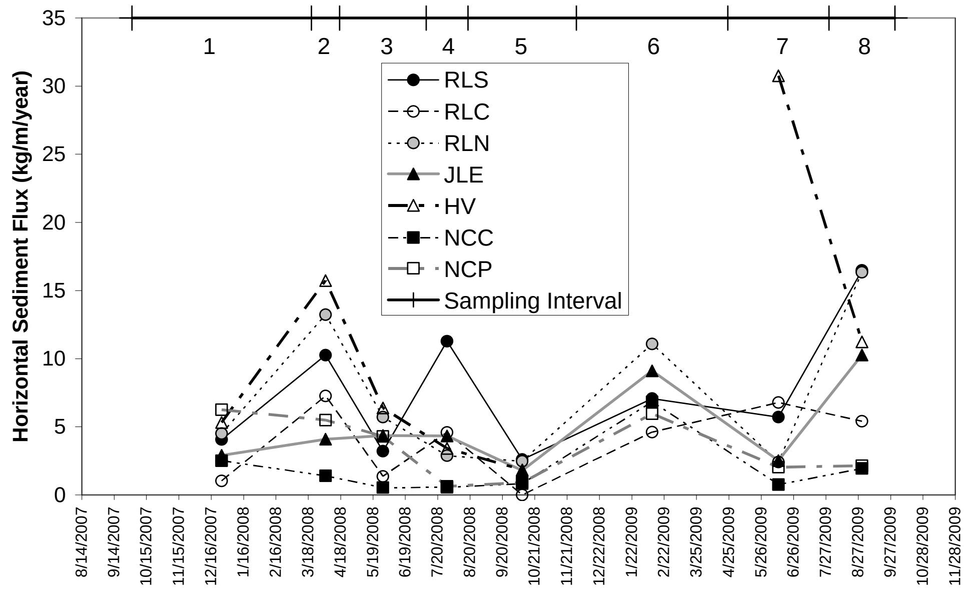


Figure 3-24. Rates of sediment transport averaged from three sediment traps at each site. Vertical lines at the top of the Figure delineate exposure periods for the sediment traps.

It was hoped that the Safire real-time sand movement sensors would provide a real-time record of the soil's susceptibility for sediment transport at each site over the study period. However, the Safire real-time sand movement sensors provided very little useful data. After instrument noise was subtracted from the measurement baseline and other quality assurance checks were applied, only those events listed in Table 3-3 were considered to have any valid data at all. Ultimately, this was because the sand transport events at the study sites were quite low in magnitude and therefore, under most cases, simply not massive enough to overcome the Safire sensors' detection limits. This is unfortunate because it would have been of considerable academic interest to specifically analyze the temporal progression of conditions that result in some sediment transport at these representative Mojave sites. As an aside, it is noteworthy that the only events which registered as above detection limits (Table 3-3) were associated with winds from the southern quadrant.

Table 3-3. Summary of sand sensor (Safire) data periods with measurements above detection limits (DL).

Site	Periods with valid sensor data	# Event above DL	Event #	Date	Event times	Safires w/ signal > DL	Range of 1-sec wind speeds (m/s)	Wind direction)
RLS	10/1/07- 4/23/08	0	N/A					
RLC	10/1/07- 10/1/09	1	1	12/13/08	9:05 – 9:30	3	17.7 - 24.5	160-190
RLN	10/1/07- 10/1/09	1	1	4/15/08	9:55 – 10:20	3	18.6 - 21.0	155 - 180
JLE	10/1/07- 7/23/09	1	1	12/13/08	11:15 – 13:00	3	20.4 - 26.9	185-220
HV	10/1/07- 12/10/08	1	1	6/24/08	13:49:08–13:49:30	2	19.7 -22.9	180 - 210
NCC	10/1/07- 10/1/09	2	1	4/14/08	21:25 – 21:50	1	15.5 - 17.9	145 - 170
			2	4/19/08	15:40 – 16:20	2	15.5 - 18.7	145 - 170
NCP	10/1/07- 10/1/09	0	N/A					

3.2.1.1 Nutrient composition of material in sediment traps

The material collected during all eight collection periods was composited for each sediment trap and subjected to chemical analysis. Compositing was necessary because the amount of material for any one collection period was too small for analysis. The sediment material was analyzed for texture, pH, electrical conductivity, NO_3, NH_4, Cl, SO_4, P, and organic carbon content. pH and electrical conductivity measurements are not comparable to those made for the bulk soil samples collected from each site because there was not enough material from the sediment traps to form a saturated paste. Thus, comparison of those two parameters should only be conducted in the context of examining site-to-site differences in sediment collected.

Texturally, the material collected in the sediment traps was dominated by sand (Figure 3-25), which constituted between 96 and 99 percent of the sample. This may be because some of the silt and clay material that enters into the sand trap is capable of leaving the trap through holes in the screening, which are required to ensure that the trap does not alter the incoming air flow. However, the very high sand content is quite consistent with the expectation that under high wind conditions sand grains are the most likely to initiate motion. It is much more difficult to aerodynamically entrain silt and clay particles.

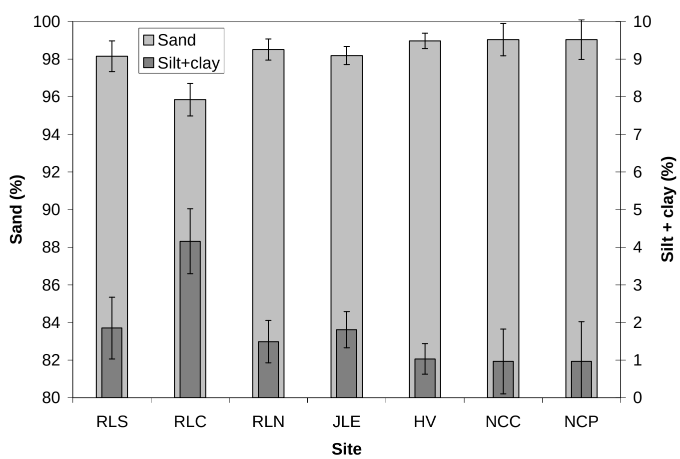
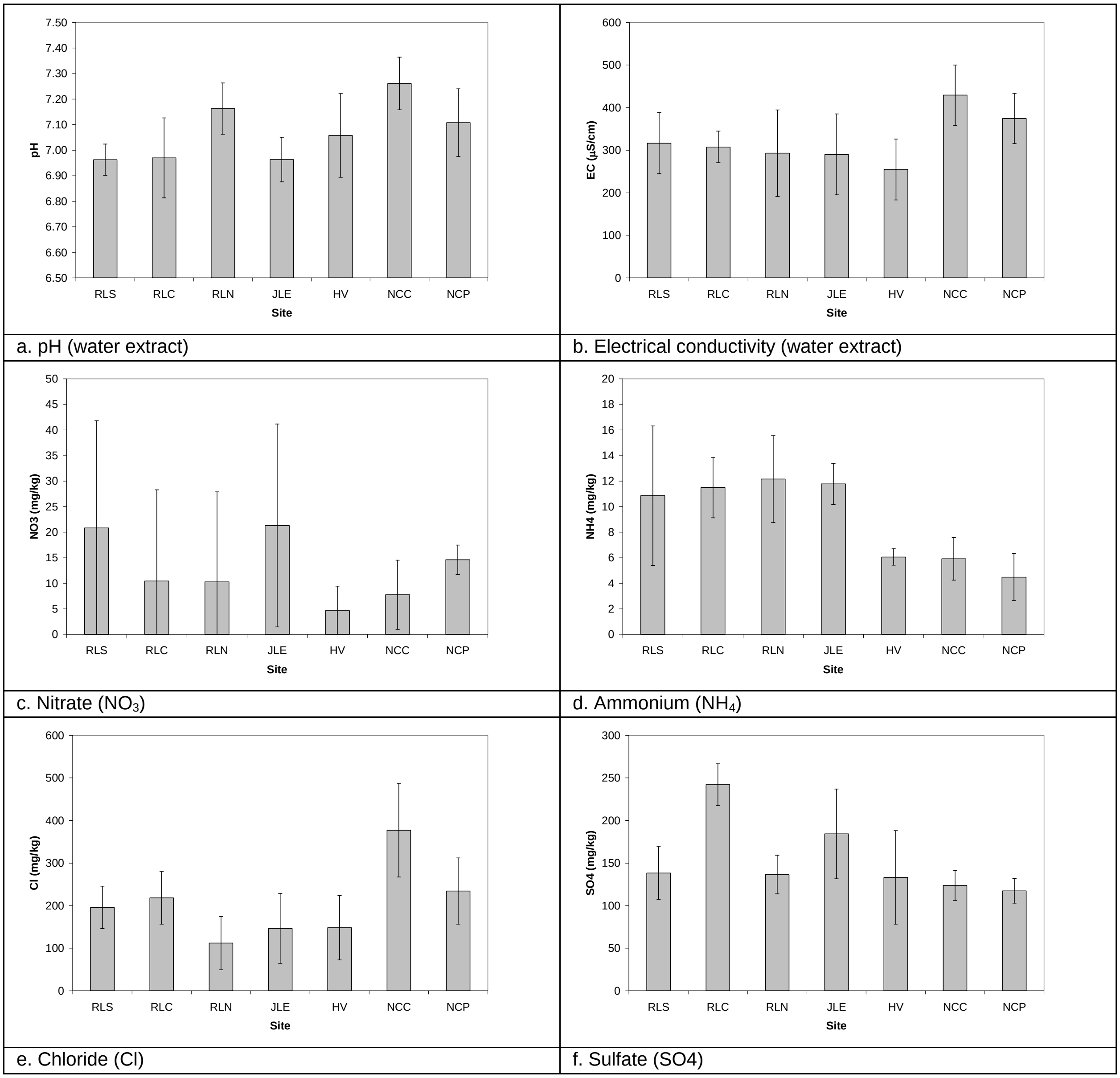


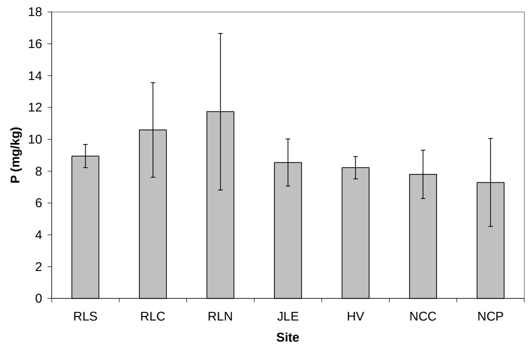
Figure 3-25. Sand (light gray, left y-axis) and silt + clay (dark gray, right y-axis) content of material in sediment traps by site. Error bars represent the standard deviations around the mean.

Figure 3-26 summarizes the results of the sediment trap chemical analyses. pH values for all samples were near neutral with some slight site-to-site variation. Electrical conductivity at the two Nye County sites was higher than the Clark County sites (α = 0.05) by about 30 percent, indicating perhaps a higher salt content in Nye County. This is somewhat supported by the Cl content, which was higher in Nye County than Clark County – although not with statistical significance, owing to the variation between the Nye County Comparison (NCC) and Nye County Penstemon (NCP) sites. NO_3 was associated with a high degree of uncertainty and only the Nye County penstemon (NCP) site had NO_3 content that was significantly different from zero. NH_4 content at the Nye County sites was significantly lower (~ 30 percent) than at the Clark County sites. The Hidden Valley (HV) site, taken alone, also had significantly lower NH_4 content as compared to the other Clark County sites. SO_4 was significantly higher at the Roach Lake Comparison site (RLC) compared to all other sites, which had similar levels of SO_4 to one another. Phosphorous (P) was comparable among all sites. Organic carbon was significantly higher at Roach Lake North (RLN) than anywhere else as was $CaCO_3$. There were no chemical species for which the concentration for comparison sites, taken as a whole, was different from penstemon sites, taken as a whole.

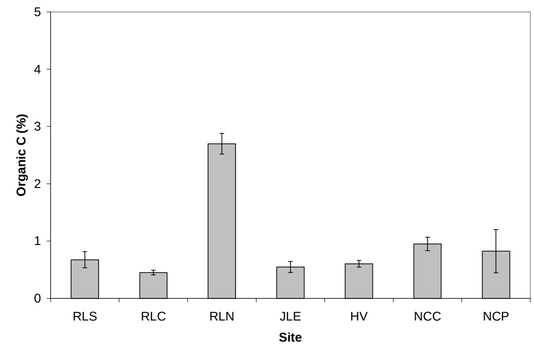


a. pH (water extract)
b. Electrical conductivity (water extract)
c. Nitrate (NO_3)
d. Ammonium (NH_4)
e. Chloride (Cl)
f. Sulfate (SO4)

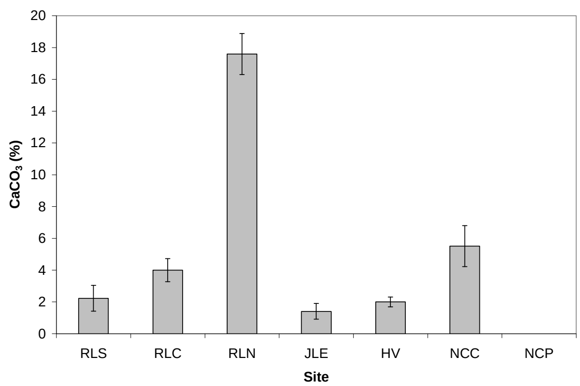
Figure 3-26. Chemical properties of material collected in sediment traps. Values based on samples over study period composited by sediment trap. Error bars are standard deviations among the three sediment traps at each site.



g. Phosphorous (P) - Olsen method



h. Organic carbon (%)



i. Calcium carbonate (%)

Figure 3-26. (Continued from previous page). Chemical properties of material collected in sediment traps. Values based on samples over study period composited by sediment trap. Error bars are standard deviations among the three sediment traps at each site.

3.2.2 Water erosion and fluvial sediment transport

The KINEROS2 model was run for several different scenarios to estimate the degree of surface runoff and sediment transport that can result under varying conditions. The site-specific soil and hydraulic properties used in the model are given in Appendix E. The four different rainfall scenarios simulated are summarized in Table 3-4. The first two scenarios are the 100-year maximum 3-hour and 30-minute peak rainfall events, respectively. Total rainfall values were obtained from the National Oceanic and Atmospheric Administration (NOAA) Atlas 14, Vol. 1, for a location near the Clark County sites. Short duration (less than a few hours) events were associated with higher rainfall in Clark County than in Nye County, so Clark County precipitation frequency data were used. The third scenario is based on the most intense 30-minutes of rainfall measured during this study, measured at Roach Lake Comparison on August 7, 2008. In this case, the rainfall intensity was available as a time series over the 30-minute period and those data were used in the model simulation. The fourth scenario corresponds to the 100-year peak 30-minute rainfall total (same as scenario 2), but with the intensity time series modeled after the real event in Scenario 3. The rainfall intensity time series for Scenarios 2-4 are shown in Figure 3-27.

For the 100-year peak 3-hr rainfall (Scenario 1), the 100-year peak 30-minute rainfall (Scenario 2), and the peak 30-minute event recorded during the study (Scenario 3), the amount of sediment transported was essentially negligible for all sites. For Scenario 4 (Table 3-5), which uses the 100-year 30-minute peak rainfall total in conjunction with a variable rain intensity, the model predicts that the highest amount of sediment transport by overland flow would be 6.5 kg/ha at the Nye County Penstemon site (NCP). Since the total rainfall amount is the same in Scenarios 2 and 4, the non-negligible sediment transport in Scenario 4 must be attributed to the higher peak rainfall intensities (Figure 3-27). Thus, sediment transport by overland flow – if it occurs at all – is most probable during very short, extremely intense rainfall events. In any case, we note that even the 6.5 kg/ha of sediment predicted to be transported at the Nye County Penstemon (NCP) site in Scenario 4 is still extremely small (about a gallon of soil). If this type of event only occurs every hundred years, then on timescales of millennia sediment movement by overland runoff is essentially zero for all seven sites in this study.

The finding that there is minimal sediment transport by overland runoff does not preclude the possibility of substantial erosion through channel flow. The fact that the landscapes at all of the study sites are characterized by erosion channels that are in some cases 1 or more meters deep is clear evidence that channels and washes are an important part of the geomorphology of the study sites. However, in the context of this study, although channel flow may incise through *P. albomarginatus* habitat areas, it does not result in the isotropic removal of sediment from the soil surfaces in habitat areas if the timescale for consideration is hundreds of years or less.

We note that one simplification employed in this modeling effort is the assumption that the study sites could be modeled as flat, sloped surfaces that exist without topographic context. That is, we assumed that the size of the catchment basin the sites are located in and the terrain upslope of the sites do not play a significant role in the potential for sediment transport. Strictly, this assumption is not satisfied at any of the sites. However, we note first that over scales of several hundred meters, the terrain at all sites is relatively homogeneous without major relief features, and second that the existence of channels suggests that flow from far upstream (i.e., mountain terrain) passes through the site areas through those channels rather than overland. Thus, while the geometry used to represent the study sites is simplistic, it is adequate for ascertaining whether or not sediment is transported to any substantive degree through overland rain runoff.

Table 3-4. Rainfall total and intensity scenarios used in KINEROS2 simulation.

Scenario	Rainfall Total/ period (min)	Basis for total rainfall	Basis for intensity
1. 100-year 180-minute event	61 mm/ 180 minutes	NOAA Atlas 14 Vol 1 for Roach Lake Locale	Constant intensity
2. 100-year 30-minute event	39 mm/ 30 minutes	NOAA Atlas 14 Vol 1 for Roach Lake Locale	Constant intensity
3. Current study peak 30-minute event	23 mm/ 30 minutes	Roach Lake Comparison, August 7, 2008 event	Measured
4. 100-year 30-minute event with variable intensity	39 mm/ 30 minutes	NOAA Atlas 14 Vol 1 for Roach Lake Locale	Profiled to resemble intensity from Scenario 3.

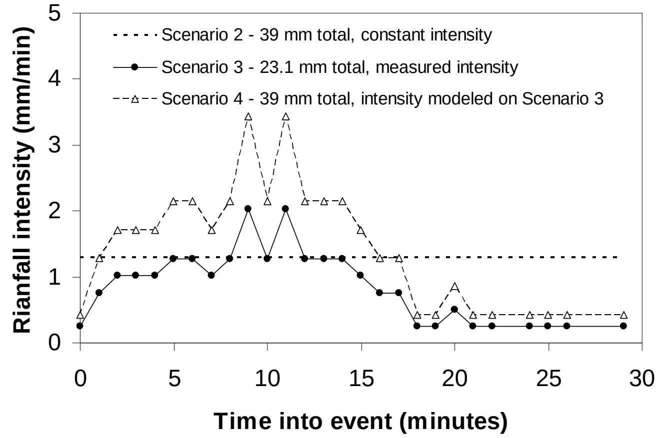


Figure 3-27. Rainfall intensities used to model Scenarios 2, 3, and 4.

Table 3-5. Results from Scenario 4. 100-year 30-minute precipitation event with variable intensity: 39 mm total precipitation, intensity proportioned to time series in Scenario 3.

Site Code	Overland Runoff (m^3/ha)	Sand (%)	Silt (%)	Clay (%)	Total sediment transport (kg/ha)
RLS	0	87.9	7.0	5.1	0.01
RLC	0.66	14.1	27.1	58.8	0.85
RLN	0	0	0	0	0
JLE	0	0	0	0	0
HV	0	0	0	0	0
NCP	4.14	16.3	33.5	50.2	6.5
NCC	0.20	16.8	29.4	53.8	0.11

3.3 Eolian transport of dust

3.3.1 Deposition of dust-sized particles

Results of measurements of atmospheric deposition are shown in Figure 3-28. The dust traps were collected twice over the two-year period to maximize the quantity of material accumulated in each of the traps. Even over that long of a time period, the Nye County sites still required combining the material collected from the separate years to yield a large enough sample for the laboratory analyses. As mentioned, the Hidden Valley (HV) site was overrun by cattle during the second deposition sample exposure period. Thus, HV data shown are based on only the first year of deposition monitoring. The error bars associated with HV data reflect the average difference between the first and second year of measurements for all other sites; they are much larger than the error bars for the other six sites, which reflect the standard deviation of the two replicate samplers. This is because the difference in the deposition rate between year 1 (4-site Clark County average: 2.0 g/m^2/year) and year 2 (4-site Clark County average: 32.3 g/m^2/year) is substantial and statistically significant (α = 0.05). Since year 1 and 2 samples for the Nye County sites had to be combined for weighing and analysis, it was not possible to determine inter-annual differences for those sites. In general, the amount of material deposited at the Clark County sites was about an order of magnitude (12.7X) higher than the deposition that occurred at the Nye County sites.

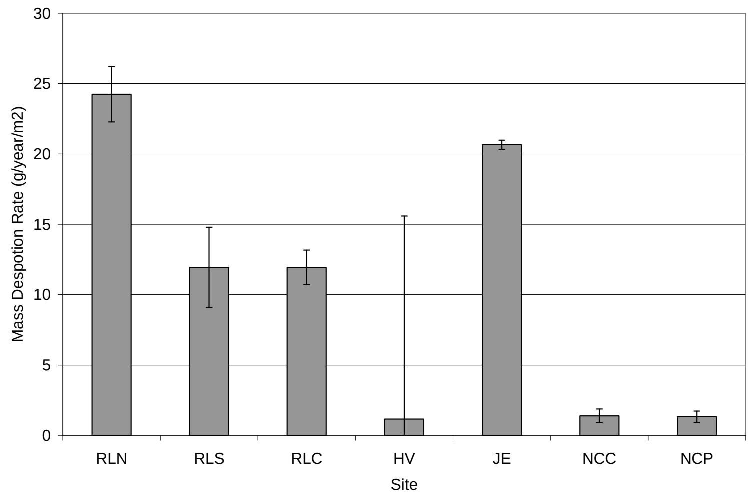


Figure 3-28. Annualized mass deposition rate of material to each site. Error bars represent standard deviations among the two traps deployed at each site. Error bars for Hidden Valley reflect uncertainty associated with the total deposited mass due to measurements in the second year being invalid.

3.3.2 Nutrient composition and characterization

Texturally, all deposition samples were dominated by sand (Figure 3-29), with Roach Lake South (RLS) having the lowest sand fraction (66 percent) and Nye County Penstemon (NCP) having the highest sand fraction (87 percent). Silt fractions ranged from 13 percent at NCP to 33 percent at RLS, while clay fractions ranged from 0 percent (± 0.36 percent) at NCP to 1.21 percent at RLS. Overall, the sand fraction was higher at the Nye County sites (82.5 percent) than at the Clark County sites (69.4 percent). Deposition samples from the Nye County Comparison (NCC) site have more in common with the Nye County Penstemon (NCP) site in terms of magnitude and texture than with the Roach Lake Comparison (RLC) site. Likewise, samples from the RLC site were similar to those obtained from the four Clark County penstemon sites.

Similar trends, where the comparison sites (NCC and RLC) had more in common with the penstemon sites located in their respective counties than they did with each other, were observed for several of the chemical species sampled from the deposited material (Figure 3-30). Deposition rates for of NO_3, Cl, SO_4, and organic carbon were higher at the Clark County sites than the Nye County sites by about an order of magnitude (ranging from a factor of 5 for SO_4 to a factor of 16 for Cl). These proportions are similar to those of total deposited mass, suggesting that these chemical species are strongly associated with local soils. In contrast, NH_4 and P deposition rates were somewhat comparable in magnitude between Clark and Nye County sites. NH_4 rates for Clark County were 1.6 times those of Nye County while P rates at Clark County were 0.9 those at Nye County. This indicates that these two chemical species exhibit more regional background levels and that their rates of deposition are more spatially uniform.

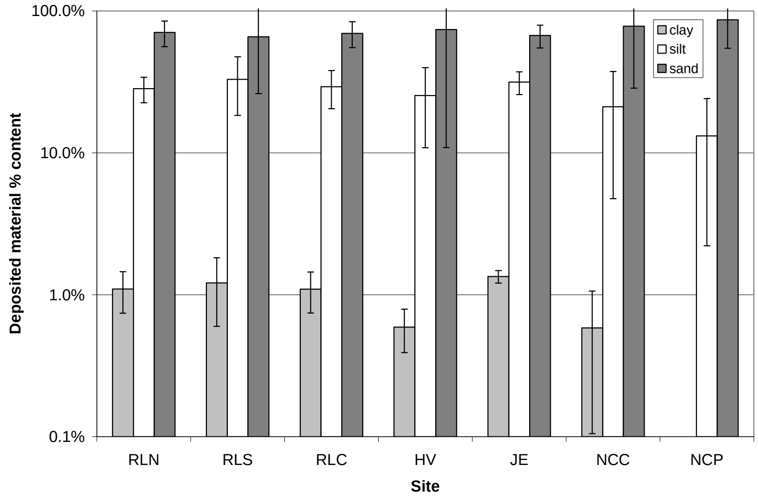


Figure 3-29. Textural composition of material collected with deposition samplers. Error bars represent standard deviations of two replicate samples collected at each site. Hidden Valley (HV) textural data are based on only one year of sample collection.

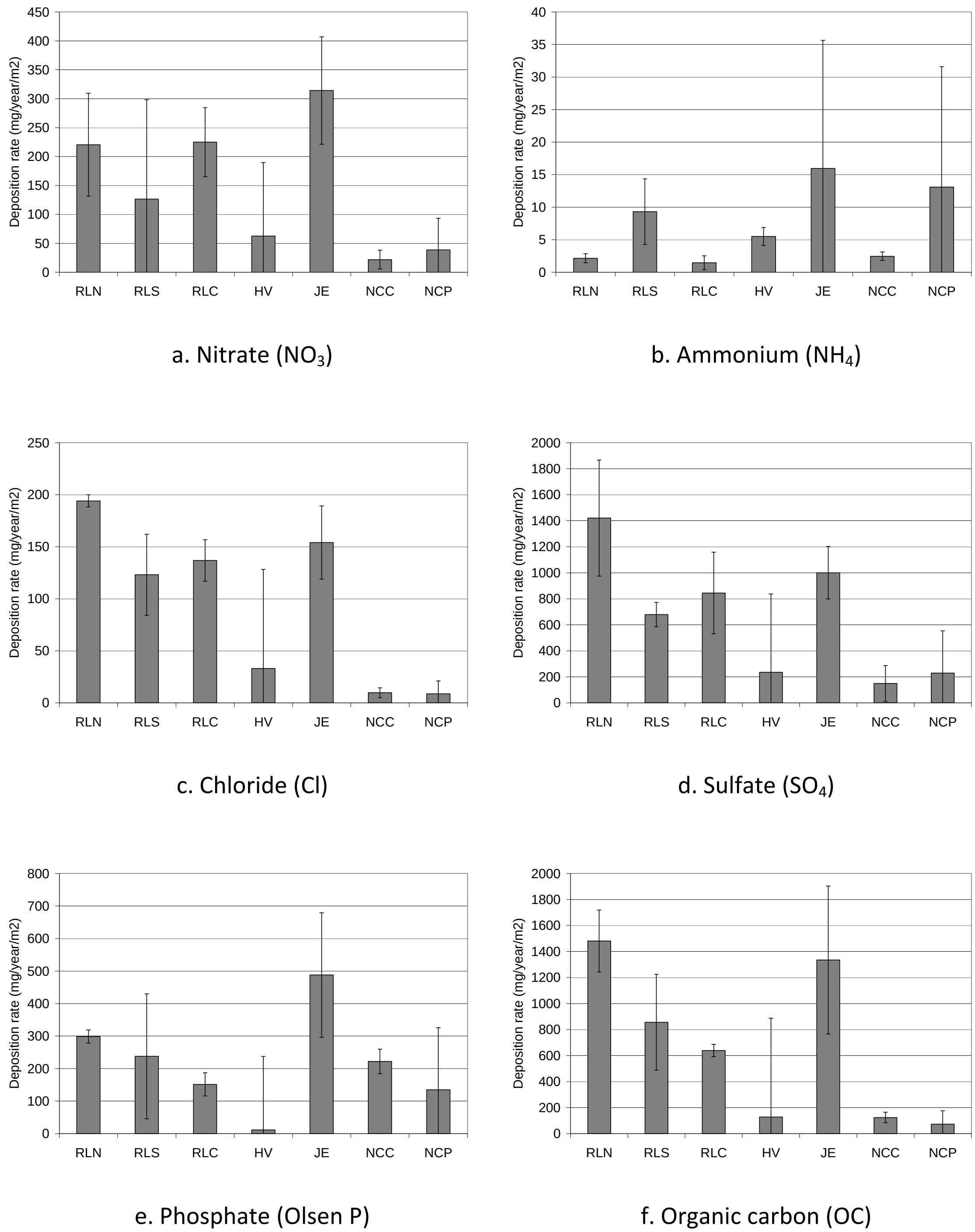


Figure 3-30. Chemically speciated deposition rates by site. Error bars represent standard deviations from two replicate samplers at each site. Hidden Valley (HV) data are based on one year of collection and error bars shown reflect an estimate of the uncertainty associated with the data from that site.

3.4 Characteristics of *P. albomarginatus* habitats and populations

3.4.1 Ranges in plant community structure supporting existing populations of *P. albomarginatus*

Photos of site landscape position and plant community structure and diversity are shown in Figure 3-31 through Figure 3-37, with higher quality versions provided in Appendix G. The dates of collection and locations of the vegetation transects are also provided in Appendix G. Total abundance of the 26 perennial plant species recorded for all vegetation transects are listed in Table 3-6. Annual plant species diversity was recorded, but densities were not estimated. In general, the Clark County study sites had higher annual plant diversity than the Nye County sites and, due to the below-average precipitation for both study years, annual densities were also below average. In Clark County, the invasive annual *Schismus arabicus* was the dominant annual, but did not occur in the Nye County sites where *Plantago ovata* was the dominant annual.

All communities had a significant component of *Ambrosia dumosa* (white bur-sage) and *Larrea tridentata* (creosote bush), but the comparison sites had significantly greater densities of these two species than the penstemon sites (Figure 3-38). Penstemon sites had significantly greater densities of *Pleuraphis rigida* (galleta grass), *Achnatherum hymenoides* (Indian ricegrass) and *Krascheninnikovia lanata* (winterfat) than comparison sites. On the whole, total perennial plant density for penstemon sites was not significantly different than comparison sites. The pattern for perennial plant cover was similar to plant density, but only *P. rigida* cover was significantly greater for penstemon sites and *Ephedra nevadensis* cover was significantly greater for comparison sites (Figure 3-39). The penstemon site mean perennial diversity of 8.09 ± 0.42 species per transect was significantly greater than at the comparison sites (6.27 ± 0.57), but essentially the presence of *P. albomarginatus* in the penstemon sites accounts for this difference.

Size class distributions for all perennial plants (based on canopy area) indicate that the penstemon sites tended to support smaller plants than the comparison sites (Figure 3-40), but this pattern is probably the result of differences in species composition rather than an actual difference in plant ages. *A. dumosa* mean height on comparison sites (27.6 ± 0.3 cm) was significantly taller than on penstemon sites (25.4 ± 0.2), but again this small difference is probably not highly correlated with plant age.

Results of a cluster analysis of the study sites (Figure 3-41) indicate that the native perennial grass, *P. rigida*, and the native shrubs, *K. lanata* and *Acamptopappus shockleyi*, are the most likely indicator species for the presence of *P. albomarginatus*. *A. dumosa*, *L. tridentata,* and *Krameria erecta* are relatively ubiquitous and apparently unrelated to the presence of *P. albomarginatus*. The cluster analysis also separated the two Nye County sites (penstemon and comparison) from the other study sites and the Roach Lake Comparison site (RLC) from the other Clark County sites. This is consistent with observations for other environmental parameters, which generally indicate that the two Nye County sites had more in common with one another than with their respective comparison or penstemon Clark County counterparts.

We note that regardless of community structure, only 25 percent of the 180 flagged plants used in our growth and phenology study occurred in under shrub or grass canopies. Of those, approximately half occurred under *A. dumosa*, 35 percent under *P. rigida* canopies and none under L*. tridentata* canopies.

Figure 3-31. Landscape position and community structure of the Roach Lake South (RLS) penstemon study site (June 2009).

Figure 3-32. Landscape position and community structure of the Roach Lake Comparison (RLC) study site (May 2009).

Figure 3-33. Landscape position and community structure of the Roach Lake North (RLN) penstemon site (June 2009).

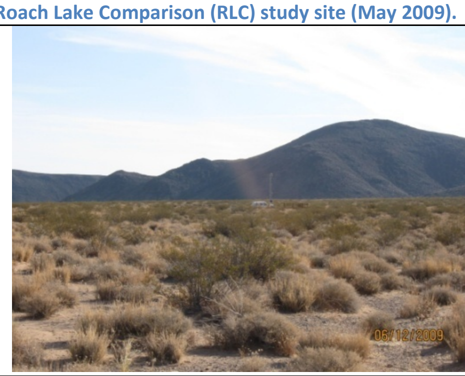


Figure 3-34. Landscape position and community structure of Jean Lake Exclosure (JLE) penstemon study site (June 2009).

Figure 3-35. Landscape position and community structure of the Hidden Valley (HV) penstemon study site (June 2009).

Figure 3-36. Landscape position and community structure of Nye County Comparison (NCC) study site (December 2007).

Figure 3-37. Landscape position and community structure of Nye County Penstemon (NCP) study site (November 2009).

Table 3-6. Perennial plant diversity and abundance found in 22 penstemon vegetation transects (50 m x 2.5 m) and 11 comparison site transects.

Family	Genus	Species	Abbrev.	Form	Common Name	Penstemon sites (22)	Comparison sites (11)
Poaceae	*Achnatherum*	*hymenoides*	*achy*	grass	Indian ricegrass	156	15
Asteraceae	*Acamptopappus*	*shockleyi*	*acsh*	shrub	Shockley's golden head	71	2
Asteraceae	*Ambrosia*	*dumosa*	*amdu*	shrub	White bur-sage	1803	1121
Apocynaceae	*Amsonia*	*tomentosa*	*amto*	forb	Amsonia	3	0
Chenopodiaceae	*Atriplex*	*polycarpa*	*atpo*	shrub	Cattle saltbush	18	0
Ephedraceae	*Ephedra*	*nevadensis*	*epne*	shrub	Mormon tea	0	27
Polygonaceae	*Eriogonum*	*inflatum*	*erin*	forb	Desert trumpet	8	1
Poaceae	*Erionuron*	*pulchellum*	*erpu*	grass	Fluff grass	2	2
Krameriaceae	*Krameria*	*erecta*	*krer*	shrub	Desert ratany	207	152
Chenopodiaceae	*Kraschenninikovia*	*lanata*	*krla*	shrub	Winterfat	125	1
Zygophyllaceae	*Larrea*	*tridentata*	*latr*	shrub	Creosote bush	149	129
Solanaceae	*Lycium*	*andersonii*	*lyci*	shrub	Anderson's wolfberry	1	0
Cactaceae	*Opuntia*	*basilaris*	*opba*	cactus	Beaver-tail cactus	0	1
Cactaceae	*Opuntia*	*echinocarpa*	*opec*	cactus	Silver cholla	19	7
Cactaceae	*Opuntia*	*ramosissima*	*opra*	cactus	Pencil cactus	4	6
Poaceae	*Panicum*	*urvillanum*	*paur*	grass	Panicgrass	1	0
Scrophulariaceae	*Penstemon*	*albomarginatus*	*peal*	forb	White-marginaed penstemon	276	0
Poaceae	*Pleuraphis*	*rigida*	*plri*	grass	Galleta grass	751	4
Fabaceae	*Psorothamnus*	*fremontii*	*psfr*	shrub	Indigo bush	3	0
Polygonaceae	*Rumex*	*hymenosepalus*	*ruhy*	forb	Wild-rhubarb	7	0
Asclepiadaceae	*Sarcostemma*	*cyanchoides*	*sacy*	forb	Climbing milkweed	33	0
Malvaceae	*Sphaeralcea*	*ambigua*	*spam*	forb	Grobe mallow	1	0
Poaceae	*Sporobolus*	*flexuosus*	*spfl*	grass	Mesa dropseed	1	0
Asteraceae	*Stephenomeria*	*pauciflora*	*stpa*	forb	Wire-lettuce	1	0
Rutaceae	*Thamnosa*	*montana*	*thmo*	shrub	Turpentine-broom	1	0
Lilliaceae	*Yucca*	*schidigera*	*yusc*	succulent	Mohave yucca	0	1

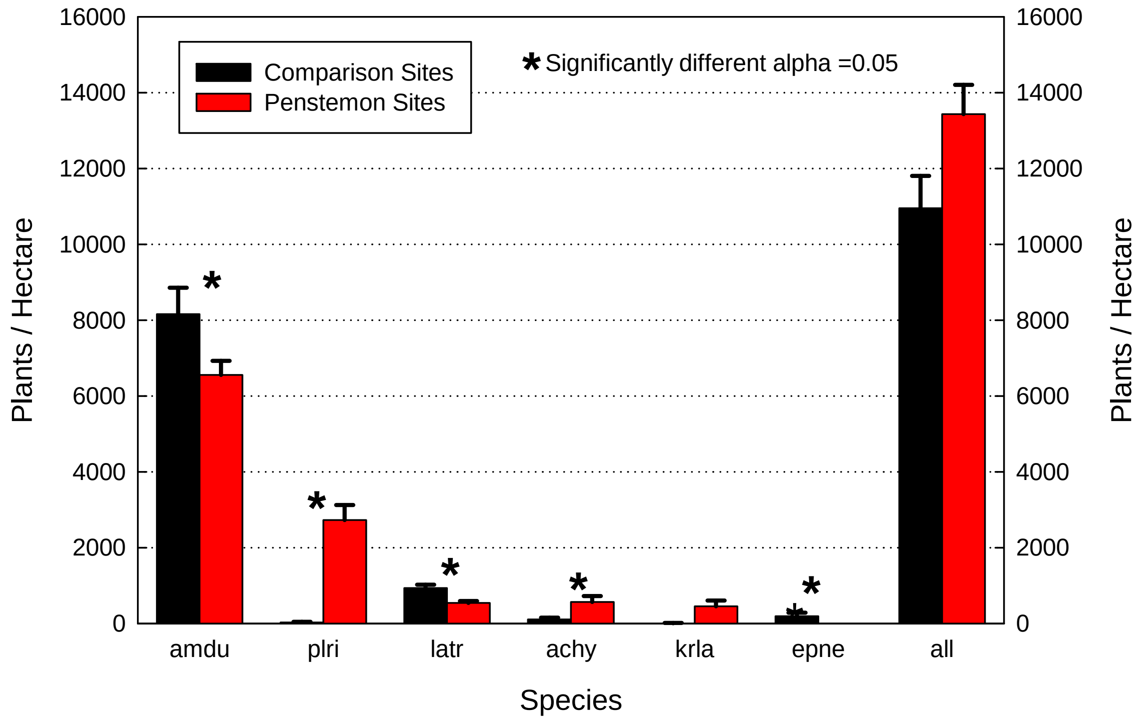


Figure 3-38. Perennial plant densities for penstemon and comparison sites. Error bars are the standard error of the mean for each species

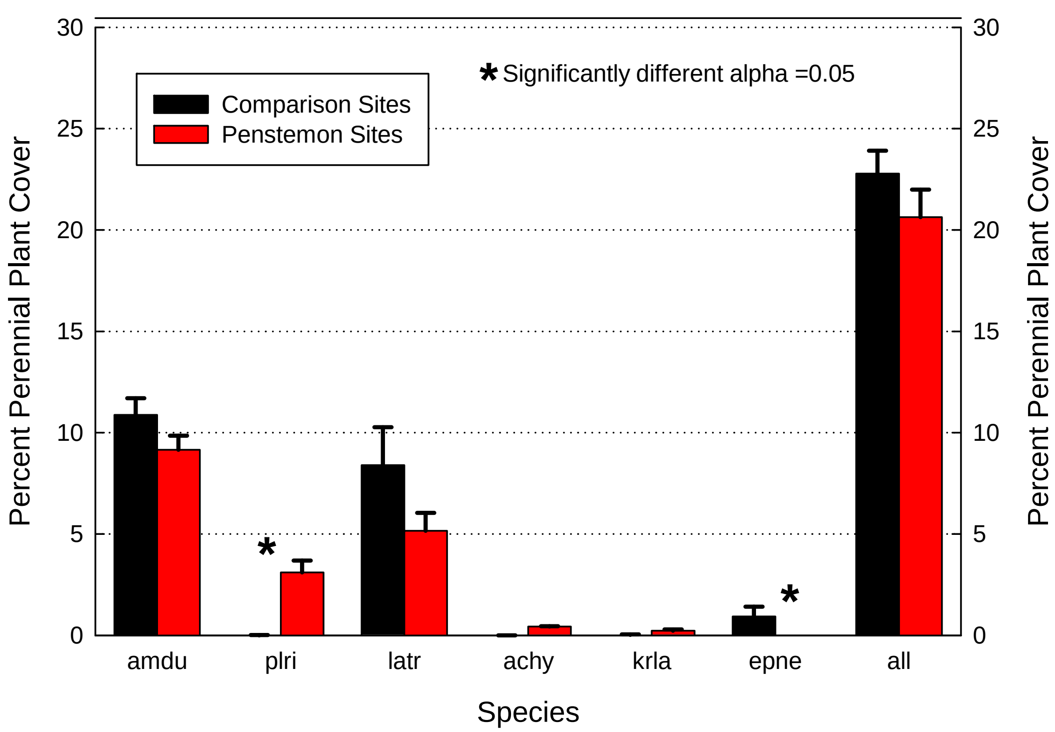


Figure 3-39. Perennial plant percent cover for penstemon and comparison sites. Error bars are the standard error of the mean for each species.

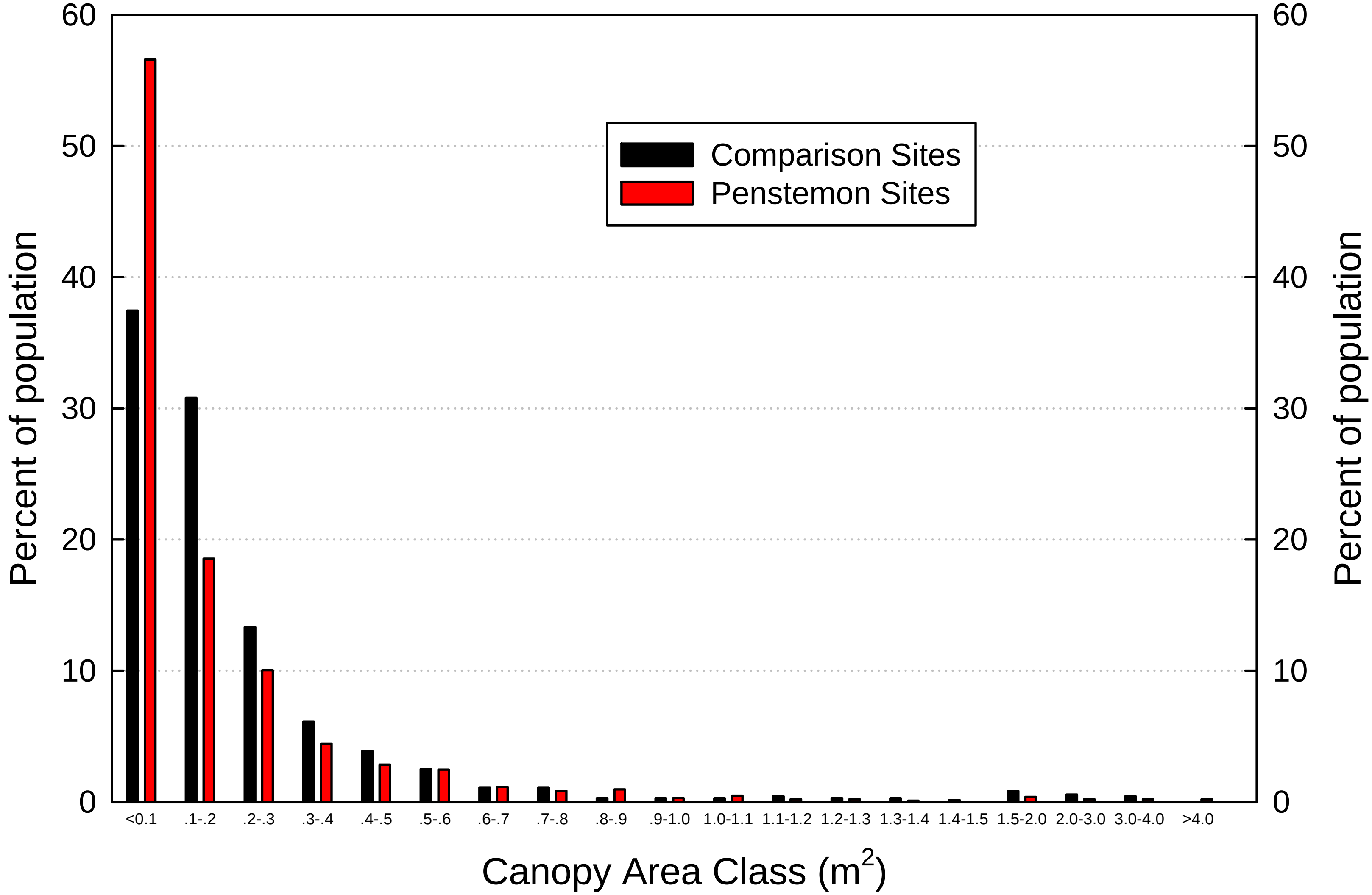


Figure 3-40. Penstemon versus comparison site size (canopy area) class distribution for all perennial plants.

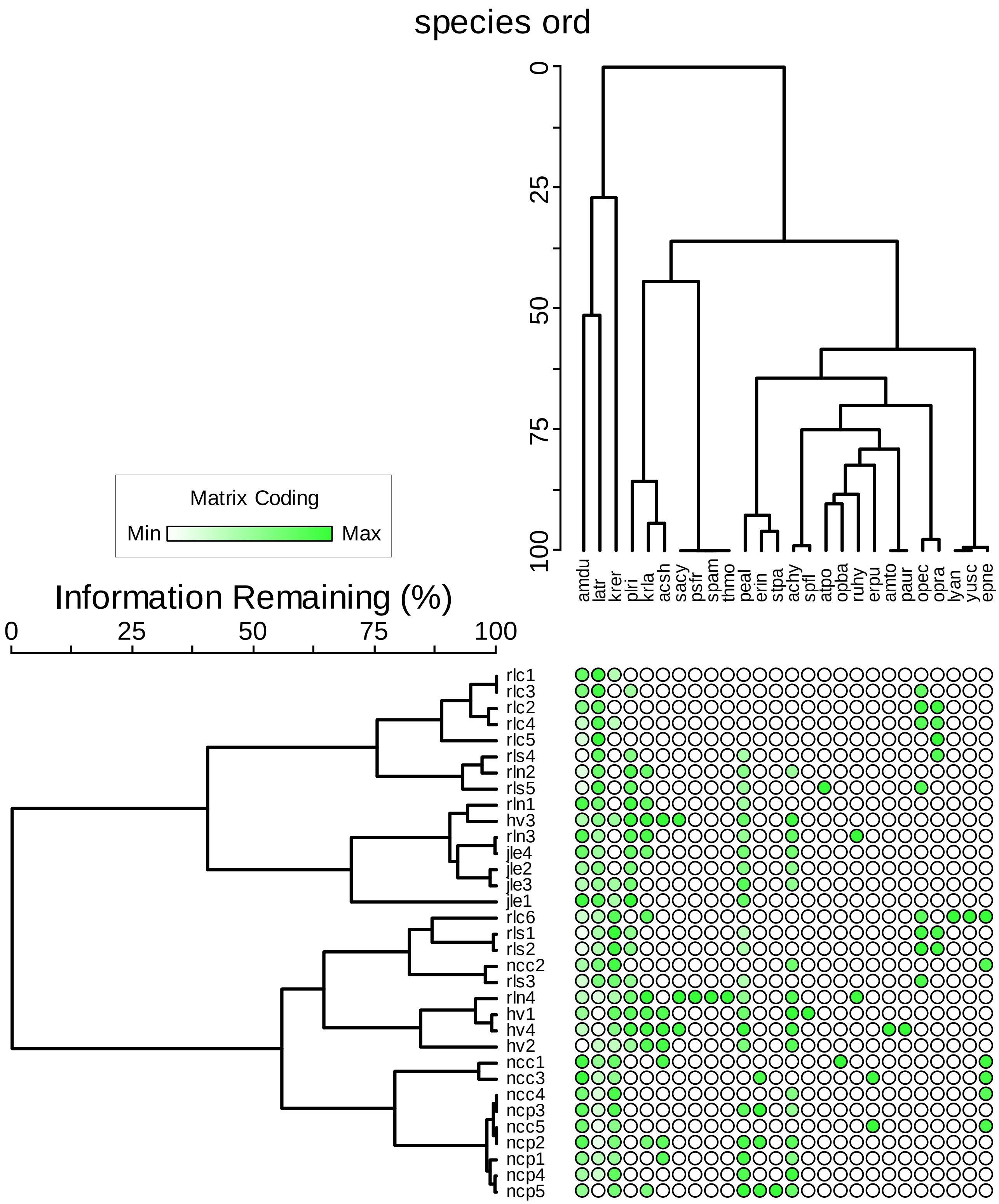


Figure 3-41. Cluster ordination by species (above) and by site (below).

3.4.2 Current estimates for *P. albomarginatus* population size, areal extent, and density

We documented *P. albomarginatus* abundance and distribution within continuous 10-meter-wide transects that intersected areas with known populations of *P. albomarginatus* and extended beyond the boundaries of these populations (Figure 3-42 to Figure 3-46, with expanded figures in Appendix H). The total length of the transects was 173.6 km in Clark County and 44.5 km in Nye County, equivalent to 429 acres and 110 acres, respectively (Table 3-7). Altogether, 3673 independent records of *P. albomarginatus* density were recorded. The objective was to develop up-to-date estimates of *P. albomarginatus* densities and distributions for providing practical information for managing populations of *P. albomarginatus* and for comparison with the 1997-8 Smith survey results*.* Surveys for *P. albomarginatus* distribution and density were only conducted for populations that were previously surveyed in 1997-8 (F.J. Smith 2001). In addition to the five instrumented penstemon study sites, surveys included one additional site in Clark County at the south end of Hidden Valley (HV) and six additional sites in Nye County.

At all sites, plants were documented outside the boundaries of the 1997-8 Smith surveys, and large areas within the Smith boundaries had extremely low *P. albomarginatus* densities or none at all, especially for the western part of the Roach Lake North (RLN) population (Figure 3-43). Based on the surveys conducted in this study, estimates of *P. albomarginatus* densities for Clark County indicate a population of 125,825 plants, which is approximately 5 times larger than the Smith (2001) estimate. For Nye County the population estimate from this study of 78,954 plants is approximately twice the Smith (2001) estimate. The standard error of the mean estimate for each population varied from 7 to 26 percent of the mean. Unfortunately, the Smith (2001) and present study population estimates are not directly comparable because of differences in methods used. Nevertheless, the substantially larger population estimates from the present study compared to the earlier Smith (2001) estimates is noteworthy. It is not possible to determine if this discrepancy between the two estimates is a result of actual increases in *P. albomarginatus* population or simply a reflection of the approximate nature of the Smith (2001) survey methodology. A ten-year BLM monitoring effort at the Jean Lake Exclosure (JLE, Figure 3-47) does suggest that, at least at JLE, *P. albomarginatus* densities were statistically lower in 1998, 1999, 2002, and 2004 than in other years between 1996 and 2006 (e.g., "AB" years in Figure). However, the highest estimate recorded in 1996 was less than both our transect estimate and our survey estimate. Thus, inter-annual variation in densities would not fully account for differences between our density estimates and those of Smith (2001).

Furthermore, we note that it is possible, perhaps likely, that there are existing *P. albomarginatus* populations in both counties that have not been found. In addition, because our density estimates were conducted during below-average precipitation years, actual *P. albomarginatus* population densities and sizes are possibly larger than our estimate would indicate, although the validity of this assumption is not immediately evident from the relationship between precipitation and plant density in Figure 3-47 (i.e., it is not clear quantitatively how rainfall impacts density).

Table 3-7. Comparison of *P. albomarginatus* density estimates based on 1) BLM monitoring data for 8 (60m x 5 m) transects for the Jean Lake Exclosure (JLE) population between 1996 and 2006, 2) *P. albomarginatus* density in 22 (50 m x 2.5 m) vegetation transects at each study sites, and 3) extensive field surveys within and outside the population boundaries delineated by 1997-8 surveys (F.J. Smith, 2001).

CLARK COUNTY

Study	Smith	Distance walked (m)	Tran-sects	Acres surveyed	Plants counted	[3]Survey pl/acre	[2]Transect pl/acre	[1]BLM pl/acre	Smith acres	Smith plants	Smith pl/acre	wt pl/ac	wt total
RLS	12	24987	428	61.7	513	67 ± 6	84 ± 22		157	>500	3.2	8.29	1302
RLN	9	66784	823	165	1494	75 ± 5	146 ± 28		2464.4	5000	2.0	9.03	22254
JLE	10	44829	666	110.7	2981	149 ± 11	202 ± 61	412 ± 72	2063.7	>10000	4.9	26.7	55018
HVS	1	9084	121	22.4	58	19 ± 5			693			4.2	2904
HVN	1	22574	653	55.8	5164	228 ± 16	462 ± 235		461	8464	18.4	92.6	42689
HV	11	5320	130	13.1	175	42 ± 7			124.6	>2000	16.0	13.3	1660
Totals		173578	2821	428.7	10502	24.50			5963.7	25964	8.9		125825

NYE COUNTY

Study	Smith	Distance walked (m)	Tran-sects	Acres surveyed	Plants counted	Survey pl/acre	Transect pl/acre	BLM pl/acre	Smith acres	Smith plants	Smith pl/acre	wt pl/ac	wt total
	2	2226	31	5.5	115	107 ± 23			16.1	1000	62.1	15.1	242
	3	2560	37	6.2	83	73 ± 23			30.7	8000	261.0	18.2	558
NCP	4, 7, 8	19647	494	48.5	3459	185 ± 18	1049 ± 304		106	5000	47.2	71.3	7554
	5	14725	225	36.4	10744	1840 ± 251			236	20000	84.7	295.4	69714
	6	5351	65	13.2	532	240 ± 32			22	5000	227.3	40.3	886
	7				191				5.1	200	39.2		
	8								57	>3000	52.6		
Total		44509	852	109.8	15124				472.9	42200	110.59		78954

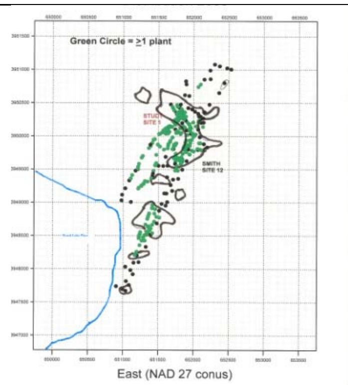


Figure 3-42. Comparison of Roach Lake South (RLS) ***P. albomarginatus*** distribution estimate based on 1997-8 surveys (black lines) with 2008-9 survey results. Green dots represent one or more ***P. albomarginatus*** plants, black dots are locations without ***P. albomarginatus***, and the blue line is the edge of the Roach Lake playa.

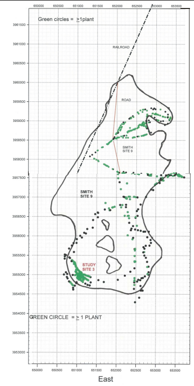


Figure 3-43. Comparison of Roach Lake North (RLN) ***P. albomarginatus*** distribution estimate based on 1997-8 surveys (black lines) with 2008-9 survey results. Green dots represent one or more ***P. albomarginatus*** plants and black dots are locations without ***P. albomarginatus***.

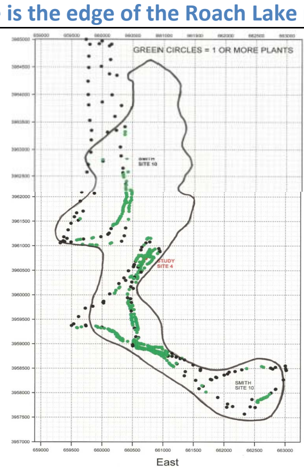


Figure 3-44. Comparison of Jean Lake Exclosure (JLE) ***P. albomarginatus*** distribution estimate based on 1997-8 surveys (black lines) with 2008-9 survey results. Green dots represent one or more ***P. albomarginatus*** plants and black dots are locations without ***P. albomarginatus***.

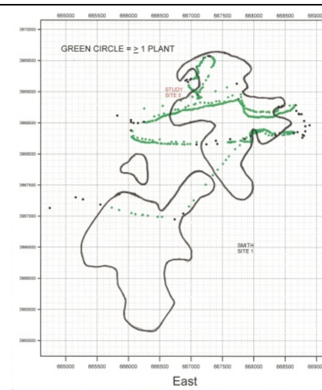


Figure 3-45. Comparison of Hidden Valley (HV) ***P. albomarginatus*** distribution estimate based on 1997-8 surveys (black lines) with 2008-9 survey results. Green dots represent one or more ***P. albomarginatus*** plants and black dots are locations without ***P. albomarginatus***.

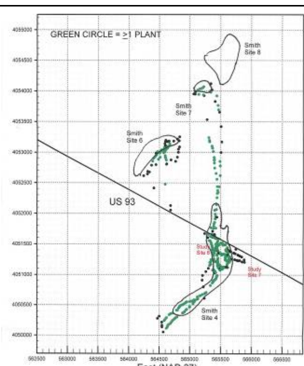


Figure 3-46. Comparison of Nye County ***P. albomarginatus*** (NCP) distribution estimate based on 1997-8 surveys (black lines) with 2008-9 survey results. Green dots represent one or more ***P. albomarginatus*** plants and black dots are locations without ***P. albomarginatus***.

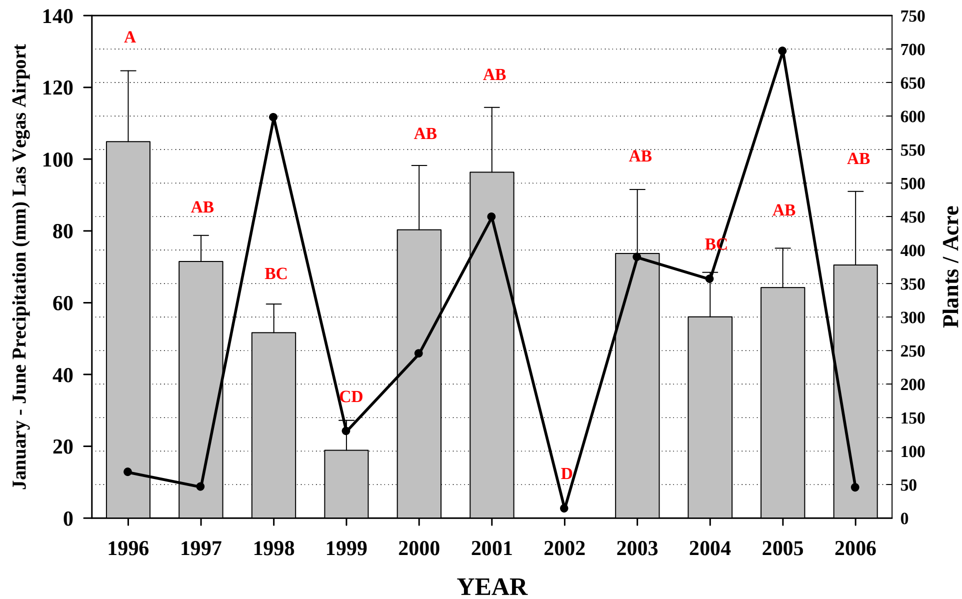


Figure 3-47. Mean *P. albomarginatus* plant density (bars) for eight (60m x 5m) BLM monitoring plots within the Jean Lake Exclosure (JLE) population for 1996 through 2006 and precipitation (line with markers) for January through June as recorded at the Las Vegas airport. Bars with the same letters are not significantly different for α=0.05. Error bars are the standard error of the mean for each date.

3.4.3 Growth, phenology, and age structure for various *P. albomarginatus* populations

Representative photographs of *P. albomarginatus* emerging, producing vegetative growth, flowering, being damaged by insects, producing fruits, dispersing seeds, and senescing are shown in Figure 3-48 through Figure 3-54. Larger versions of the photographs are available in Appendix F. *P. albomarginatus* growth and phenology during the 2009 growing season for the four study sites in Clark County and one site in Nye County are shown in Figure 3-55 through Figure 3-59 and summarized in Table 3-8. Plant emergence in 2009 occurred sometime between February 23 and March 11. The peak number of shoots per plant occurred by the end of March, and height and canopy growth were also essentially completed by the end of March with only slight increases in height during April. The other major event that occurred in March was the onset of insect herbivory, which ranged from 2 to 20 percent and was mainly caused by a leaf-mining caterpillar species. During April, peak numbers of shoots with flowers occurred at all sites except at Jean Lake Exclosure (JLE), which peaked at the end of March and also had the second lowest percent of shoots with flowers (23.8 percent).

May is the most dynamic month in terms of *P. albomarginatus* phenology. Herbivory peaked in May 2009, with a range of 29 to 79 percent of shoots suffering some insect damage and greater than 70 percent of all shoots being damaged at the Roach Lake North (RLN), Jean Lake Exclosure (JLE), and Nye County Penstemon (NCP) sites. During late May (at least, in the 2009 below-average precipitation year), fruits and seed are produced before all remaining above-ground biomass senesces. The Jean Lake Exclosure (JLE) and Nye County Penstemon (NCP) sites produced no fruits in 2009. The Hidden Valley (HV) population had the greatest reproductive output for 2009, with 57 percent of shoots with flowers and 33 percent of all shoots with fruits, and subsequently dispersed more seeds than the other populations.

Comparisons of growth, herbivory, and reproduction for 2008 and 2009 are shown in Table 3-9. Peak numbers of shoots per observed plant were similar for the Roach Lake South (RLS), Roach Lake North (RLN), Jean Lake Exclosure (JLE), and Hidden Valley (HV) sites by year, while *P. albomarginatus* plants at the Nye County Penstemon (NCP) site produced fewer than half the number of shoots in 2009 than 2008. The trend for plant height was similar to the trend for shoots, with no apparent difference between 2008 and 2009 except for the Jean Lake Exclosure (JLE) site where mean height was only 60 percent of the mean height for 2008. The Roach Lake South (RLS), Roach Lake North (RLN), and Hidden Valley (HV) sites had slightly greater percentages of flowering and fruiting shoots in 2009 compared to 2008, while reproduction for the Jean Lake Exclosure (JLE) and Nye County Penstemon (NCP) sites was much lower in 2009 with lower ratios of fruit-to-flower shoots. Herbivory in 2009 was lowest at the Roach Lake South (RLS) site, but was twice as large as it was in 2008, with 29 versus 14 percent of all shoots damaged by insects, respectively. Herbivory in 2008 was caused by pallid-winged grasshoppers rather than by caterpillars. Herbivory during 2009 was greatly reduced at the Hidden Valley (HV) site and greatly increased at the Jean Lake Exclosure (JLE) site, whereas it was similar for both years at the Roach Lake North (RLN) and Nye County Penstemon (NCP) sites.

The root systems of ten *P. albomarginatus* plants were excavated from the Roach Lake North (RLN) and Hidden Valley (HV) sites in fall 2009. Rooting depth, root biomass, and root xylem ring counts were not significantly correlated with either above-ground *P. albomarginatus* canopy areas or the number of shoots (Figure 3-60). However, *P. albomarginatus* rooting depth was positively correlated with root biomass and root xylem ring counts. It is not clear if root xylem ring counts are significantly correlated with *P. albomarginatus* age, nor can current year above-ground *P. albomarginatus* growth be used reliably to predict plant age. However, data from a 10-year BLM monitoring effort at the Jean Lake Exclosure (JLE) indicate that individual *P. albomarginatus* plants can survive for at least ten years and not have a linear increase in aboveground growth. Excavated roots did not have ectomycorrhizal infections. Root tissues were not examined for endomycorrhiza, but it is likely that endomycorrhizae are important *P. albomarginatus* root symbionts during the growing season. Lastly, based on these ten plants, it is highly unlikely that *P. albomarginatus* parasitizes the roots of nearby shrubs and grasses.

Figure 3-48. *P. albomarginatus* emergence at Roach Lake North (RLN) site (March 11, 2009).

Figure 3-49. *P. albomarginatus* vegetative growth at Jean Lake Exclosure (JLE) site (March 31, 2009).

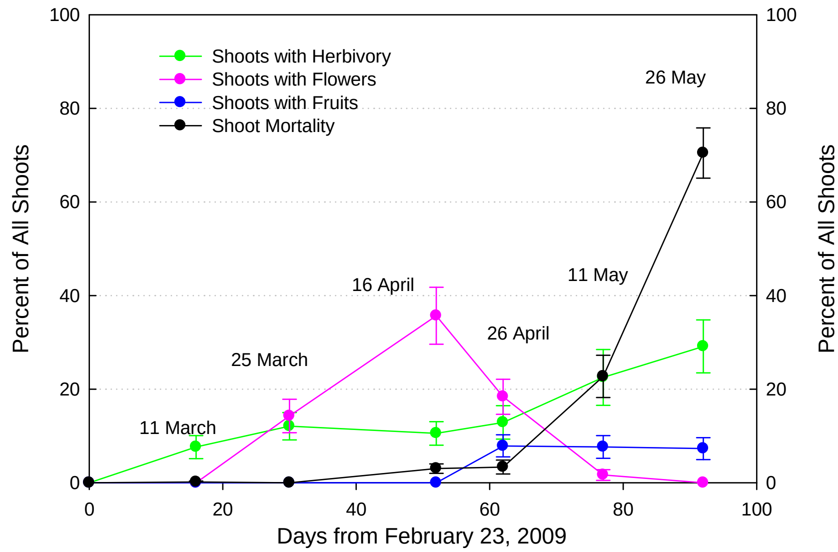
Figure 3-50. Flowering *P. albomarginatus* at Hidden Valley (HV) site (April 17, 2009).

Figure 3-51. Insect herbivory on *P. albomarginatus* at Roach Lake South (RLN) site (April 26, 2009).

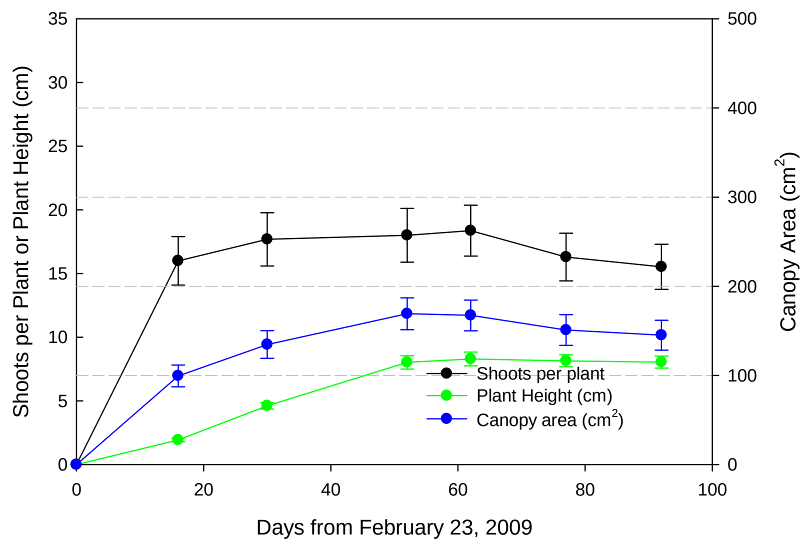
Figure 3-52. Ripening *P. albomarginatus* fruit at Hidden Valley (HV) site (May 11, 2009).

Figure 3-53. *P. albomarginatus* seed dispersal at Hidden Valley (HV) site (May 26, 2009).

Figure 3-54. *P. albomarginatus* senescence at Nye County site (May 27, 2009).

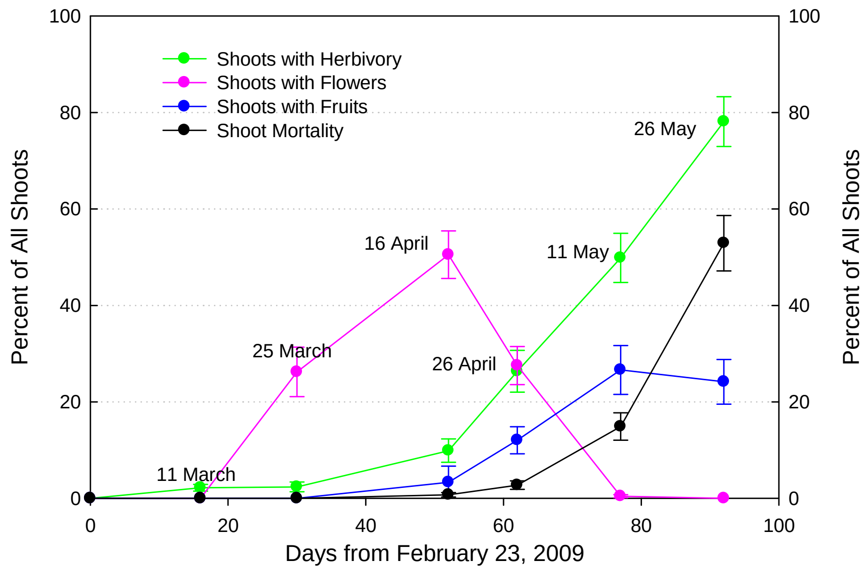


a.



b.

Figure 3-55. a) *P. albomarginatus* phenology and b) growth at the Roach Lake South (RLS) site, Clark County, Nevada, for the 2009 growing season. Error bars are the standard error of the mean for each date.



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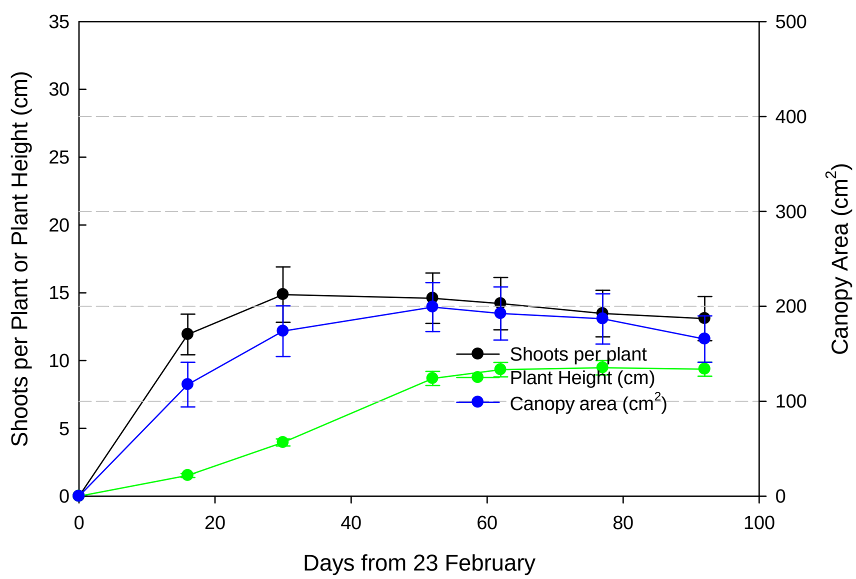
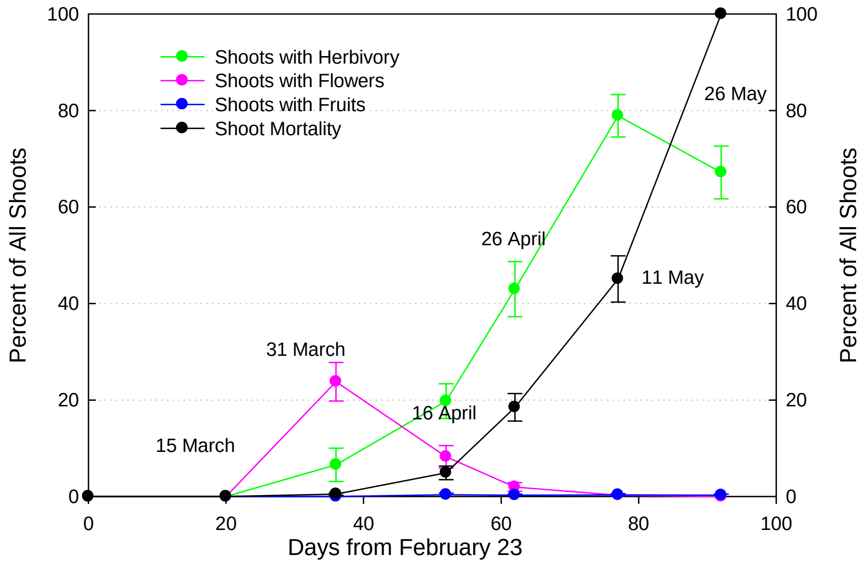
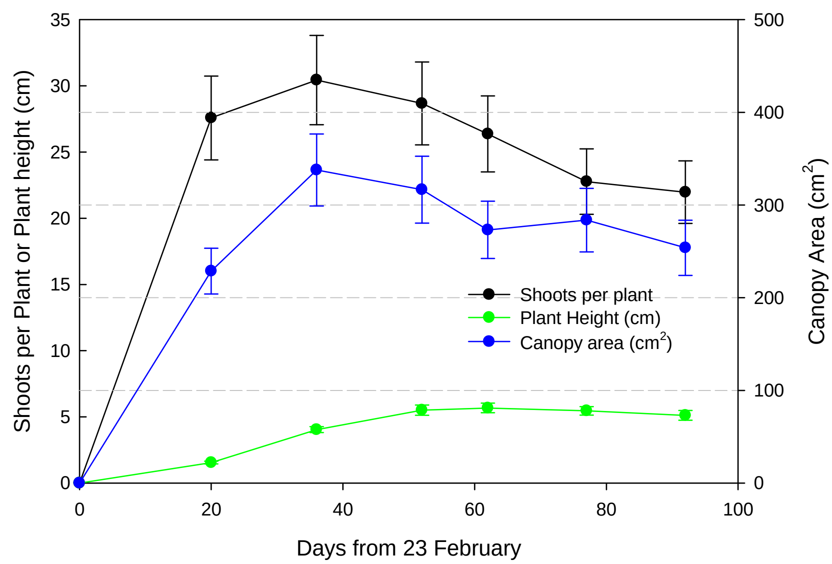


b.

Figure 3-56. a) *P. albomarginatus* phenology and b) growth at the Roach Lake North (RLN) site, Clark County, Nevada, for the 2009 growing season. Error bars are the standard error of the mean for each date.

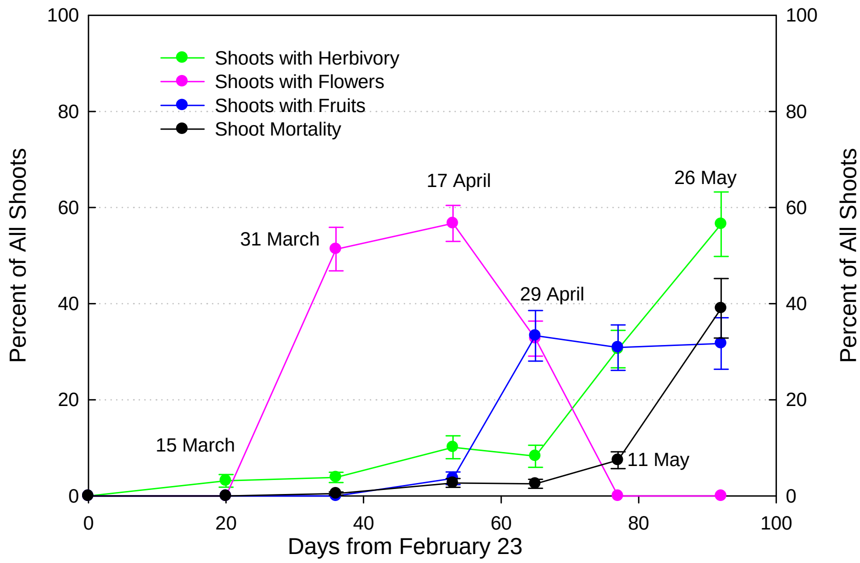


a.

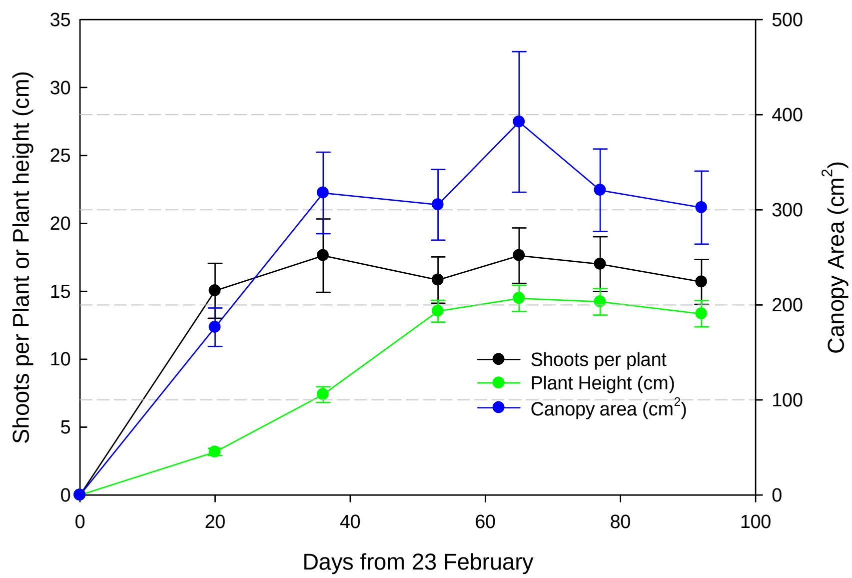


b.

Figure 3-57. a) *P. albomarginatus* phenology and b) growth at the Jean Lake Exclosure (JLE) site, Clark County, Nevada, for the 2009 growing season. Error bars are the standard error of the mean for each date.

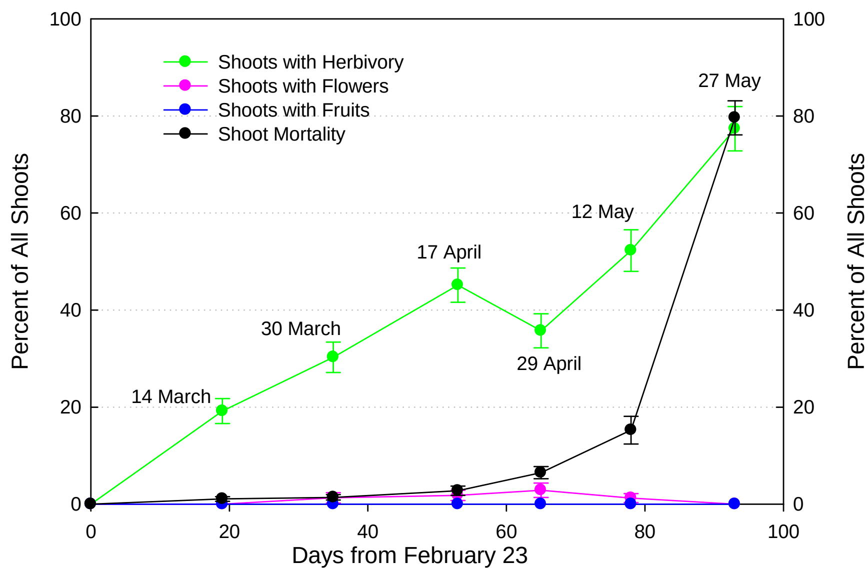


a.

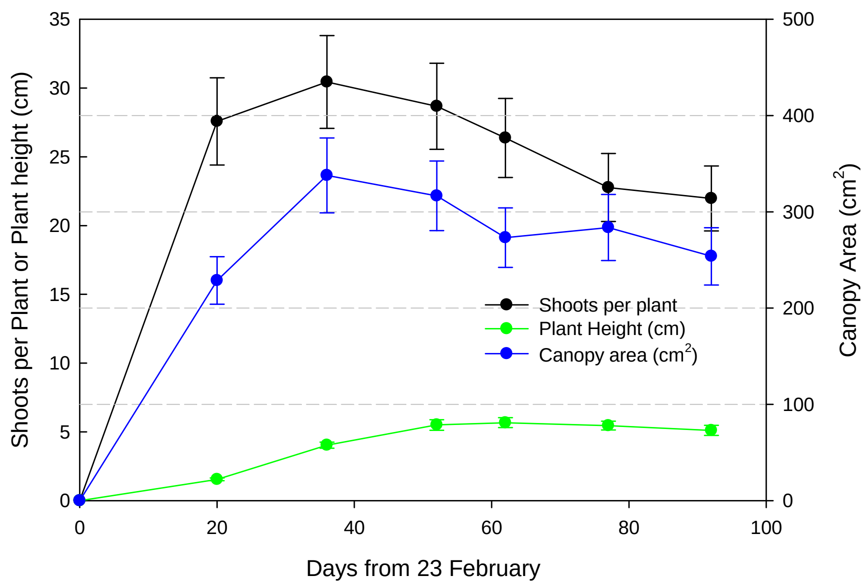


b.

Figure 3-58. a) *P. albomarginatus* phenology and b) growth at the Hidden Valley (HV) site, Clark County, Nevada, for the 2009 growing season. Error bars are the standard error of the mean for each date.



a.



b.

Figure 3-59. a) *P. albomarginatus* phenology and b) growth at the Nye County Penstemon (NCP) site for the 2009 growing season. Error bars are the standard error of the mean for each date.

Table 3-8. Means and standard errors in 2009 for peak shoot numbers, shoot heights, and percent shoots with flowers, fruits, dead, and insect herbivory, sorted by sampling date of *P. albomarginatus*. Based on 30 randomly selected plants for all sites except Hidden Valley (HV), which is based on 60 plants.

	RLS			**RLN**			**JLE**			**HV**			**NCP**		
	date	*mean*	*Std error*	*date*	*mean*	*std error*	*date*	*mean*	*std error*	*date*	*mean*	*std error*	*date*	*mean*	*std error*
peak shoots	26-Apr	18.67	2.00	25-Mar	14.87	2.04	31-Mar	30.43	3.36	31-Mar	17.62	2.70	30-Mar	8.04	0.62
peak height	26-Apr	8.30	0.54	26-Apr	9.47	53.00	26-Apr	5.67	0.36	29-Apr	14.48	0.97	29-Apr	5.98	0.31
percent flowering	16-Apr	35.70	6.10	16-Apr	50.50	4.90	31-Mar	23.80	4.00	17-Apr	56.70	3.70	29-Apr	2.90	1.50
percent fruiting	26-Apr	7.90	2.40	11-May	26.60	5.10	none	0.30	0.20	26-May	33.30	5.30	none	0.00	0.00
percent dead	26-May	70.40	5.40	26-May	53.00	5.70	26-May	100.0	0.00	26-May	39.00	6.20	27-May	79.60	3.50
initial herbivory	11-Mar	7.60	2.50	11-Mar	2.20	0.70	31-Mar	6.60	3.50	15-Mar	3.20	1.30	14-Mar	19.20	2.60
peak herbivory	26-May	29.10	5.70	26-May	78.10	5.20	11-May	78.90	4.40	26-May	56.50	6.70	27-May	77.20	4.60

Table 3-9. Growth and phenology trends of *P. albomarginatus* for 2008 compared with 2009. Means and standard error of peak shoots per plant, peak height (cm), percent flowering, percent fruiting, percent dead, start herbivory, and percent peak herbivory, totaled by sampling year. Based on 30 randomly selected plants for all sites except Hidden Valley (HV), which is based on 60 plants.

		RLS		RLN		JLE		HV		NCP	
		2008	*2009*	*2008*	*2009*	*2008*	*2009*	*2008*	*2009*	*2008*	*2009*
peak shoots	mean	17.00	18.67	17.40	14.87	24.47	30.43	14.60	17.62	18.40	8.04
	std. err.	1.90	2.00	3.10	2.04	2.99	3.36	1.70	2.70	1.40	0.62
peak height (cm)	mean	7.83	8.30	10.63	9.47	9.32	5.67	12.23	14.48	9.12	5.98
	std. err.	0.54	0.54	0.91	53.00	0.64	0.36	0.95	0.97	0.42	0.31
percent flowering	mean	23.20	35.70	47.30	50.50	44.09	23.80	48.00	56.70	11.10	2.90
	std err.	4.50	6.10	4.60	4.90	5.09	4.00	6.00	3.70	2.20	1.50
percent fruiting	mean	4.60	7.90	11.00	26.60	11.10	0.30	17.70	33.30	1.50	0.00
	std. err.	2.10	2.40	2.90	5.10	0.00	0.20	3.70	5.30	0.40	
percent dead	mean	3.10	70.40	12.90	53.00	43.10	100.0	91.20	39.00	100.00	79.60
	std. err.	1.30	5.40	3.10	5.70	5.90	0.00	8.80	6.20	0.40	3.50
initial herbivory	mean	0.00	7.60	0.00	2.20	0.00	6.60	0.00	3.20	17.20	19.20
	std. err.	0.00	2.50	0.00	0.70	0.00	3.50	0.00	1.30	2.00	2.60
peak herbivory	mean	14.00	29.10	72.00	78.10	18.90	78.90	97.50	56.50	83.70	77.20
	std. err.	6.30	5.70	6.20	5.20	4.50	4.40	7.60	6.70	3.20	4.60

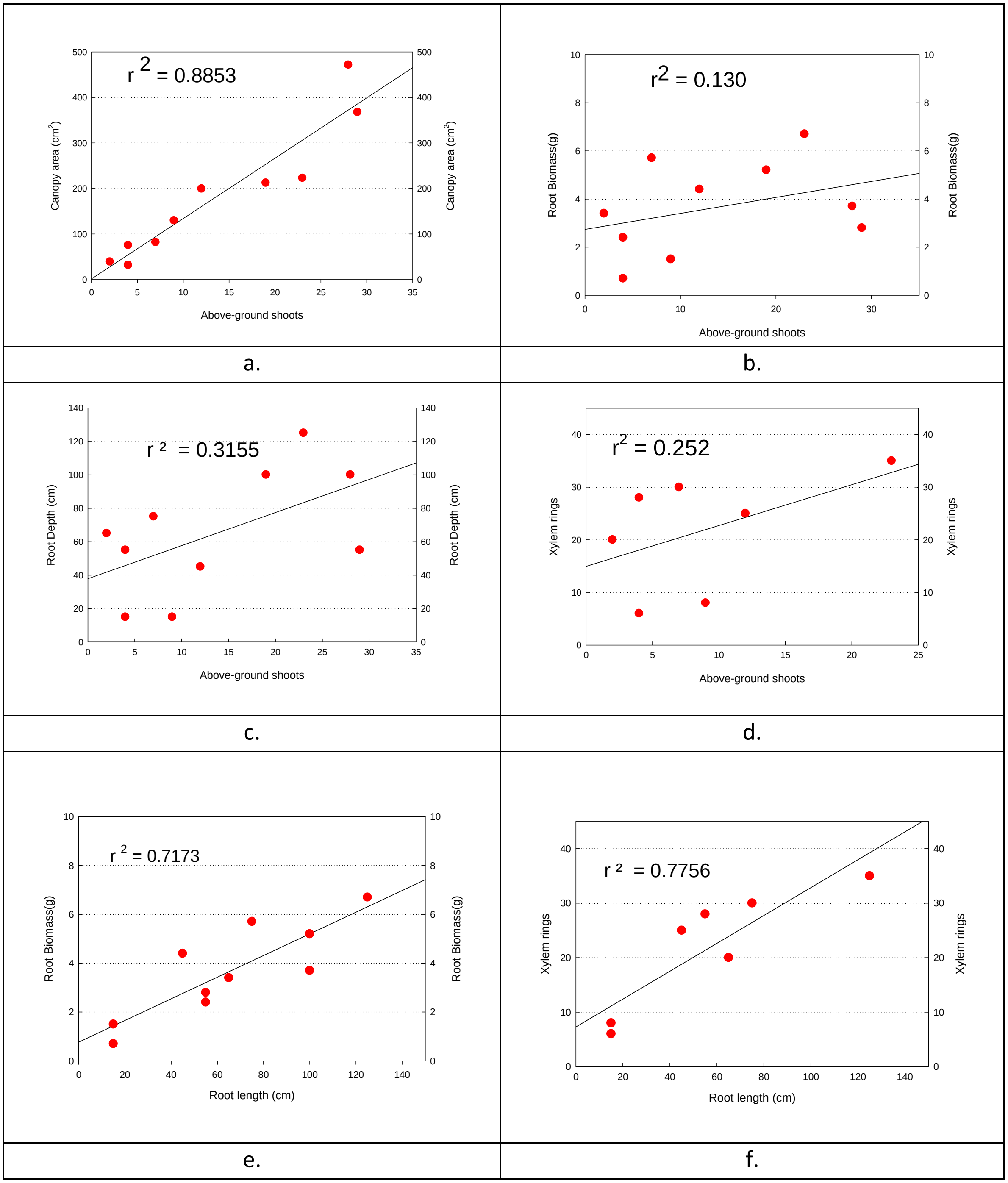


Figure 3-60. Linear relationships of above-ground shoots with canopy area (a), root biomass (b), root depth (c), number of root xylem rings counted (d) and root biomass with root length (e), and root xylem counts with root length (f).

4 Discussion

4.1 Soils, climate, and physical environment

4.1.1 Soils

There were some differences in soil texture and chemistry between the samples collected in the under canopy of *L. tridentata* plants at the study sites and those collected in the inter-spaces between plants. However, *P. albomarginatus* were found primarily in the inter-spaces between perennial plant canopies, so if there are differences in soils between sites that result in better or poorer habitat areas for *P. albomarginatus* then those differences would be most important for soils collected in the inter-space regions of the sites.

Texturally, all of the inter-space surface soil samples at all of the sites were quite sandy, with sand constituting more than 85 percent of the soil. Sand, silt, and clay content were fairly uniform with depth, although the Nye County sites (NCP, NCC) exhibited kinks in the texture depth profile, which indicates the presence of distinct layers of comparatively silt- and clay-rich soil. Penstemon sites on the whole exhibited comparatively elevated clay content (up to 8 percent) at a depth of 5-30 cm compared to the study comparison sites. This kink in the clay content profile coincided with a kink in the calcium carbonate ($CaCO_3$) profile which was also significantly different between penstemon and comparison sites. Overall, the entire depth of all profiles was dominated by sand, with sand content always greater than 80 percent.

Chemically, nitrate (NO_3), ammonium (NH_4), and phosphorus (P) content were higher in the top 5 cm of the soil surface compared to deeper layers. Profiles for organic carbon were considerably more variable, with surface samples being richer at some sites than deeper samples and vice versa for other sites. None of these depth trends of chemical species concentrations were consistent between comparison sites as a group and penstemon sites as a group.

Cryptobiotic crusts were essentially absent from penstemon sites. Minimal crust development at the Nye County Penstemon (NCP) site was similar in extent and spatial distribution to minimal crust formation at the Nye County Comparison (NCC) site. The Roach Lake Comparison (RLC) site exhibited the greatest degree of crust development, but even there the crust composed 0-10 percent of the soil cover and varied greatly in space. All in all, it does not appear that the presence of cryptobiotic crust defines what constitutes a sustainable penstemon site. This is more of a casual observation than a rigorous assessment of the effects of cryptobiotic crusts on *P. albomarginatus* habitat since this study did not focus on characterizing microbial communities.

Soil classification was a potentially important differentiating factor between penstemon and comparison sites. Soil parent materials were eolian for all penstemon sites and mixed alluvium for comparison sites. Eolian sand was associated with the Prisonear and Bluepoint soil series at the Clark County penstemon sites (RLS, RLN, JLE, HV) and with the Bluepoint series at the Nye County Penstemon (NCP) site. The Roach Lake Comparison (RLC) site was composed of the Tonopah and Arizo soil series while the Nye County Comparison (NCC) site was composed of the Weiser and Canoto series. All of these soils are characterized as well-drained and highly permeable. The Weiser-Canoto Association at the Nye County Comparison (NCC) site is described as moderately well-drained (as compared to "well" or "excessively [well drained]" for other sites), but on-site measurements of saturated hydraulic conductivity (K_{sat}) did not indicate that drainage at NCC was especially different than the Nye County Penstemon (NCP) or any of the Roach Lake sites (RLS, RLC, RLN).

Examination of an earlier survey by Smith (2001) indicated that soils supporting *P. albomarginatus* in Nye County also included the St Thomas-Rock outcrop-Commski, Commski-Arizo association, Arizo-Bluepoint association, and Bluepoint series.

4.1.2 Precipitation, soil moisture, and other environmental parameters

Both 2008 and 2009 were below-average precipitation years in Clark and Nye Counties. In Nye County, the average precipitation for the two years was less than half the historical average. Not surprisingly, both historical data and the measurements of this study indicate that the precipitation patterns are more alike at sites located within the same region than for penstemon sites as a group or comparison sites as a group. Volumetric soil moisture content in vegetation inter-space locations responded to precipitation similarly in comparison and penstemon sites, but there were some differences in response within a site between inter-space and under canopy water content. Since *P. albomarginatus* is found mostly in inter-spaces, differences in under canopy water content are probably not relevant to the study.

Related to precipitation, saturated soil hydraulic conductivities (K_{sat}) as measured by tension infiltrometer varied slightly from site to site and exhibited a high degree of variation within sites. In all cases, K_{sat} was lower – sometimes much lower – in the under canopy than in the inter-space. On a site-average basis, all of the K_{sat} values were indicative of very permeable, very well-drained soils. Using a hydrological model to estimate the potential for overland runoff confirmed that there are no differences in how well rain infiltrates the soil among sites, even for rare, high-intensity rains.

Temperature, solar radiation, relative humidity, and wind speed varied more between Clark and Nye County than they did between the Nye County Comparison (NCC) and the Nye County Penstemon (NCP) sites or the Clark County comparison (RLC) and the Clark County penstemon sites (RLS, RLN, JLE, HV). At all sites, high winds were confined to two major ordinal directions, north and south at the Roach Lake sites (RLS, RLC, RLN), northeast and southwest at the Jean Lake Exclosure (JLE) and Hidden Valley (HV), and northeast and south at the Nye County sites (NCP, NCC). High winds were more frequently from the south than the north, especially for the Clark County sites. For all sites, including the comparison sites, winds from the south have the potential to transport sediment from a nearby playa or playa fringe. The extent of such transport is examined below.

All in all, there are no systematic differences between penstemon and comparison sites with regard to precipitation, soil moisture, soil permeability/drainage, temperatures, relative humidities, solar radiation, wind speeds, or wind directions. The Nye County penstemon (NCP) and comparison (NCC) sites had more in common with one another for these parameters than with the Clark County penstemon or comparison sites, respectively. Similarly, the three Roach Lake sites, including the comparison site, had more in common with one another than with either the Jean Lake or Hidden Valley site.

4.2 Sediment transport: actual, potential, fluvial, eolian

4.2.1 Sand and dust transport by eolian and fluvial processes

While the inability of the Safire sensors to provide detailed timelines of when sediment was transported by wind is unfortunate, the conclusions about whether or not eolian sand movement is an important source of fresh sand for the penstemon study sites are clear. The net sand transport into the study sites was estimated from sand traps that were deployed over the study period.

The sediment transport fluxes recorded at the study sites are relatively low for loose unconsolidated sediment within arid environments (Table 4-1). Sediment fluxes from unvegetated to vegetated surfaces from available data range from 2.5 kg to 1156 tonnes of sediment per meter per year. The range for this study is from 2.5-10.1 kg/m/year and is included in the range reported by Bergametti and Gillette (in press) for the Chihuahuan Desert within creosote, tarbush, and mesquite dominated communities; however, those authors report a much higher upper end for long-term average sediment fluxes (182 kg/m/year). In addition to vegetation density, variations in wind strength, lag cover, soil crusts, and moisture content were the controlling factors in the other studies presented in Table 4-1.

Table 4-1. Eolian sediment transport fluxes for the present study and other studies for vegetated and unvegetated surfaces within the southwest US.

Location	Vegetation Density (λ)	Original rate (g/cm/event)	Event Duration (hours)	Estimated flux (kg/m/year)	Reference
Chihuahuan Desert	0.1 – 0.45	0.50 – 0.16	24	18.3 – 5.84	Li et al., 2007
Owens Lake, CA	0.01 – 0.2	57.2 – 0.01	24	2092 – 0.05	Lancaster and Baas, 1998
Chihuahuan Desert	0	15840 – 80	12	1156320 – 5840	Gillette & Chen, 2001
Chihuahuan Desert	0.04 – 0.11	1516700 - 66700	720	182 – 8.0	Bergametti & Gillette, in press
Mojave Desert	**0.10 – 0.15**	**252000 – 4500**	**720**	**10.1 – 2.5**	**Present Study**

The amount of sediment transport at the study sites based on the soil type is relatively low because of the vegetation extracting a large proportion of the momentum from the wind. Using Equation (3), the ratio (R_t) of the shear stress reaching the surface compared to the measured shear stress occurring above the vegetation canopy at each site can be estimated. Based on the community vegetation, the vegetation density (λ) for the sites varies from 0.10 to 0.15; with a reasonable assumption that the value of β is about 200 (Gillies et al. 2002) values of R_t at our study sites range from 0.20 to 0.23. This translates to a reduction of ~80 percent of the shear stress measured above the vegetation before the soil surface "feels" the momentum from the wind. A rough calculation based on the soil particle size distribution suggests that the threshold shear velocity for sand movement would only be reached when the wind speed at a height of 10 m exceeds ~20 m/s (44 mph). It is interesting to note that the contribution of perennial vegetation to λ scales roughly with the percent area plant cover of the different species (See Figure 3-39). Thus, at comparison sites, most of the wind's momentum is extracted by *Ambrosia dumosa* (White bur-sage) and *Larrea tridentata* (Creosote bush). At penstemon sites, *Pleuraphis rigida* (Galleta grass) also contributes substantially to λ.

In addition to the barrier that the vegetation presents to the wind the surfaces at all of the sites had some degree of lag cover that like vegetation extracts a portion of the momentum from the wind. If this lag was accounted for, then the threshold wind speed for sand movement would be even higher. With all of these reductions in wind strength it would seem unlikely that any sediment transport would occur at all. However, because of the spatial heterogeneity of both the vegetation and lag cover, a spectrum of wind conditions can act on the surface at different points in space and time, with some portions experiencing local conditions that can move sand grains over short distance scales. The magnitude of this type of sediment transport is relatively low and generally results in very little net transport because the full blown saltation process cannot be achieved.

The total amounts of sediment accumulated over the entire study period from each of the three traps at a given site were compared. The flux from the trap with the least sediment was subtracted from the flux from the trap with the most sediment. It was assumed that the difference in flux was wholly attributable to the net sediment that was deposited at the study site over the two-year period. The effective area of deposition was assumed to be 1 meter wide and to span the distance between the two sand traps that were used to calculate the net sediment. This estimate is conservative because in reality, differences in sediment collected among the three traps are largely the result of spatial heterogeneity of the sediment transport process and not of the systematic loss of material between the two traps with the highest and lowest amount of sediment. In addition, we have not considered the prevailing winds in selecting the two traps that are intended to serve as the high and low gross sediment flux points. That is, we allow the trap with the highest sediment to be the northernmost trap at the site, even though the wind rose for that site might clearly indicate that if there were any net sediment transported into the site by wind, the maximum gross sediment flux would have to be associated with a trap that is located at the southern end of the measurement site. The results of this analysis are presented in Table 4-2. The site that exhibited the greatest difference between the highest and lowest sediment trap flux measurements was Nye County Penstemon (NCP) with a 2-year average net flux of 2,688 g/m/year. Net fluxes for the other penstemon sites range from 516 g/m/yr at Roach Lake South (RLS) to 1260 g/m/yr at Roach Lake North (RLN). The net fluxes at the Roach Lake (RLC) and Nye County (NCC) comparison sites were respectively 629 g/m/yr and 926 g/m/yr.)

There are two indicators that sand transport into *P. albomarginatus* habitat is not the critical process that controls population health and numbers. First, as discussed in an earlier section, the amount of sediment transport does not appear to be limiting in terms of establishing or maintaining *P. albomarginatus* habitat. This was evidenced by higher sediment transport rates at the Roach Lake Comparison (RLC) site than at the Nye County Penstemon (NCP) site. Second, as indicated by Table 4-2, the magnitudes of material entering the sites are so small that the timescale for raising or lowering the soil surface by 1 cm is on the order of several centuries. Thus, while the soils at the penstemon sites are of eolian origin, it is very unlikely that present-day wind processes exert any meaningful influence on sediment transport into or out of *P. albomarginatus* habitat areas.

Table 4-2. Summary of net sediment transport into study sites assuming that the difference in mass between the highest and lowest sediment traps is wholly explained by net deposition of sediment to study site.

Site	Annualized net flux (g/m/year) – Difference in flux between highest and lowest sand traps at site	Distance between sand traps (m)	Net soil volume per surface area (m^3/m^2/year) X 10^6	# years required for 1 cm of soil deposition
RLS	516	22.9	14.0	712
RLN	1260	21.8	36.1	277
RLC	629	18.3	21.5	466
JLE	609	24.1	15.8	632
HV	542	15.8	21.4	467
NCC	996	19.1	32.6	307
NCP	2688	21.0	79.9	125
Penstemon site average	1123		33.4	443
Penstemon site standard deviation	927		27.4	244
Comparison site average	813		27.0	387
Comparison site standard deviation	260		7.9	113

Deposition from the atmosphere, as measured by the two deposition traps at each of the study sites, is also very small as a source of soil mass. Study-averaged rates of sediment deposition, consisting primarily of sand by weight, range from 1.2 g/m^2/year at the Hidden Valley (HV) site to 24.2 g/m^2/year at the Roach Lake North (RLN) site. This range is consistent with measurements using similar deposition traps at several sites across the Mojave Desert. Reheis

(2006) reports dust deposition fluxes on the order of 2 - 20 g/m^2/yr. In order for these deposition rates to account for 1 cm of soil, 660 years of deposition would be required at Roach Lake North (RLN) and 13,300 years would be required at Hidden Valley (HV). Thus, the present rate of atmospheric deposition does not represent meaningful deposition of sediment mass when considered on timescales of centuries in the context of building up the soil surface.

Overland flow was also shown not to be a fast process for sediment removal from any of the study sites. Simulations of 100-year intense rain events indicated essentially negligible amounts of sediment transport downslope through overland flow processes. That said, the landscape clearly shows signs of channelized flow and it is highly probable that sediment erosion through channel incision, meandering, and transport is the most important process that affects soil surfaces at both penstemon and comparison sites, on timescales of decades to centuries.

4.2.2 Nutrients associated with sand transport and dust deposition

In determining whether or not atmospheric deposition of dust or eolian transport of sand into *P. albomarginatus* habitat areas constitute potential significant sources of a nutrient, there are two factors that must be considered. First, the concentration of the nutrient must be greater in the transported sediment or dust than it is in the existing surface soil. If not, then the transported sediment or deposited dust would actually dilute the soil with respect to a nutrient. Second, the total amount of nutrient that is added to the soil surface must be substantial enough to replenish or raise the nutrient's concentration in the soil.

To address the first consideration, we define an enrichment factor for $CaCO_3$ as well as four potential nutrients: phosphorus (P), ammonium (NH_4), nitrate (NO_3), and organic carbon. For a nutrient *a*, we define the enrichment factor (EF_{ST}) of the eolian sediment transported into the site with respect to the existing soil as

$$EF_{ST} = \frac{\eta_{ST}^{a}}{\eta_{ES}^{a}} \qquad (10)$$

where η^a is the mass fraction of nutrient *a* found in the material in units of mg of *a* per kg of material and the subscripts ST and ES stand for sediment transport and existing soil, respectively. The mass fraction for the existing soil is computed based on the soil analyses of the top 5 cm of surface soil from each site, while the mass fraction of the sediment transported into the site is computed from a composite of the material found in the three sand traps for the site.

Likewise, we define an enrichment factor of material deposited from the atmosphere (EF_{AD}) as

$$EF_{AD} = \frac{\eta_{AD}^{a}}{\eta_{ES}^{a}} \qquad (11)$$

where the subscript AD stands for atmospheric deposition. The mass fraction of a nutrient in the material deposited from the atmosphere is calculated from a composite of the two deposition samplers deployed at each study site and the two sample collection periods, each lasting approximately one year.

Values of EF_{ST} and EF_{AD} are reported in Table 4-3 and Table 4-4, respectively. Note that because enrichment factors are a ratio of two measured properties, the standard deviations reported are geometric standard deviations. This means that one standard deviation in the reported EF value is the value divided by the geometric standard deviation (low end) or the value multiplied by the geometric standard deviation (high end). Most of the values of EF_{ST} are near unity, meaning that the material caught in the sediment traps is not especially enriched with respect to the nutrient reported. In contrast, values of EF_{AD} are almost all substantially higher than unity, with most higher than 10. One notable exception is phosphorus enrichment in Hidden Valley (HV). Thus, material deposited from the atmosphere definitely serves to increase the concentration of the reported nutrients in the soil. In order for sediment that is transported by wind to raise the concentration of nutrients in the soil by an amount comparable to material deposited from the atmosphere, net sediment flux into an area would have to be a factor of 10 or more higher than the material deposited from the atmosphere.

Table 4-3. EF_{ST}: Enrichment factors of P, NH_4, NO_3, organic carbon, and $CaCO_3$ in eolian sediment transported into the site with respect to the site's soil material. Standard deviations reported are geometric.

Site	RLS	RLC	RLN	JLE	HV	NCC	NCP
P	0.9	1.3	1.2	0.8	1.1	1.1	1.0
Geo std	1.1	1.3	1.4	1.2	1.1	1.2	1.4
NH_4	1.2	1.7	1.9	1.4	0.7	0.6	0.7
Geo std	1.6	1.3	1.3	1.2	1.2	1.4	1.5
NO_3	3.0	1.1	3.4	2.0	1.2	3.6	5.1
Geo std	2.2	2.8	2.7	2.0	2.0	2.0	1.3
Org C	0.8	0.7	4.1	0.9	1.0	1.7	1.5
Geo std	1.4	1.2	1.2	1.2	1.1	1.2	1.5
$CaCO_3$	0.5	1.6	1.2	0.5	0.4	0.6	
Geo std	1.4	1.2	1.1	1.4	1.3	1.2	

Table 4-4. EF_{AD}: Enrichment factors of P, NH_4, NO_3, and organic carbon in material deposited from the atmosphere into the site with respect to the site's soil material. Standard deviations reported are geometric.

Site	RLS	RLC	RLN	JLE	HV	NCC	NCP
P	9.5	8.4	7.5	12	1.3	27	18
Geo std	1.7	1.3	1.2	1.5	1.3	1.2	1.1
NH_4	23	22	5.4	10	58	19	106
Geo std	1.4	1.6	1.7	1.1	1.5	1.2	2.2
NO_3	328	552	790	147	1491	672	1035
Geo std	2.1	1.7	1.2	1.5	1.4	1.7	1.4
Org C	12	13	13	11	19	16	18
Geo std	1.3	1.3	1.2	1.4	1.2	1.2	1.5

Figure 4-1 compares the relative magnitudes of nutrient delivery from sediment transported by wind and material deposited from the atmosphere. The values in the figure for sediment transported by wind are based on the measured net fluxes summarized in Table 4-2 and the chemical analyses of the material found in the sediment trap, while those for atmospheric deposition are based on the total amount of material deposited over the study period and the chemical analyses associated with that material. The figure shows the increase in percentage of a nutrient if the nutrient in the sediment transported in one year or the material deposited in one year was confined to the top 1 cm of soil. The choice of 1 cm is somewhat arbitrary, but the relative magnitudes shown in the figure would be the same for any depth of soil chosen.

In almost all cases, atmospheric deposition is a much larger source of the chemical shown than sediment transport. We remind the reader that the deposition data for Hidden Valley (HV) have a high degree of uncertainty because they are based only on one year of sampling. Hidden Valley aside, it is notable that the other four Clark County sites (RLS, RLC, RLN, JLE), including the Roach Lake Comparison (RLC) site, all exhibit a consistently higher effect – in terms of changing soil nutrient content – of atmospheric deposition than the Nye County sites (NCP, NCC). In other words, as we have observed for other parameters, the difference in the impact of atmospheric deposition varies more by regional location than it does between penstemon sites taken as a whole and comparison sites taken as a whole.

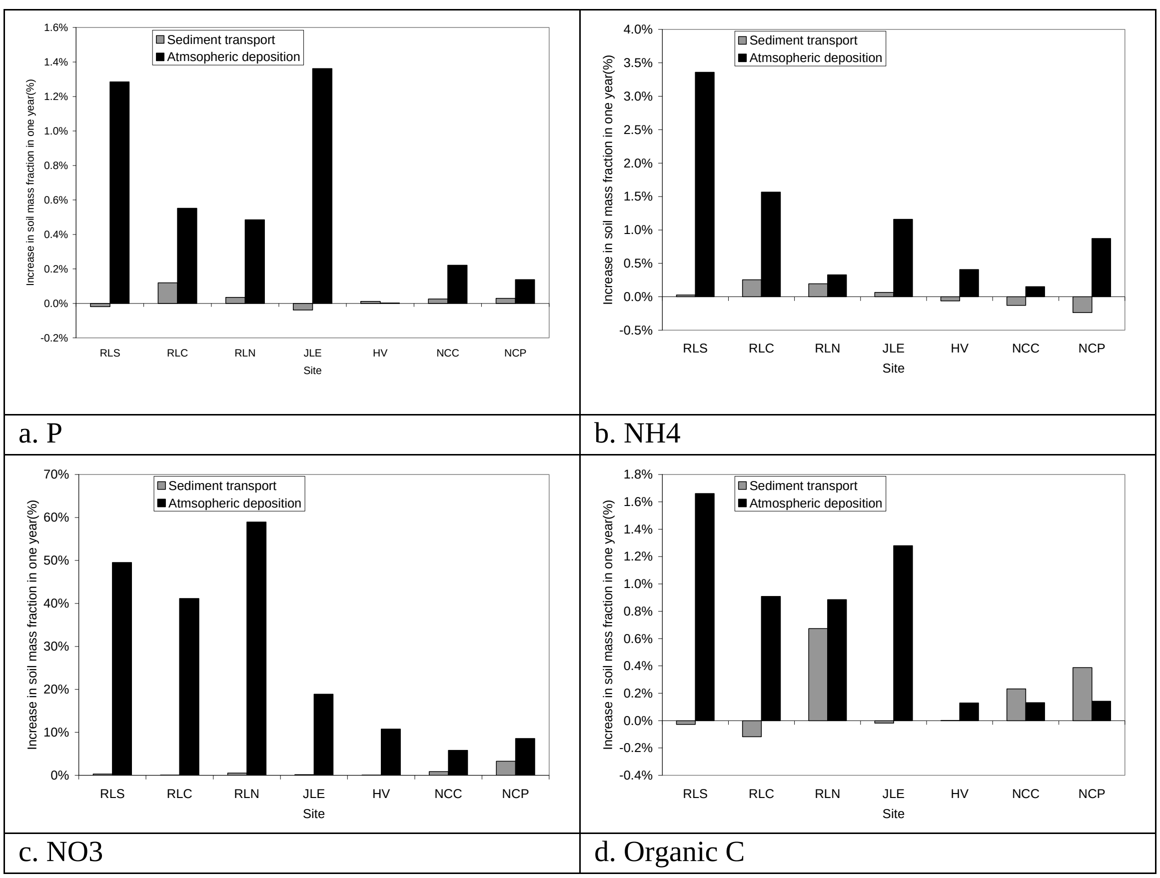


Figure 4-1. Estimated change in mass fraction of nutrient shown in top 1 cm of soil if all sediment transported by wind or all material deposited from the atmosphere were confined to the top 1 cm of soil.

Though it is not directly pertinent to the objectives of this study, it is notable that atmospheric deposition is a very significant source of nitrate (NO_3) for the soil. Nitrate deposition can occur through a number of pathways. These include wet deposition or the deposition of nitrate that is dissolved in rain, dry deposition of nitrate aerosol where particles that contain nitrate fall out of the atmosphere, and dry deposition of nitric acid gas (HNO_3) through direct sorption onto dry or wet surfaces. The deposition samplers used in this project reflect to some extent all three of these processes – with varying degrees of quantitative capture – so that it is not possible to determine the relative magnitude of the contribution of each of these processes to the nitrate deposited. In general, we expect the deposition samplers to underestimate the actual nitrate deposition to the soil surface, so that the numbers shown in Figure 4-1 are likely to be underestimates.

4.3 Sustainability of *P. albomarginatus* populations

Based on variations in *P. albomarginatus* densities, our results indicate that *P. albomarginatus* prefers sandy soils of the Bluepoint and Arizo series. However, *P. albomarginatus* can grow in a variety of adjoining soils that are similar chemically to Bluepoint and Arizo soils, but that can contain significant quantities of gravel, cobbles, and rocks. The most unique chemical signature of the penstemon sites is the accumulation of carbonates in the top 10 cm of soil, apparently coincident with a slight increase in clay content. Community ordination analysis of penstemon sites showed that the presence of *P. rigida* and *K. lanata* is a useful indicator of the potential for supporting *P. albomarginatus* populations in Clark County but not Nye County.

All 12 *P. albomarginatus* populations documented during the 1997-8 surveys (F.J. Smith 2001) were resurveyed in 2008-9. Our surveys documented live *P. albomarginatus* plants within and adjacent to the 1997-8 estimated population boundaries. The total length of our 10m wide linear transects was 217 km which is equivalent to approximately 540 acres. We counted 25,626 live *P. albomarginatus* plants, providing a density of approximately 47 plants per acre. The 1997-8 total estimated areal extent of 6,437 acres and 68,164 plants for all the known Nevada populations results in a density of approximately 10.6 plants per acre. Except for the southernmost population in Nye County, all our density estimates were significantly greater than the 1997-8 density estimates. Unfortunately the 1997-8 survey report did not provide an estimate of the spatial variation of *P. albomarginatus* density within populations. The total area we surveyed (540 acres) represents only 8.4 percent of the 1997-8 estimated 6,436 acres for the total areal extent of *P. albomarginatus,* but the 25,626 *P. albomarginatus* plants we counted is almost 38 percent of the 68,164 plants estimated for the entire Nevada population. This clearly suggests that our population and overall density estimates are much higher than those provided by Smith (2001) based on his 1997-8 surveys.

Furthermore, during spring 2009 we met a group surveying the Roach Lake North (RLN) site in support of an environmental impact statement (EIS) for a proposed solar project; they stated they had counted more than 16,000 *P. albomarginatus* plants, approximately three times the 1997-8 estimate (5000) for that site; admittedly, a casual conversation in the field is no substitute for published data, however, this does provide support to our conclusion that it is highly probable that the actual size of the area currently occupied by *P. albomarginatus* in Nevada is more than 10,000 acres, may include undiscovered populations, and includes more than 200,000 plants. This greater than three-fold increase in the estimated size of the Nevada *P. albomarginatus* population may still be an underestimate because 2008-9 were both drought years.

It is important to note that due to differences between the Smith (2001) and the present survey methods, variations in population estimates between the two surveys cannot be reliably attributed to actual increases in *P. albomarginatus* population between 1997–8 and 2008–9. Nevertheless, the magnitude of the difference in estimates allows us to state conservatively that it is very unlikely that the southern Nevada population has decreased over the last decade.

Besides the linear transect estimate of *P. albomarginatus* density for each population we also calculated *P. albomarginatus* densities based on the vegetation transect data and estimated the temporal variation in density for the Jean Lake Exclosure (JLE) population based on eight transects the BLM had been monitoring from 1996 through 2006. The BLM monitoring data for 1996-2006 indicates that plant density varies annually along with variations in annual precipitation, but density probably varies more as a function of plant dormancy rather than mortality and recruitment. During our study, of the 180 plants we flagged in 2008, 178 of these plants also emerged in 2009 which may represent a mortality rate of approximately 1 percent. Furthermore, during our linear transect surveys we did not observe any small plants which might be considered to be new seedlings.

Currently, not all suitable *P. albomarginatus* sites in Nevada, per our characterization of *P. albomarginatus* sites as part of this study, support *P. albomarginatus* populations, probably due to limited seed production and dispersal. Drought and insect herbivory were the causes for the lack of reproductive success at the Nye County penstemon (NCP) and Jean Lake Exclosure (JLE) sites. Among the other sites, actual seed dispersal was only observed for the Hidden Valley (HV) population in 2009 and dispersal distances ranged from 1 to 15 cm.

5 Summary

This report summarizes the findings from a two-year field study conducted in Southern Nevada. Framed through a series of objectives, the overall goal was to better understand factors that affect the suitability of certain areas for *P. albomarginatus* habitats. Several objectives were specifically aimed at identifying relationships between the presence of *P. albomarginatus* and the extent of eolian sediment transport of sand and dust from upwind dry lake beds. This was motivated by the hypothesis that development of large areas of the Roach Lake basin for the planned Ivanpah Airport may adversely affect *P. albomarginatus* populations around Roach Lake by impacting the eolian mobility of sediment through *P. albomarginatus* habitat areas.

Field measurements were targeted at characterizing climatic parameters, characteristics of *P. albomarginatus* habitat areas, and soil properties. The study relied on comparing characteristics of sites with *P. albomarginatus* populations to sites that are nearby and appear quite similar, but do not have *P. albomarginatus* plants. Seven sites were selected, five in Clark County (four *P. albomarginatus* and one comparison) and two in Nye County (one *P. albomarginatus* and one comparison). The findings of this study are summarized in the context of the original objectives. Shortcomings of the study and specific recommendations for future follow-up activities are provided in the last section of this Chapter.

5.1 Objectives met

The original objectives, posed as questions to be answered by the study, are enumerated below along with summaries of our findings

5.1.1 What are the characteristics of *P. albomarginatus* habitats?

Determine the areal extent, density, spatial patterns, age structure, seed production viability and dispersal, and rooting depths and distributions for P. albomarginatus populations.

and

Determine the range in plant community structures supporting existing populations of P. albomarginatus: Species composition including non-vascular plants (cryptobiotic crusts and mycorrhizal associations), density (plants/m^2), spatial patterns, and age (size) structure.

All 12 *P. albomarginatus* populations documented during the 1997-8 surveys (F.J. Smith 2001) were resurveyed in 2008-9. Our surveys documented live *P. albomarginatus* plants within and adjacent to the 1997-8 estimated population boundaries. Based on 2008-9 field surveys of all known populations of *P. albomarginatus* in Clark and Nye Counties, we estimated that there are approximately 125,825 *P. albomarginatus* plants in Clark County and 78,954 plants in Nye County. These estimates are almost five times greater than the 1997-8 estimates of 25,964 for Clark County and two times greater than the 42,200 plants estimated for Nye County. Furthermore, our results are based on below-average precipitation years, so that the actual size of the *P. albomarginatus* population could be even greater than our estimate. Without knowing the uncertainty of the 1997-8 *P. albomarginatus* population estimates it is not possible to quantitatively compare those estimates to our estimates for population size. It is instead more accurate to state that it is unlikely that *P. albomarginatus* populations have declined in the past ten years.

The age structure of *P. albomarginatus* populations could not be determined based on the aboveground growth characteristics we measured. However, there were significant differences in mean *P. albomarginatus* canopy height and area among the five populations we measured, but these differences were not consistent when the 2008 growth data are compared to the 2009 data. The root length, biomass, and xylem ring count data indicated that annual aboveground plant biomass production is not significantly correlated with plant age or reproductive potential. If xylem ring counts for root collars do represent annual growth increments – a reasonable but unproven hypothesis - , then the ages of the ten root systems we excavated ranged from approximately 5 to 35 years. During the study the percent of shoots with flowers varied from 3 to 56, while the number of shoots with fruits varied from 0 to 33 percent. The Nye County plants produced essentially no fruits in both study years and the Jean Lake Exclosure (JLE) population also did not produce fruits in 2009. Drought and insect herbivory were the causes for the lack of reproductive success at the Nye County penstemon (NCP) and JLE sites. Among the other sites, actual seed dispersal was only observed for the Hidden Valley (HV) population in 2009 and dispersal distances ranged from 1 to 15 cm.

Plant community structure for *P. albomarginatus* populations differed more between counties than between penstemon and comparison sites. Results of a cluster analysis of the study sites indicated that for Clark County, the native perennial grass, *P. rigida*, and the native shrubs, *K. lanata* and *Acamptopappus shockleyi*, are the most likely indicator species for the presence of *P. albomarginatus*. *A. dumosa*, *L. tridentata,* and *Krameria erecta* are relatively ubiquitous and apparently unrelated to the presence of *P. albomarginatus*.

Within each population 66 to 94 percent of the *P. albomarginatus* plants occurred in the canopy inter-spaces with a mean of 85 ± 10 percent. For the small number of *P. albomarginatus* that occurred in under canopy locations, the overstory species was equally likely to be *A. dumosa* or *P. rigida* (only in Clark County), but never occurred under *L. tridentata* canopies. There was a weak positive, non-significant correlation between perennial cover and the percent of *P. albomarginatus* growing in canopy inter-spaces. We could not determine whether competition with other perennial species or other micro-environmental factors is responsible for *P. albomarginatus* being apparently more abundant in canopy inter-spaces than under canopy spaces. Our results also indicate that similar to most Mojave Desert perennial plant species, *P. albomarginatus* recruitment events are rare and episodic and may require a combination of successive wet years that favor seed production, seed germination and seedling growth.

5.1.2 What are the ranges in soils, geomorphology, and climatic properties supporting *P. albomarginatus* populations?

Determine ranges in properties including texture, structure, chemistry, hydraulic conductivity, and moisture, as well as other environmental parameters such as slope, aspect, rainfall, temperature, wind, and solar radiation.

All of the study sites where *P. albomarginatus* was present can be characterized as sandy (>80 percent sand, > 85 percent at surface) to a depth of at least 60 cm, having slopes in the range of 1.8 to 4.6 percent with aspects (facing direction) in the range of 174-309 degrees from North. Due to their texture, soils were all very well drained with measured saturated hydraulic conductivities in excess of 50 mm/hr. Soil moisture content was typically low, with annual average volumetric water content generally less than 5 percent, but with peak months approaching 8-10 percent. Precipitation was below average during the 2008-9 study years with measured rainfall in Clark County and Nye County averaging about 80 mm/year and about 50 mm/year, respectively over the two-year period. Long-term monitoring data collected by the Bureau of Land Management at the Jean Lake Exclosure (JLE) site suggests that plant emergence can occur in years with as little as 10 mm of precipitation (measured only from January till June).

In comparing the five sites from the present study with *P. albomarginatus* populations to the two comparison sites (no *P. albomarginatus*), it was found that the parameters mentioned above varied more between sites in different counties than between penstemon and comparison sites. This was also true for average and extreme values for temperature, relative humidity, solar radiation, and wind speeds. Small differences between counties notwithstanding, overall, these climatic variables were very similar across all sites and exhibited typical ranges for Mojave Desert basins. Therefore, these parameters may be part of a range of conditions that are suitable for *P. albomarginatus*, but there was no evidence that the comparison sites had critically different conditions than the penstemon sites in the context of these parameters.

There were several differences between soils at penstemon and comparison sites. The soil acidity measured from 0 to a depth of 2.5 cm was slightly higher at penstemon sites, although the difference probably is not meaningful (near neutral in any case). At penstemon sites, the profile with depth of clay content exhibited a peak in the 5-30 cm depth, changing in value from about 4 percent to about 7 percent. This appeared to coincide with a peak in carbonate content (up to about 18 percent carbonate in the vegetation inter-space region) over the 5-15 cm depth. Both of these peaks were muted or altogether absent from the soil profiles at Comparison sites.

A common attribute of soils at penstemon sites was that they were mapped as soils formed in alluvium that are covered by eolian sand. According to NRCS soil maps, all of the penstemon sites from this study and sites with previously documented *P. albomarginatus* populations that were not instrumented in this study, shared a few common soil series.

In summary, even though eolian sediment transport rates recorded during our study were relatively low, it is probably the eolian nature of the soils for most of the known *P. albomarginatus* populations in Nevada that results in the lack of significant cryptobiotic crust development in the *P. albomarginatus* habitats. Sandy soils with shrub covers of less than 20 percent and an accumulation of surface carbonates in the canopy inter-spaces appear to provide the best habitats for sustainable *P. albomarginatus* populations. Based on *P. albomarginatus* densities, the Bluepoint and Arizo soil series supported the healthiest *P. albomarginatus* population in both Clark and Nye Counties and where ever these soils occur the possibility of discovering new *P. albomarginatus* populations exists. It is not clear if the higher carbonate content near the surface of the soil is of importance to *P. albomarginatus* habitat or if it is only an incidental consequence of the types of soils that the *P. albomarginatus* occur on.

5.1.3 To what extent does eolian transport of sand occur?

Determine the scales of sand transport: Is sand transported from distances of kilometers upwind or is it redistributed within an area?

and

Determine to what degree vegetation structure affects sand transport and to what degree P. albomarginatus populations rely on such sand transport.

The five sites that were examined in this study where *P. albomarginatus* was present were clearly shaped by eolian transport of sand and the presence of this sand appears to be an important factor in *P. albomarginatus* habitat areas. However, the eolian deposits in *P. albomarginatus* sites were formed over geological time scales. On-site measurements of sand transport indicate that present-day rates for eolian sediment transport are in line with the low end of the range of other measurements reported for desert regions vegetated with creosote and tarbush (Bergammetti and Gillette, in press). At these rates, on the order of 2.5-10 kg soil/meter/year, it would take centuries for new sediment deposits to add 1 cm of soil.

The vegetation density at the seven study sites is the primary reason for the low sediment transport rates. Estimates based on measured densities indicate that about 80 percent of the wind's momentum is extracted by the vegetation, with only the remainder available to initiate sediment transport. A lag cover composed of rocks and pebbles at most sites further denudes the winds momentum and provides additional stability to the soil surface. Furthermore, sand saltation, the dominant mechanism for eolian transport is attenuated by the presence of vegetation, which removes sand grains and prohibits the full blown mobilization of surface sediment. Under these conditions sediment transport occurs in short fits and starts, often resulting in a reshuffling of surface sand within a site.

The sediment collected in the sand traps was also examined for chemical content. Overall, the chemical composition of the material was similar to the native soil, suggesting that present-day sand transport does not serve to replenish nutrients at *P. albomarginatus* sites.

Based on these findings, despite the strong association between the presence of *P. albomarginatus* and well drained sandy soils of eolian origin, it is unlikely that present-day eolian sand transport processes have any appreciable effect on *P. albomarginatus* habitat areas. Permanent changes in vegetation density notwithstanding (e.g. from climate change, land use), the density of present-day vegetation at the study sites greatly reduces the extent of eolian sand transport.

5.1.4 To what extent does eolian transport of dust occur?

Determine how prevalent dry deposition of dust-sized particles is and to what degree those particles originate from upwind playas.

and

Determine if such particles carry specific nutrients or appear to cause conditions that are essential for P. albomarginatus populations.

Deposition of dust varied in magnitude more by county than between penstemon and comparison sites, with deposition rates to Clark County sites (1.1-24 g/m^2/year) about five times those to Nye County sites (1.3-1.4 g/m^2/year) on average. Enrichment factors of deposited dust with respect to the surface soil material for phosphorous (P), ammonium (NH_4), and organic carbon were all significantly greater than unity indicating that deposition is a net source of these materials to the soil. In all cases, dust was a larger source of these materials than eolian sand, with annual mass deposition rates that were comparable to a small fraction (few percent) of the amount of material in the top 1 cm of soil. Nitrate deposition represented a very significant source of nitrate for the soil, with annual mass deposition rates equal to as much as 60 percent of the nitrate present in the top 1 cm of soil.

Although we were not able to determine of the material deposited to the sites is of importance in the context of maintaining sustainable *P. albomarginatus* populations, patterns of deposition rates, with significant obvious differences between Clark and Nye County clearly indicate that the material deposited is dominated by regional-scale (10-100s of kilometers) sources rather than local (10-1000s meters) basin sources. This is most clearly illustrated by the enhanced nitrate deposition in Clark County (due to proximity to Los Angeles basin and high levels of nitrate air pollution) as compared to Nye County.

This study did not assess the magnitude or impacts on *P. albomarginatus* habitat of deposition of pollutants resulting from operation of the planned Ivanpah airport. The effects of increased aircraft and motor vehicle traffic in the vicinity of habitat areas ought to be bounded in the future either through estimates of pollution from airport activities or through direct measurements.

5.1.5 To what extent do fluvial processes that push sediment downslope counteract eolian processes?

Determine if the balance or difference in sediment transport through fluvial and eolian processes is relevant to survival of P. albomarginatus populations?

On-site measurements of hydraulic conductivity were used in conjunction with the KINEROS2 hydrologic model and study-measured as well as historical rainfall data to assess the potential for sediment transport through overland runoff. The model results indicated that even exceptional events were considered (e.g., 100-year rainfall), the amount of sediment transport through overland runoff is very small – smaller even than the eolian transport over 100 years. Admittedly a simplistic representation of basin hydrology, the model did underscore the exceptional drainability of the surface soils at our study sites and reinforced the descriptions of drainability based on the soil mapping units.

Channels were a dominant feature of the landscape, both at penstemon and comparison sites and it is likely that channel flow is the primary pathway for fluvial sediment transport downslope. In fact, consistent perhaps with expectation for the Mojave's basin and range topography, it appears that channel flow is the dominant present-day geomorphic process, with eolian transport and overland runoff occurring at much lower rates – at least at sites suitable for *P. albomarginatus* habitats.

5.2 Additional considerations

5.2.1 Study shortcomings

In aspects related to *P. albomarginatus* habitat, density, and community characterization as well as climatic, environmental, and sediment transport measurements, the major shortcoming of this study is that it took place over a relatively short two-year period and at a limited number of locations. Wherever possible, we have attempted to incorporate longer temporal information (e.g., examining 100-year rainfall events) or larger spatial coverage (e.g., previous Smith survey sites). In some cases, this was not possible. For example, it was not possible to establish a direct relationship between wind conditions and the eolian sand transport at a given site. This precluded the possibility of examining the effects of the 100-year wind; we note in passing that rainfall at a specific location in the desert is much more variable temporally than the occurrence of high wind.

Nevertheless, extreme, unpredictable events notwithstanding, the conclusions that we have provided are fairly robust. We do have two specific recommendations for collection of better temporally and spatially representative data. First, the establishment of one or more long-term monitoring sites is suggested. Ideally, these sites would focus on measurement of environmental parameters as well as the health of *P. albomarginatus* populations. Additional deposition and sand flux measurement instrumentation would not further impact costs or labor requirements and may yield useful longer-term information. Perhaps existing BLM monitoring locations such as the Jean Lake Exclosure or the Hidden Valley *P. albomarginatus* population monitoring area would be suitable for this purpose.

Second, our study focused on *P. albomarginatus* in Southern Nevada sites. As mentioned in the Introduction, *P. albomarginatus* is also documented to occur in the Mojave Desert of southeast California the Sonoran Desert of northwest Arizona (F.J. Smith, 2001). The soils, climatic properties and habitat characteristics at those two locations can further our understanding of the range of conditions that are suitable for *P. albomarginatus* habitat. Therefore, we recommend that those populations be better characterized and the results of that work be compared to those of the present study.

Related to spatial representativeness, it is also recommended that a genetic analysis of existing *P. albomarginatus* populations be conducted to better understand the impact of the reproductive isolation of the Clark and Nye County populations (as well as the California and Arizona populations) and to assess the overall genetic diversity within the species.

5.2.2 Management considerations

Historical development patterns suggest that the Clark County populations of *P. albomarginatus* are more likely than the Nye County populations to be negatively impacted by land use. Due to the large, deep root system of *P. albomarginatus*, transplanting *P. albomarginatus* from threatened populations to suitable sites will not likely be a practical mitigation tool. Possibly, *P. albomarginatus* seed can be used to establish new populations at sites that would be suitable.

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