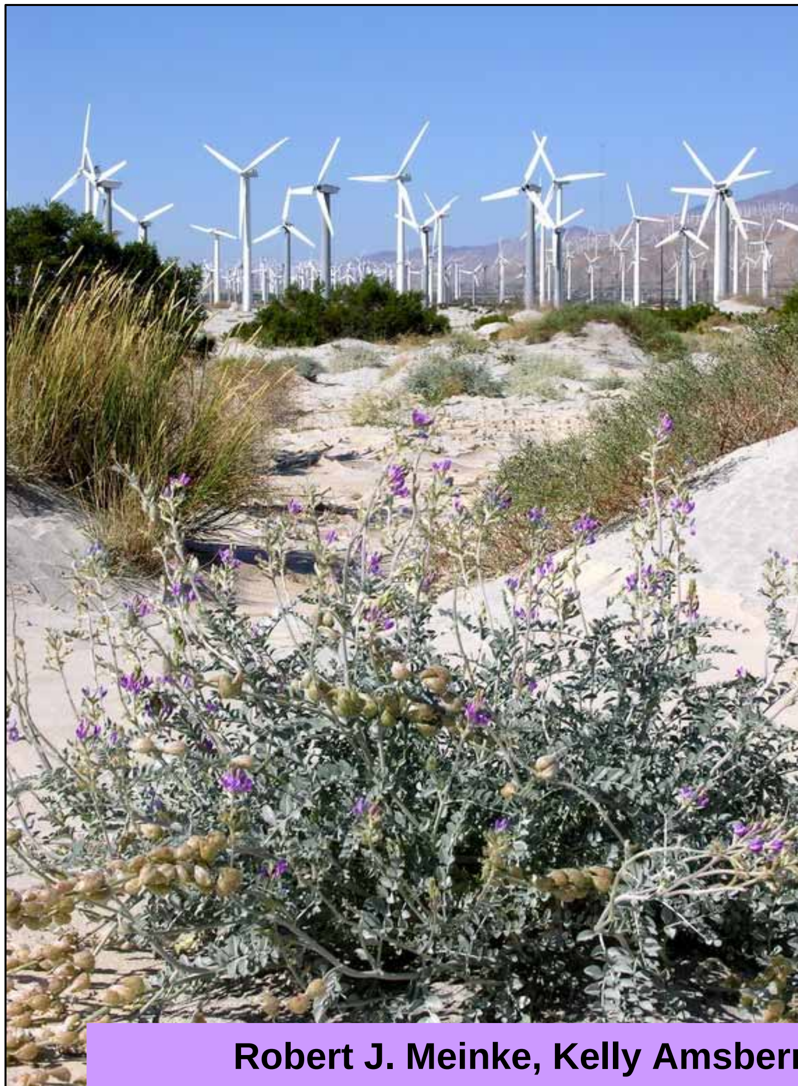
OREGON DEPARTMENT OF AGRICULTURE

NATIVE PLANT CONSERVATION PROGRAM

Evaluating the Biological Conservation Status of the Coachella Valley Milkvetch (*Astragalus lentiginosus* var. *coachellae*)



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EXECUTIVE SUMMARY

The Coachella Valley milkvetch (*Astragalus lentiginosus* var. *coachellae*) is a federally-listed endangered taxon, restricted to a highly active sand dune environment near the eastern base of the San Jacinto Mountains in the western Sonoran Desert. A recent assessment confirms that var. *coachellae* is endemic to the Coachella Valley, and that reported populations from the Desert Center area (disjunct ca. 75 km to the east) actually represent *A. lentiginosus* var. *variabilis*.

Much of the range of *A. lentiginosus* var. *coachellae* overlaps the cities of Palm Springs, Cathedral City, and other nearby communities, where remaining populations are threatened by the effects of urbanization and habitat fragmentation. A Habitat Conservation Plan (HCP; in preparation) is expected to place several of the more significant remaining sites within administratively protected reserve areas located outside the urban core. However, little information has been available that describes the natural history and ecological status of Coachella Valley milkvetch populations, and specific management plans have yet to be developed.

The current study (conducted in 2005 and 2006) corroborates earlier reports that var. *coachellae* exhibits a labile life history correlated with annual precipitation, in which short-lived perennials loosely dominate the less arid, northern end of the range and annuals are more prevalent in the drier south. Fecundity was high among both annual and perennial individuals, although northern populations were more productive due to the greater proportion of longer-lived plants. Flowers were capable of only limited self-fertilization, and appeared to be highly outcrossed. Pollination was effected almost entirely (>99%) by honeybees, and native pollinators were scarce. Realized (as opposed to potential) seed set was low, at about 27%, and was heavily influenced by pre-dispersal ovule predation. Chalcid wasps and Bruchid beetles accounted for most of the damage, although other species were present as well. Fruit herbivory by rodents may also be important in some years. Other factors (herbivory of foliage and flowers, and pathogens) had minimal negative effects. After accounting for predation losses, an average milkvetch plant at the northern end of the range individually dispersed ca. 1,700 seeds in 2005. Measurements from northern study populations revealed plants released an estimated 189,000 seeds per acre into the seed bank in 2005. Seeds may be retained in dried pods for months, aiding in wind dispersal.

Milkvetch populations were shown to be tolerant of light trampling and vehicular traffic. Distribution of younger plants was often proximal to trails, tracks, access roads, etc., with higher recruitment and more seed produced here than in areas with fewer impacts. While habitat conversion and other major disturbances clearly limit population viability, moderate substrate abrasions may be beneficial in some cases, most notably in areas where aeolian sand flow is reduced and habitats are stabilizing as a result of urbanization or invasion by exotics.

Encroachment by Sahara mustard (*Brassica tournefortii*) is considered the most serious threat to var. *coachellae* populations, particularly in the reserve areas identified in the HCP. Especially in wet years, mustard populations dominate the landscape in many areas, physically excluding milkvetch plants and other natives. Sahara mustard plants dispersed an estimated 2.43 million seeds per acre into milkvetch habitat at the Coachella Valley National Wildlife Refuge in 2005. Repeated annual cycles of *B. tournefortii* infestations may in time deplete or extirpate *Astragalus* populations, through shading, resource competition, and substrate stabilization.

Results presented here suggest that the Coachella Valley milkvetch is not reproductively limited, despite pre-dispersal seed predation. Seeds crops are capable of sustaining a 5% harvest level during favorable reproductive years, which would support a substantial *ex situ* seed banking program for future reintroduction work. The greater demographic stability and fecundity levels of northern populations suggest that some populations may have better conservation value than others. While milkvetch plants apparently function in a metapopulation environment in natural settings, these dynamics have generally been disrupted by recent landscape changes. An enhanced understanding of seed bank ecology, recruitment in relation to disturbance, and interactions with Sahara mustard will aid in the development of effective monitoring and recovery programs.

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INTRODUCTION

When initially described forty-three years ago, the Coachella Valley milkvetch (*Astragalus lentiginosus* var. *coachellae*) (Fig. 1) was an apparently insignificant member of a geographically and morphologically complex species group (Barneby, 1964), yet another of several similar-appearing, closely related varieties of *Astragalus lentiginosus* native to arid sections of western North America. Endemic to the east base of the San Jacinto Mountains, a hot Sonoran Desert landscape with far fewer human residents than milkvetch plants, the populations of the new taxon were, at the time, little affected by threat of development or other action. Its long-term prospects appeared secure.

Figure 1. Coachella Valley milkvetch, growing south of the Whitewater area, Riverside County (February, 2006).

But unlike its close congeners, which for the most part tend to remain in isolated and remote localities even today, *A. lentiginosus* var. *coachellae* was restricted to an area destined to become one of the most intensely developed urban centers in the United States, including the rapidly expanding resort cities of Palm Springs, La Quinta, Rancho Mirage, Desert Hot Springs, and Palm Desert, among others. The accelerated pace of urban development, along with the affluent aspect of these essentially contiguous

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communities, has resulted in swift habitat conversion affecting a wide range of unique dune species, including locally-adapted insects, reptiles, rodents, and plants. Wide boulevards, vast hotel grounds, luxury car dealerships, extensive housing tracts, and numerous golf courses have dramatically altered much of the Coachella Valley (Fig. 2), converting it from an open landscape of xeric sand fields and shifting dunes to a Bermuda grass and concrete mosaic. The fragmentation, degradation, and loss of habitat ultimately reached the point where a number of these species potentially faced extinction as populations declined.

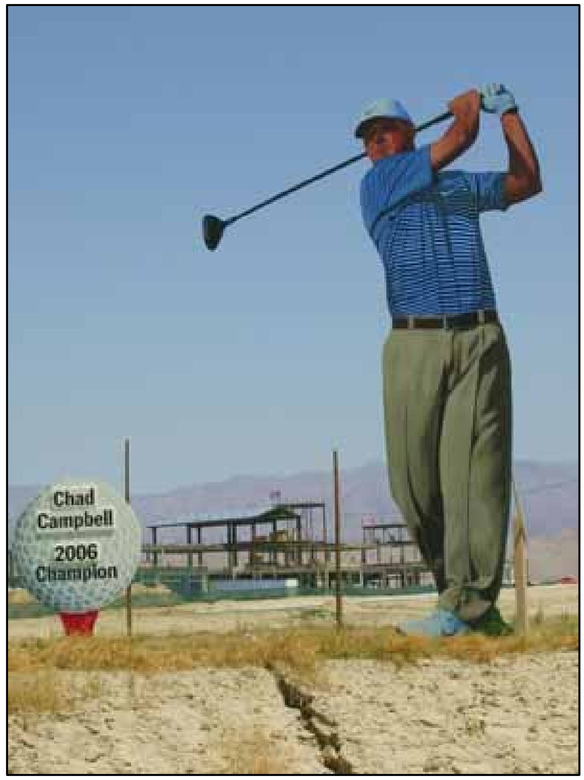

Figure 2. A golf advertisement dominates a berm along the east side of Interstate 10. More than a hundred courses are currently operating in the Coachella Valley, many of which have replaced sand fields and dunes that once supported local endemics.

Accordingly, steps were taken to list several area taxa under the Endangered Species Act (ESA), including *Astragalus lentiginosus* var. *coachellae*. Formally designated as endangered nearly ten years ago (USFWS, 1998), the Coachella Valley milkvetch was added to a suite of local species, some similarly obscure (including the desert slender salamander) and others well-known (e.g., the desert tortoise), as a beneficiary of federal protection. The milkvetch joined the Coachella Valley fringe-toed lizard as the only other true dune specialist in the area listed under the ESA. Exactly how the listing was to play out under the wide assortment of property ownerships, governmental jurisdictions, and individualized approaches to environmental regulation in the Coachella Valley remained to be seen. The departure of the milkvetch from anonymity was further hastened by the designation of critical habitat seven years later (USFWS, 2005), as well as its inclusion in the draft *Coachella Valley Multiple Species Habitat Conservation Plan* (HCP), a long-term and well-publicized effort by a coalition of federal, state, and municipal agencies to reach a consensus on the protection and management of local endangered and threatened species. Work on the plan started in 1995 – encompassing over 240,000 acres, it has yet to be implemented (approval is expected in 2008).

Despite the proximity of *Astragalus lentiginosus* var. *coachellae* to the cities and academic centers of southern California, virtually nothing was known about its ecology when the variety was first described. Very little has been added to the knowledge base since that time, although it was listed as endangered nine years ago. However, this is not particularly surprising, since most of the rare and endangered plant species in California (and elsewhere in the nation) are not well-studied due to a chronic lack of funding. Most of the available information for the Coachella Valley milkvetch (prior to this project) is summarized in the HCP (CVMSHCP, 2007), although much of this is anecdotal. A more complete accounting of the ecology of the milkvetch, and how this relates to its conservation requirements, is important to any recovery and management efforts. However, this is essentially lacking in the HCP. Yet to be fair, there are many species covered by the plan, and with a few noteworthy exceptions (including the desert tortoise, peninsular bighorn sheep, and Coachella Valley fringe-toed lizard), very little ecological data were available for most of them, especially the plants and invertebrates. Carrying out thorough, independent reviews for each of these species as part of the HCP would have been a significant undertaking, and impossible to complete with the time and resources at hand. Considering the exponential growth in the valley since 1995, when work on the HCP was first started, it would not have been feasible to conduct a wide range of species-specific field studies, and still keep up with the myriad of plan adjustments required as a result of the continually evolving land use patterns and contentious political climate.

SPECIES OVERVIEW

General description and phenology. *Astragalus lentiginosus* var. *coachellae* is one of several closely related milkvetch varieties comprising an ecologically labile, polymorphic species complex (Knaus et al., 2005) in the deserts of North America, many of which are local endemics. Plants range from less than one to a few dm high, with numerous gray-green leaves and one or (more often) several to many stems arising from the base. Stems and foliage are usually densely pubescent, presumably an adaptation to high temperatures during the growing season. Corollas (Fig. 3) are deep purple to violet

Figure 3. Recently opened flowers of *Astragalus lentiginosus* var. *coachellae* at Snow Creek, San Gorgonio Pass (March, 2005).

and streaked with white on the banner, with several to many flowers produced per raceme (inflorescences in peak flower are usually showy unless affected by drought or disease).

Astragalus lentiginosus has a variable life history, and certain varieties, including var. *coachellae*, may exhibit mixed populations, consisting of highly fecund perennials (Fig. 4) as well as reproductively viable annuals (Fig. 5) (described in more detail later). Perennating plants generally die back after reproduction (in May or June) and then crown sprout the following winter. Past observers (Barrows, 1987; CVMSHCP, 2007) have remarked on yearly fluctuations in population size, with some sites supporting hundreds or even thousands of plants in wet years, a typical pattern for desert annuals in El Niño years (Bowers, 2005), with very few present after drier winters.

Figure 4. A third-year milkvetch plant in full fruit, near San Gorgonio Pass (April, 2006).

Flowering may start as early as December for plants behaving as perennials, but generally not until late January or February for first year plants, and continue into April. The greenish to straw-colored pods are inflated and turgid, and may be red-mottled or not. They typically dry out and dehisce while still attached to the stem and apparently scatter seeds locally, or may eventually detach and become wind-blown, potentially dispersing seeds a great distance from parent plant (discussed later). Seeds are hard-coated and blackish-brown to jet black.

Geographic distribution. The Coachella Valley milkvetch ranges from Cabazon to just north of Indio, in a southeasterly arc. In addition, six outlying occurrences have been reported within a five mile area west of Rice Road, in the Chuckwalla Valley north of Desert Center (USFWS, 2005), but morphological evidence suggests that these plants

Figure 5. A first-year reproductive milkvetch plant growing in the Coachella Valley National Wildlife Refuge (February, 2006). Although many sites have both annuals and perennials, the majority of *Astragalus lentiginosus* plants in this particularly arid part of the valley behave as annuals, and seldom survive to reproduce a second year.

probably represent the southernmost location for *A. lentiginosus* var. *variabilis*, which is typically found within and north of Joshua Tree National Park (this is addressed under Project Objectives, and discussed in more detail later in the report). The total number of known populations for var. *coachellae* is uncertain (based on different estimates from various agencies), but the most recently cited number of 122 (CVMSHP, 2007) is probably reasonably accurate. Populations may include numerous plants, as indicated above, or very few (depending on precipitation in a given year, disturbance, amount of inhabitable space, and other factors). We believe there are no substantial populations remaining on undisturbed or unaltered habitat.

The following range summary is taken from the CVMSHCP (2007): "*The current and apparently historical distribution (of var.* coachellae*) is within a longitudinal (more or less) west to east range of approximately 33 miles. This species is known in locations from One Horse Spring near Cabazon to the sand dunes off Washington Avenue, north and west of Indio. Extensive dune systems at the base of the Santa Rosa Mountains in what are now the cities of Palm Springs, Cathedral City, Rancho Mirage, Palm Desert, Indian Wells, and La Quinta, now much reduced from what once occurred, provided suitable habitat for the Coachella Valley milkvetch. While the overall range of this (taxon) may not be significantly reduced from the historical distribution, the number of extant occurrences has declined dramatically.*" We can also add that the quality (in terms of habitat) of extant sites has also been substantially reduced in recent decades.

PROJECT OBJECTIVES

The current project was conducted for the California Department of Fish and Game (CDFG) under a research contract initiated in 2005. The primary goal of the study has been to qualitatively and quantitatively consider ecological and conservation-related topics for *Astragalus lentiginosus* var. *coachellae* that had not been previously addressed, to contribute to management and planning efforts for remaining populations. A number of fundamental inventory and population status assessments have been conducted over the last decade in association with the development of the HCP (described in CVMSHCP, 2007), and for the most part this type of work was not duplicated here. The focus of this project includes, in a broad sense, subject areas identified in the HCP as being important to the long-term survival or recovery of *Astragalus* populations, falling under the general categories of threats, limiting factors, and adaptive management. Considering that Coachella Valley milkvetch populations will ultimately be subject to the conservation and management protocols identified in the HCP, once implemented, it seems appropriate to consider the findings from this project supplemental to the overall conservation goals for the species as already outlined in the plan.

Taxonomic considerations. Taxonomic accuracy is essential in conservation planning for endangered species. Specimens of *Astragalus lentiginosus* from the California deserts have frustrated several generations of plant taxonomists, and there have been lingering questions about the geographic status of the Coachella Valley milkvetch and its relationships to other taxa. With this in mind, a taxonomic assessment was made of var. *coachellae* with a particular focus on several populations that have been reported from a limited area near Desert Center, approximately 75 km east of the Coachella Valley in east-central Riverside County. The disjunct location and the anomalous nature of the habitat there (i.e., gravelly-sandy creosote bush scrub) have generated concerns regarding the identification of this material. Since these populations are specifically addressed in formal planning documents (USFWS, 2005; CVMSHCP, 2007), it is important that their identity be confirmed. One member of our study group (Brian Knaus) is presently evaluating selected members of the *Astragalus lentiginosus* complex (including var. *coachellae* and its close relatives) as part of his Ph.D. dissertation research in systematics at Oregon State University, and he agreed to review the Desert Center populations.

Conservation biology and management. Different land use impacts have different environmental consequences, with some constituting immitigable threats to plant populations. The HCP describes the loss of habitat due to urban sprawl (i.e., direct habitat conversion due to paving, landscaping, construction, etc.) as the leading threat to *Astragalus* sites in the valley, which from an historical perspective is plainly true. And since the plan proposes to preserve only certain "core areas" of milkvetch habitat, leaving sizeable expanses with the species open to development, habitat conversion will continue to take a substantial toll on populations for the foreseeable future. Nothing can be done about this. So the critical issue, with respect to threats, is how do we effectively deal with the areas designated as off-limits to development (i.e., how do we manage them effectively for milkvetch populations), and what biological information can help us achieve this?

Unlike the finality of habitat conversion, which typically eliminates necessary substrates and extirpates populations, other threats to milkvetch sites identified in the

Fig. 6. Wind energy facility located in Whitewater Wash near Garnet, due north of Palm Springs. Wind turbine placements are one of many land uses competing for space with *Astragalus lentiginosus var. coachellae* populations in the Coachella Valley.

HCP can potentially be dealt with through mitigation and management. Such threats include trampling, off-highway vehicle (OHV) activity, maintenance of industrial areas (Fig. 6), habitat fragmentation and isolation of populations, the degradation of sandy ecosystems due to human-effected changes in dune dynamics, and competition with invasive species. Nothing is certain, but assuming at least some portion of a population remains intact through such disturbances, it is theoretically possible to manage in such a way that will maintain or even enhance the quality of the site. With little ability to conduct rigorous, experimental ecological research in advance of habitat alteration, biologists will need to develop flexible management schemes that reflect the on-the-ground reality of native species conservation in the Coachella Valley. The concept of adaptive management, a structured, iterative process of best case decision-making in the face of uncertainty (Stankey et al., 2005), is clearly the logical approach, as advocated in the HCP. The information gathered through this study, from sites with a wide range of disturbances, will hopefully be useful to local biologists in their efforts to adaptively manage the Coachella Valley milkvetch.

For the current study, several specific study themes focusing on the conservation ecology of milkvetch populations were identified by the authors and CDFG. These included **(1)** selecting known, accessible populations to gather *basic demographic data*, focusing on life history variation within and between sites across the Coachella Valley,

(2) assessing *reproductive ecology* (i.e., flower and fruit production), including an evaluation of potential seed set limitation associated with breeding system and pollination ecology; **(3)** evaluating *seed production* and factors that may affect post-fertilization seed maturation, with an assessment of pre-dispersal seed and floral predation, predation levels, and types of predators; **(4)** assessing the potential for *ex situ seed banking* (based on measured seed production levels), and evaluating the feasibility of live plant reintroduction as a recovery strategy for var. *coachellae*; and **(5)** developing *management recommendations* with respect to habitat fragmentation, breeding system, pollination ecology, and related issues.

Although not specified in the original project proposal, the relationship between *substrate disturbance* and milkvetch recruitment was also evaluated. This seemed appropriate considering that OHV impacts, trampling, and substrate compaction are all listed in the HCP as potentially serious limiting factors for var. *coachellae*. Additional basic information gathered included a comparative assessment of study sites across the valley based on floristic composition, and preliminary observations on the potential impact of *exotic species* on milkvetch populations, especially Sahara mustard (*Brassica tournefortii*).

Field and greenhouse work associated with the project was conducted from January, 2005 through October, 2006. We attempted to ask questions and structure our sampling protocols in ways that maximized the conservation value of the data we gathered. The information was also contrasted, where appropriate, with the species summaries provided for the milkvetch in the HCP.

Permits and permissions. Field work was primarily conducted on federal lands administered by the U.S. Fish and Wildlife Service (USFWS) or the Bureau of Land Management (BLM). Written permission to access populations and conduct census and ecological observation work was obtained from these agencies prior to the study. Seeds acquired specifically for germination trials were collected under USFWS Permit No. TE066318-0 issued to Brian J. Knaus. Aside from seed for limited greenhouse work, no additional material of var. *coachellae* was collected or otherwise reduced to possession during the work. All reproductive ecology and seed production data (e.g., pollinator and breeding system evaluations, floral biology, seed crop assessments, etc.) were recorded on site, without plant loss or damage. In cases where mature pods were removed from plants for selected counts or examinations, any ripe seeds they contained were manually re-dispersed *in situ* after data were gathered, resulting in zero loss from local seed banks.

Field work was also conducted at two open access, undeveloped parcels (on non-tribal lands), which were later discovered to be privately owned after the fact. The sites, off Landau Boulevard and Gene Autry Trail in Cathedral City and Palm Springs, respectively, were not posted and were extensively used by local residents (i.e., foot traffic, active bicycle and OHV trails, refuse dumping, rock and boulder gathering, etc.). Our sampling at these sites was limited and unobtrusive, and followed the same "non-take" approach described above for federal lands.

Finally, the taxonomic assessment of var. *coachellae* reported here relied solely on information taken from existing herbarium sheets or morphological measurements recorded in the field. Since the critical floral traits that distinguish varieties of *Astragalus lentiginosus* were easily measured on living plants, it was not necessary to collect specimens, rendering a permit unnecessary for this phase of the work.

STUDY SITES

Study sites for evaluating the demography, ecology, and conservation status of Coachella Valley milkvetch were delineated within seven populations, distributed from San Gorgonio Pass to the Coachella Valley National Wildlife Refuge south of Thousand Palms (see Fig. 7). A "study site" may or may not include the entire population. An eighth location, occurring a few km northeast of Desert Center, was also included. Due to the uncertainty of the taxonomic status of plants at this disjunct locality, populations here were not used in ecological assessments (except for general habitat comparisons).

Snow Creek (Fig. 8). The Snow Creek study site (N33º 54.43' W116º 40.38') is located south of Highway 111 in the San Gorgonio Pass area, just east of the paved road leading to Snow Creek. The milkvetch population is distributed along an open sandy wash, which showed considerable evidence of recent OHV use. An estimated 850 reproductive *Astragalus* plants were present within the approximate twelve acre study area boundary in 2005, and approximately 400 in 2006. Many were large perennials.

Figure 8. *Snow Creek study site*, showing fresh OHV tracks and heavy Sahara mustard infestation on coppice dunes. (Estimated study area: 12 acres)

Windy Point (Fig. 9). This study site (N33º 54.15' W116º 38.61') is located 0.1 km south of Highway 111, ca. 1.3 km west-northwest of Windy Point. The extensive milkvetch population here is mostly in deep sand created by large coppice dunes, which are maintained by a more extensive dune system and wash area to the immediate south of the site. Sand also piles up along an extended line of *Tamarix* trees that forms a barrier between Highway 111 and milkvetch habitat just south of the roadway. *Astragalus* plants were locally common over the eight acre study area here, which supported roughly 1,400

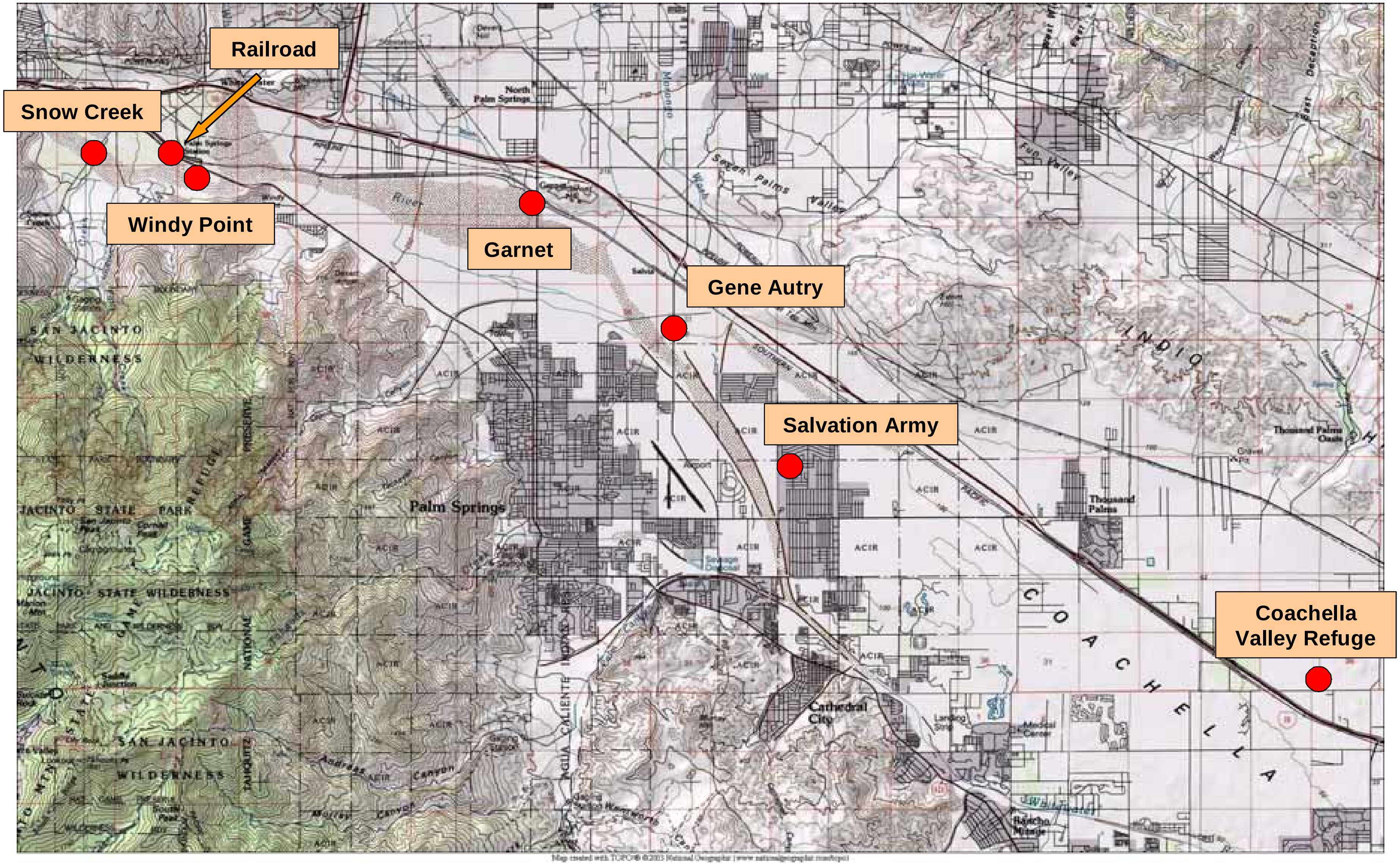

Figure 7. *Study Sites*: Map of *Astragalus lentiginosus* var. *coachellae* study areas for 2005 and 2006. Site specifics, including GPS data (NAD 83) and estimated site acreages, are provided in the text and picture captions. The study sites were situated from the San Gorgonio Pass area southeast through the Coachella Valley, to include as much geographic variation as possible within sample populations. Study areas were selected in consultation with managing agencies. The Coachella Valley Refuge site consisted of two subpopulations on adjacent dunes that were sampled independently, or (depending on the data collected) pooled as a single site. Virtually the entire geographic range of var. *coachellae* is depicted on this map, from immediately west of Snow Creek to the Coachella Valley Refuge area.

reproductive individuals observed here in 2005, and 950 in 2006. The area is posted by BLM as off-limits to OHV activity, but violations are common, and the fences erected here to provide a barrier to off-road traffic appear to be routinely cut. Coachella Valley fringe-toed lizards were frequently observed within the eight acre study area.

Figure 9. Cut fences were common at the *Windy Point study site*, where milkvetch populations and fringe-toed lizards often coincided with recreational vehicle traffic. (Estimated study area: 8 acres)

Railroad (Fig. 10). The Railroad study site (N33º 54.43' W116º 39.04') is located across Highway 111 from the Windy Point study area, along Tipton Road ca. 1.1 km west of the highway junction Milkvetch plants here were situated in unsettled sand and sand veneers, and in small dunes associated with scattered shrubs. Numerous plants also occurred just outside an adjacent railroad right-of-way, on the slope leading to the tracks, and in a loose, secondary access road base below the main track bed. Sahara mustard was not a common component within the study site itself, but was a dominant on BLM land to the east (on the other side of Tipton Road). Roughly 620 milkvetch plants flowered within the six acre study area in 2005, and 250 in 2006. Additional scattered plants occurred back along Tipton Road towards the intersection with Highway 111.

Figure 10. Milkvetch plants on the west edge of the *Railroad study site*, growing along the margin of a secondary access road. The site is located immediately west of Tipton Road and just east of Highway 111 (situated beyond line of *Tamarix* at top of photo). (Estimated study area: 6 acres)

Garnet (Fig. 11). The Garnet study site (N33º 53.69' W116º 32.76') is situated 0.7 km south of the Garnet interchange at Interstate 10, near the paved access road leading to the Palm Springs Amtrak Station. The area is characterized by low, shifting dunes, in a part of the valley particularly subject to high winds. Local disturbance (road maintenance) and nearby wind farm activities serve to facilitate the aeolian flow and encourage sand accumulation along fences. Milkvetch plants here are a mix of annuals and perennials, and a number of them will overwinter for one or more years in areas that are sheltered from excessive sand movement. An estimated 450 reproductive plants were present in the study area in 2005, and about 350 in 2006. Sahara mustard was not dominant here as it was at other sites, although it is abundant a short distance away near the Amtrak Station, and along Indian Avenue heading into the Garnet area.

Figure 11. Low dunes and blowing, shifting sand characterize the *Garnet study site*, located parallel to Indian Avenue along the west side of the Palm Springs Station Road. The west edge of the study site adjoins a wind energy facility at the northern fringe of Whitewater Wash. (Estimated study area: 4 acres)

Gene Autry (Fig. 12). This study site (N33º 51.78' W116º 30.31') is situated off the east side of North Gene Autry Trail, ca. 2.8 km south of Interstate 10. The milkvetch population here is scattered within the remnants of Whitewater Wash, occurring on sand veneers, wash edges, and coppice dunes. Most plants at this site were annual, although a few perennials were present along the edges of the dry wash. This was the smallest population sampled, with approximately 140 plants present in 2005 and fewer than 50 in

2006. The population was diffuse, however, and more plants were scattered outside the 12 acre delineated study area, further to the southeast along Whitewater Wash. The site is routinely accessed by the public, where sand and rock collection for landscaping purposes and OHV traffic were familiar occurrences. Sahara mustard is present, but was not as common here as it was at the Snow Creek and Windy Point study sites.

Figure 12. The *Gene Autry study site* located south of Interstate 10. The area features scattered rocks and boulders from past floods associated with Whitewater Wash, and is commonly traversed by OHV traffic. (Estimated study area: 12 acres)

Salvation Army (Fig. 13). This study site (N33º 49.59' W116º 28.46') is named for the Dick and Beverly Davis Cathedral City Corps Salvation Army Community Center located at 40-300 Landau Boulevard in Cathedral City. The roughly eight acre study area is located within a large vacant lot immediately south of the community center (just east of Landau Boulevard), and is a leftover piece of native desert scrub surrounded by housing developments and busy streets. Aerial photos reveal that it was apparently slated to join the housing boom at one point (based on a patchwork pattern of what appear to be lot boundaries or cross streets that were never paved), but has been temporarily spared for unknown reasons. Currently the site is heavily disturbed, mostly by pedestrian traffic and bicycles. A remnant population of Coachella Valley Milkvetch persists on the site and is doing well despite its precarious long-term position. An estimated 640 reproductive plants (many perennial) were present in 2005, and approximately 450 in 2006, occurring in sandy furrows, stabilized sand flats, and consolidated low dunes. Sahara mustard is prevalent here, though not overly dominant, and numerous native taxa remain abundant.

Figure 13. The *Salvation Army study site* is a mixture of native desert scrub and sandy lanes, the latter (now used as shortcut trails) presumably once marking lot lines or perhaps unpaved streets for an unfulfilled development project. This parcel will almost certainly be developed at some future date. (Estimated study area: 8 acres)

Coachella Valley Refuge (Fig. 14). This study area (comprised of two closely situated study populations, one at N33º 46.56' W116º 19.12' and the other at N33º 46.55' W116º 19.22') is located approximately halfway between Thousand Palms and Bermuda Dunes on the east side of Interstate 10, ca. 0.4 km north of 38th Avenue and 1.1 km west of Washington Street. The study populations grew on large primary dunes within the Coachella Valley National Wildlife Refuge (administered by the U.S. Fish and Wildlife

Service), partially on open dune crests and windward slopes that were semi-stabilized by old *Tamarix* plantings (some of which have been recently removed, although a number of large trees remain). *Astragalus lentiginosus* plants are scattered throughout this location – an estimated 280 flowering individuals occurred within the ca. 20 acre study area perimeters in 2005 (on the upper dune areas), and perhaps half as many in 2006. Milkvetch populations are scattered throughout this portion of the refuge, and over 2,500 plants were counted within half a mile radius of the actual study site, during local reconnaissance and walks to and from our vehicles parked on 38th Avenue. All milkvetch plants observed here in 2005 and 2006 were annual. This study area had the most serious infestations of Sahara mustard observed during the project, with thousands of acres of sand flats, washes, and lower dunes inundated with dense populations. Many of the areas here that were covered with *Brassica* in 2005 and 2006 probably supported *Astragalus lentiginosus* populations in the past, based on the scattered distribution of occasional milkvetch plants or patches among the extensive mustard stands. This site is home to other rare dune endemics, including fringe-toed lizards and giant sand treader crickets.

Figure 14. Dune crest and windward slope (foreground) supporting the milkvetch study population at the *Coachella Valley study site* located northeast of Bermuda Dunes on the CV National Wildlife Refuge. *Brassica tournefortii* sporadically invades the crests of active dunes in wet years, but even in drier years, sizeable populations (background left) may seasonally cover and stabilize lower dunes and sand flats throughout much of the refuge, displacing native vegetation. (Estimated study area: 20 acres)

Desert Center (Fig. 15). Unlike the previous seven sites, Desert Center was visited only for the purpose of collecting materials for assessing the taxonomic status of anomalous *Astragalus lentiginosus* populations growing there. The study site is located ca. 10 km northeast of Desert Center, off the west side of Rice Road (N33º 46.85' W115º

19.20'). The habitat was markedly different from the Coachella Valley sites, with scattered desert pavement and gravel interspersed with sandy pockets. An estimated 2,000 to 3,000 milkvetch plants were scattered along Rice Road for up to 2 km in this area, extending one to two hundred meters in from the road on the west side.

Figure 15. The *Desert Center study site* supported a dense herbaceous flora in 2005. It shared certain dominant species with the Coachella Valley locations for var. *coachellae* (i.e., *Abronia villosa* and *Oenothera deltoides*), although several other species (i.e., *Plantago ovata*, *Lupinus arizonicus*, and *Hesperocalis undulata*) were unique to this site or only observed at one other. The habitat differences here (particularly related to substrate) contributed to questions about the taxonomic status of the *Astragalus lentiginosus* populations located in this area.

RESULTS AND DISCUSSION

Habitat summary. Examples depicting the range of sandy habitats occupied by Coachella Valley milkvetch populations are shown in Figs. 8 through 14. The sediment-delivery system facilitating the active dunes and associated habitats favored by milkvetch plants consists of fluvial depositions, fed episodically by ephemeral streams originating in and near the San Gorgonio Pass (Fig. 16). The fluvial depositional areas tend to be connected with floodplains of the Mission Creek–Morongo Wash and Whitewater–San Gorgonio Rivers, with lesser drainages also contributing sediments to the aeolian system (Griffiths et al., 2002). The dunes are transitory due to the unidirectional sand movement the depositional areas, and are periodically recharged with fine-grained sediment from episodic floods that occur during high rainfall years. Aeolian sand generally moves from west to east through the valley, with the period of maximum transport occurring from April into June (Griffiths et al., 2002). Over the last few decades, the active dune systems that support milkvetch populations have significantly decreased in area, a result of road construction, urban development, modifications to natural stream channels, and the introduction of tamarisk species as windbreaks.

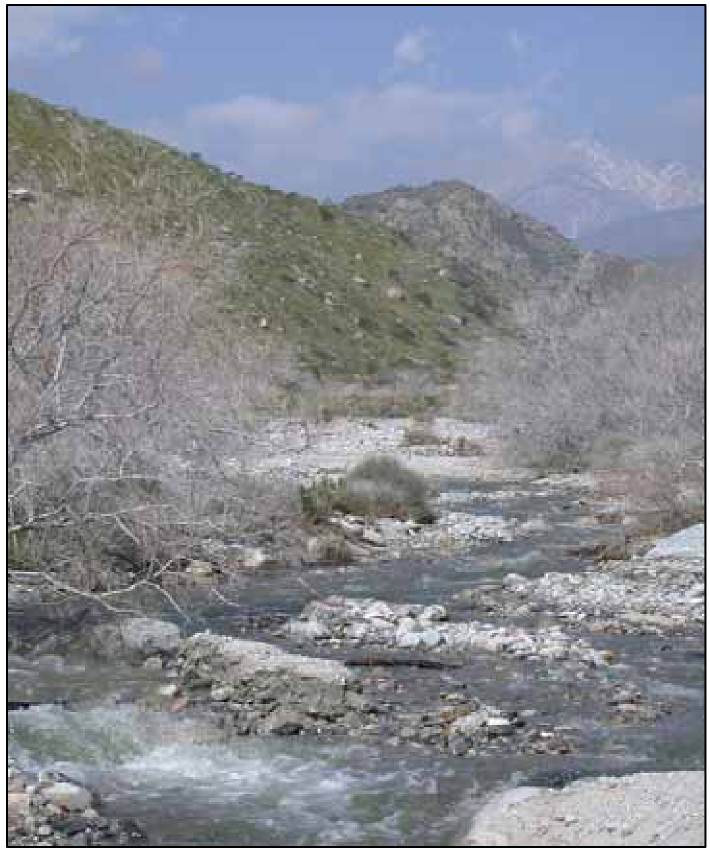

Figure 16. Floodwaters recede along Mission Creek wash, west of Highway 62 (February, 2005).

The habitat preferences of *Astragalus lentiginosus* var. *coachellae* more or less coincide with those of the Coachella Valley fringe-toed lizard, with populations of both taxa occurring on active dunes, semi-stabilized dune edges, and comparable sites. That said, the two species do not always occur together. Unlike fringe-toed lizards, which appear to prefer the leeward flank of dunes that are characterized by more open expanses of deeper sand (Barrows, 1997, 2006), milkvetch plants are generally associated with the windward side, especially in the southern end of the valley. Populations may also occur away from primary dune systems on coppice mounds anchored by dominant shrubs such as *Larrea* and *Psorothamnus*, or even in more compacted substrates, including sand veneers covering non-aeolian surfaces, sandy washes, and sometimes along road margins or railroad right-of-ways. Not surprisingly, a large number of milkvetch populations have been stranded on urban parcels within highly developed areas across the valley, and many are now scattered over sandy lots and along the edges of housing developments and golf courses. Due to the fragmented nature of such habitats, the long-term persistence of milkvetch populations in these areas (even if such sites were somehow protected from destruction) is threatened by reduced sand transport and a corresponding increase in substrate stabilization.

Although the geographic distribution of *Astragalus lentiginosus* var. *coachellae* is rather limited (Fig. 7), significant microhabitat variation exists among populations, which occur across a complex landscape (Barrows and Allen, 2007). This is largely associated with annual rainfall patterns, with milkvetch populations oriented along a southeasterly precipitation gradient from the San Gorgonio Pass to near Indio. In non-drought years, the rainy period typically extends from December through March, and accounts for most of the yearly precipitation. Thunderstorms may produce locally significant rainfall from July into September, though this has far less impact on the recruitment and establishment of spring-flowering herbaceous species than late fall and winter weather. Precipitation is not uniformly distributed from year to year or place to place across the Coachella Valley, and any single storm front may drop more than the average annual rainfall for a given location. In general, precipitation decreases from west to east across the range of milkvetch populations, with a concurrent shift in vegetation type (as reflected by associate species composition). Yearly rainfall averages (encompassing annual totals from 1927 or 1948 through 2006 – see www.wrcc.dri.edu/summary/Climsmsca.html) are 12.45 inches for the Cabazon area, 12.93 for Snow Creek, 5.53 for Palm Springs, and 3.11 for Indio.

Species lists were developed for each of the study sites, and included all vascular plant species observed within the boundary of the active study area (i.e., the zone within the population where sampling was taking place). Table 1 lists the native and exotic species recorded at each of the study sites, along with an abundance ranking (described in the table caption). The lists were not intended to be absolute for a given locality, but were geared towards determining the primary suite of species that best characterized each site. Accordingly, Table 1 probably excludes at least some uncommon annuals that may have co-occurred with milkvetch plants, and potentially a few other nearby species that did not happen to grow within the sampling perimeters. This list does, however, include the great majority of native species that occurred with (or in the immediate vicinity of) milkvetch populations visited in February, March, and April of 2005 and 2006, including all local dominants, and provides a reasonable representation of the ecological variation among the study sites.

While study sites exhibited considerable floristic overlap (Table 1) – for example, most included *Larrea tridentata*, *Palafoxia arida*, and *Dicoria canescens* as dominants – differences were clearly noted, both in terms of species composition as well as overall physiognomy. Corresponding with the geographic shift in annual precipitation across the valley, higher biomass taxa, including numerous woody perennials (e.g., *Lepidospartum squamatum*, *Hymenoclea salsola*, *Ambrosia dumosa*, and *Psorothamnus arborescens*) characterize milkvetch habitats in and near the eastern San Gorgonio Pass, where winter rainfall totals are highest. Moving southeast into the northern valley, the rain shadow influence of the San Jacinto Mountains intensifies – *Astragalus* plants occur here on open sandy flats and low dunes, associating with generally lower biomass subshrubs and perennials (e.g., *Croton californicus*, *Psorothamnus emoryi*, *Petalonyx thurberi*, *Tequilia* spp., and occasional *Atriplex canescens*), and a higher percentage of annuals (*Abronia villosa*, *Eriastrum erimicum*, *Lotus strigosus, Camissonia* spp., and *Cryptantha* spp.). The proportion of annual species in the overall spring flora further increases to the southeast,

TABLE 1. Native and exotic vascular plant species routinely observed within the *Astragalus lentiginosus* var. *coachellae* study areas in late winter and spring of 2005 and 2006. Species were recorded if they occurred within the sampling perimeters for a given site, or within approximately 10 meters of any milkvetch plant that had been marked for demographic sampling (this aspect of the study is described elsewhere in the report). For the species below, a "0" indicates it was not recorded at the site, a "1" indicates 1-10 observations within the sample area, a "2" indicates 11-50 observations, and a "3" indicates over 50 observations. The Desert Center site is included here because it was assumed, at the outset of the study, that Coachella Valley milkvetch populations did in fact occur here (this issue is discussed in more detail in the Taxonomic Relationships section).

Native Species	**CV Refuge**	**Garnet**	**Gene Autry**	**Windy Point**	**Snow Creek**	**Railroad**	**Salvation Army**	**Desert Center**
Abronia villosa	3	2	0	1	0	0	3	1
Allionia incarnata	0	0	2	0	0	0	0	0
Ambrosia dumosa	0	2	0	2	3	0	0	0
Astragalus aridis	3	0	0	0	0	0	0	3
Atriplex canescens	2	0	0	0	0	2	0	1
Atriplex polycarpa	1	0	0	0	0	0	0	0
Baccharis sarothroides	0	2	0	0	1	0	0	0
Baileya pauciradiata	2	0	0	0	0	0	0	0
Calyptridium monandrum	1	0	0	0	0	0	0	0
Camissonia boothii	0	0	0	0	0	0	0	1
Camissonia brevipes	1	0	0	0	0	0	0	2
Camissonia californica	0	0	0	2	2	2	0	0
Camissonia claviformis	2	3	3	2	2	0	3	0
Camissonia pallida	0	1	0	2	3	0	0	0
Camissonia refracta	2	0	0	0	0	0	0	0
Chaenactis carphoclinia	0	0	1	0	0	0	1	0
Chaenactis fremontii	0	0	3	0	2	0	3	2
Chamaesyce albomarginata	0	0	1	0	0	0	0	0
Chamaesyce polycarpa	0	0	2	0	0	0	0	0
Chilopsis linearis	0	0	0	1	1	0	0	0
Croton californicus	0	3	0	2	2	2	0	0
Cryptantha angustifolia	0	2	2	0	0	0	3	3
Cryptantha micrantha	0	0	0	2	0	0	0	0
Cryptantha muricata	1	1	0	0	0	1	0	0

Table 1 (continued)

	CV Refuge	Garnet	Gene Autry	Windy Point	Snow Creek	Railroad	Salvation Army	Desert Center
Dalea molissima	1	0	0	0	0	0	2	1
Datura discolor	0	0	0	0	1	1	0	0
Dicoria canescens	2	2	0	3	1	3	3	0
Ditaxis californica	0	1	0	0	0	0	2	0
Dithyrea californica	1	1	0	0	0	0	0	1
Encelia frutescens	0	0	1	1	0	0	0	0
Ephedra aspera	0	0	0	0	2	0	0	0
Eremalche exilis	2	0	0	0	0	0	0	2
Eriastrum erimicum	0	0	0	0	0	2	1	0
Eriophyllum ambiguum	0	0	0	0	1	0	0	0
Eriophyllum wallacei	0	0	1	0	2	0	0	0
Erodium texanum	1	0	0	0	0	0	0	0
Fagonia laevis	0	0	0	0	0	0	0	1
Geraea canescens	2	0	0	0	0	0	0	2
Hesperocallis undulata	0	0	0	0	0	0	0	2
Hymenoclea salsola	0	1	0	1	2	0	0	0
Hyptis emoryi	0	0	0	0	1	0	0	0
Larrea tridentata	1	3	3	3	3	2	2	3
Layia glandulosa	0	0	0	0	1	0	1	0
Lepidospartum squamatum	0	2	0	0	3	0	0	0
Loeseliastrum schottii	0	0	2	0	0	0	0	0
Lotus heermannii	0	0	0	0	1	0	0	0
Lotus strigosus	0	3	2	0	3	0	0	0
Lotus wrangelianus	0	0	0	0	0	0	2	2
Lupinus arizonicus	0	0	0	0	0	0	0	2
Lupinus concinnus	0	0	0	0	2	0	0	0
Lupinus hirsutissima	0	0	0	0	2	0	0	0
Lupinus micranthus	0	0	0	0	1	0	0	0
Lupinus sparsiflorus	0	0	0	0	1	0	0	0
Malacothrix glabrata	1	1	2	2	2	0	0	0
Nemacaulis denudata	0	2	0	0	1	2	0	0
Oenothera deltoides	3	1	0	2	0	0	1	2
Oligomeris linifolia	2	0	0	0	0	0	0	2

Table 1 (continued)

	CV Refuge	Garnet	Gene Autry	Windy Point	Snow Creek	Railroad	Salvation Army	Desert Center
Oryzopsis hymenoides	0	0	0	2	2	0	0	0
Palafoxia arida	2	2	1	2	2	1	1	2
Pectis papposa	1	0	0	0	0	0	0	0
Pectocarya platycarpa	1	0	0	0	0	0	0	1
Petalonyx thurberi	0	2	2	2	1	0	0	0
Phacelia crenulata	0	0	0	0	1	1	0	0
Plantago ovata	1	0	0	0	0	0	0	3
Psorothamnus arborescens	0	2	2	3	3	0	0	0
Psorothamnus emoryi	0	0	3	0	0	1	2	0
Psathyrotes ramosissima	0	0	1	0	0	0	1	0
Rafinesquia neomexicana	0	0	0	0	3	0	0	0
Salvia columbariae	1	0	0	0	0	0	0	1
Stephanomeria exigua	0	0	0	0	0	2	1	0
Stillingia linearifolia	0	0	0	0	0	0	0	1
Tequilia palmeri	0	0	3	0	0	0	0	0
Tequilia plicata	0	3	1	3	0	0	0	0
Tidestromia oblongifolia	1	1	0	0	0	0	0	0
Trichoptilium incisum	0	0	0	0	0	0	0	1
Exotic Species								
Brassica tournefortii	3	3	2	2	3	3	2	1
Bromus rigidus	0	0	0	0	2	0	0	1
Bromus rubens	0	0	0	0	1	0	1	1
Erodium cicutarium	0	0	0	1	1	1	1	0
Marrubium vulgare	0	0	0	0	1	1	0	0
Salsola tragus	2	0	0	0	1	1	0	0
Schismus barbatus	0	2	2	0	2	1	2	2
Tamarix sp.	2	0	0	2	0	0	0	0

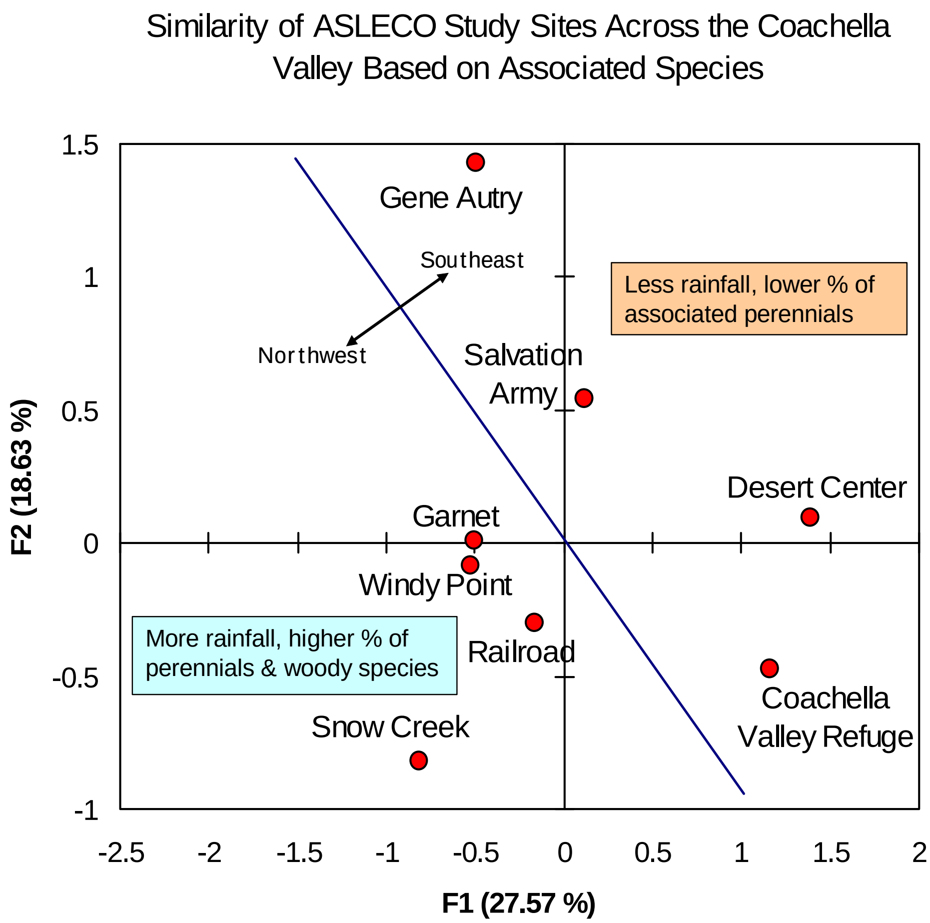

Figure 17. Relationships of milkvetch study sites, based on a correspondence analysis of species frequency and abundance data from Table 1. Study sites from the Palm Springs area and south (right side of graph) are characterized by a predominantly annual flora and less rainfall – sites to the north (lower left) exhibit more perennial vegetation, supported by two to three times as much annual precipitation. The life history of *Astragalus lentiginosus* var. *coachellae* varies along the moisture gradient – plants from the southern end of the range are smaller and seldom overwinter, acting as annuals, while those from the north often become suffrutescent and may reproduce for three or more years.

reaching its highest level in the dune habitats at the southern end of the range near Indio, where var. *coachellae* populations commonly co-occur with psammophytic specialists such as *Abronia villosa*, *Oenothera deltoides*, *Geraea canescens, Oligomeris linifolia*, *Astragalus aridis*, and *Baileya pauciradiata*. Fig. 17 illustrates the floristic relationships of the study sites as reflected by associate species and precipitation.

Sympatry with exotic species. Of the eight exotic species recorded within study sites (Table 1), five are not particular to sandy habitats (i.e., *Bromus rigidus*, *B. rubens*, *Erodium cicutarium*, *Marrubium vulgare*, and *Schismus barbatus*), and were not considered serious threats to var. *coachellae* plants. However, Russian-thistle (*Salsola tragus*) and salt-cedar (*Tamarix* sp.) are well-adapted to dune environments, and have the potential to impact milkvetch populations in selected areas. Salt-cedar trees (established as windbreaks and dune stabilizers, and a prominent feature of the landscape in parts of the Coachella Valley Refuge and Windy Point study areas) can co-opt dune habitat, reduce ground water, and stabilize or alter the flow of aeolian substrates. And Russian-thistle, a robust summer annual that was especially widespread at the Coachella Valley Refuge site in 2006, can be a serious pest on selected dunes and adjacent sandy areas (Fig. 18). It is highly proficient in terms of seed production and dispersal in windy, arid climates, and remains green and competitive for soil moisture into early summer.

The most noteworthy threat, however, is almost certainly posed by the cool weather annual *Brassica tournefortii* (Sahara mustard) (Figs. 19 and 20), an aggressive species thought to have been accidentally imported from the Middle East with date palms in the early 20th century (Sánchez-Flores, 2007). In terms of sheer numbers, Sahara mustard was by far the most common plant (native or exotic) seen at the study areas, but

Figure 18. *Salsola tragus* infesting milkvetch populations in April, 2006 at the Coachella Valley Refuge study area. Russian thistle can be a serious pest at the refuge and may significantly reduce habitat quality, especially in the dune areas near 38th Avenue.

especially at Snow Creek and the Coachella Valley Refuge (both of which are publicly owned and managed). Reported as being particularly invasive on roadsides and dunes (Malusa et al., 2003), Sahara mustard is a vigorous rosette-former (Fig. 20) that may repress milkvetch populations by competitive exclusion, suppression of sand movement, and potential allelopathy (Lovett and Jackson, 1980). It is considered a serious noxious weed in Australia and several U.S. states, and is of management concern throughout southeast California and much of the American Southwest (Trader et al., 2006).

Figure 19 (left). Sahara mustard (*Brassica tournefortii*), occurring with first-year milkvetch plant on an active dune north of Indio. In general, Sahara mustard plants appear less capable of invading open dunes, particularly in steeper areas with loose, unstable sand. However, after winters with especially heavy rainfall, resulting infestations may even reach the dune crests. Multiple years with large population build-ups promote an extensive seed bank that ensures long-term impacts to native vegetation.

Figure 20 (right). Sahara mustard population at the Coachella Valley National Wildlife Refuge in February, 2005. Plants tended to mass in washes and open, sandy flats, and coincided with habitat for a wide range of native species, including *Oenothera deltoides, Abronia villosa*, *Dalea molissima*, *Tidestromia oblongifolia*, *Baileya pauciradiata*, *Palafoxia arida*, and others. The closed canopies and overlapping rosettes that characterize heavy mustard infestations may deplete milkvetch populations and other natives via competitive exclusion, and potentially impact reproduction by affecting pollination dynamics.

Taxonomic appraisal. The Coachella Valley milkvetch has been known from the Palm Springs region of Riverside County at least since 1913 (Eastwood *3116*; NY, CAS, GH). However, the epithet *Astragalus lentiginosus* var. *coachellae* was not applied until the description of the taxon in 1964 (Barneby, 1964a). Since then, the identification of var. *coachellae* and its close relatives has occasionally been problematic due to the relatively minor taxonomic differences that distinguish them. Further complicating the issue have been a number of pre-1964 herbarium specimens of this milkvetch group labeled with currently unrecognized or misapplied names. The recent designation of var. *coachellae* as an endangered species (USFWS, 1998) has re-emphasized the importance of accurate identifications for *A. lentiginosus* populations from southern California.

Astragalus lentiginosus is a highly polymorphic and evolutionarily active species, comprising at least 40 recognized varieties that occur throughout the intermountain and southwest desert areas of North America (Isely, 1998). Although each of these are more or less morphologically distinct, zones of intermediacy are frequently encountered where varieties geographically overlap. Before this was fully appreciated, many current varieties of *A. lentiginosus* were originally described as species. But as the number of collections increased over the years, the distinctiveness of many taxa became obscured. As a result, misidentifications have become common, as reflected in the uncertainty surrounding milkvetch specimens from gravelly soils in the Desert Center area (USFWS, 1998, 2005).

Knaus (2007) has completed a preliminary morphometric and geographic review that focuses on endemic varieties of *A. lentiginosus* in the deserts of southern California, including var. *coachellae* (molecular systematics work is currently in progress for the group). With regards to nearby congeners, the varietal neighbor to the immediate south of var. *coachellae* is *A. lentiginosus* var. *borreganus*. Both taxa are purple-flowered and densely white-hairy, but are readily distinguishable by the degree of inflation of the pod (Barneby, 1964). Fruits of var. *borreganus* are described as "slightly inflated," and are noticeably longer than wide, while the legume of var. *coachellae* is depicted as "strongly inflated," and usually nearly as wide as long (Barneby, 1964). In addition to what appear to be clear morphological differences, these taxa do not overlap geographically.

Of greater interest here is *A. lentiginosus* var. *variabilis*, situated immediately to the north of var. *coachellae*. As its name implies, this variety encompasses considerable morphological variation and is similar to several other taxa (Knaus, pers. comm.). At the southern fringe of its range, where it approaches the Coachella Valley, var. *variabilis* is most easily distinguished from var. *coachellae* by the length of its calyx teeth, which are shorter. The teeth of var. *coachellae* reportedly range from 1.7–2.9 mm long, while those of var. *variabilis* are 1.0–1.4 mm (Barneby, 1964). Apparently little else separates the two taxa, outside of their presumably occurring in distinct regions, and the fact that var. *coachellae* is a strict sand specialist while var. *variabilis* may occur on sand to gravelly or even rocky substrates. Although the calyx lobe differences are slight, they are evidently very consistent, and as a result Knaus (2007) considers var. *coachellae* to be restricted to the Coachella Valley and nearby San Gorgonio Pass. With respect to the populations from Desert Center previously reported as var. *coachellae*, Knaus (2007) indicates they are most likely var. *variabilis*, or possibly the related var. *fremontii* (more study of this issue is evidently needed, but see below). In any case, the Desert Center occurrences are considered outside the morphological and ecological boundaries of var. *coachellae*.

In concluding, Knaus (2007) speculates on the confusion surrounding the identity of the Desert Center material: "*Specimens from Desert Center were* reportedly *identified (i.e., confirmed) by Barneby in 1973 as* A. lentiginosus *var.* coachellae *at Rancho Santa*

*Ana Botanic Garden (USFWS, 1998). However, a visit (by Knaus) to Rancho Santa Ana during the summer of 2005, as well as an herbarium loan from RSA, failed to turn up these specimens. The author would like to suggest that this report was in error. The authority for this (varietal) name is Barneby, so the complete name may appear (on specimens) as "*Astragalus lentiginosus *var.* coachellae *Barneby" (sometimes also including "ap. Shreve & Wiggins," in reference to the book the name was published in). The inclusion of the authority in the name on the Desert Center specimens (cited in USFWS, 1998) may have been confused with an annotation by Barneby; however, it was Barneby's practice to initialize his annotations (e.g., R.C.B.) and not to include his last name in full. An example of this can be seen on Eastwood* 3116 *(type of* A. lentiginosus *var.* coachellae*), available for viewing online at www.nybg.org. Further, Barneby has left evidence that he had seen material from the Desert Center region previously (Barneby, 1964: map no. 132), and had determined this material to be* A. lentiginosus *var.* variabilis*. This, in addition to the new data presented (in Knaus, 2007), seems to confirm the identity of the Desert Center material as* A. lentiginosus *var.* variabilis."

Demographic overview. Life history variation has been reported for *Astragalus lentiginosus* var. *coachellae*, with some populations consisting primarily or entirely of annual plants (Fig. 21), while others are often characterized by a significant proportion of multi-stemmed, woody-based perennials (Fig. 22). Prior observations (Barrows, 1987)

Figure 21. Milkvetch plants living a year or less, and reproducing once, are particularly common at the Coachella Valley Refuge study area, but may occur throughout the range of var. *coachellae* in drier microsites (such as here at the Windy Point study site).

have suggested this may be related to yearly precipitation, as governed by location in the Coachella Valley area. The current project was only scheduled for two years, so there was limited ability to set up a meaningful demographic study to evaluate recruitment levels and trends in population growth or decline, particularly among the perennial segments of the populations. Our evaluation was therefore restricted to simply measuring survival rates from 2005 to 2006, which at least offered the opportunity to record variation in longevity across the valley.

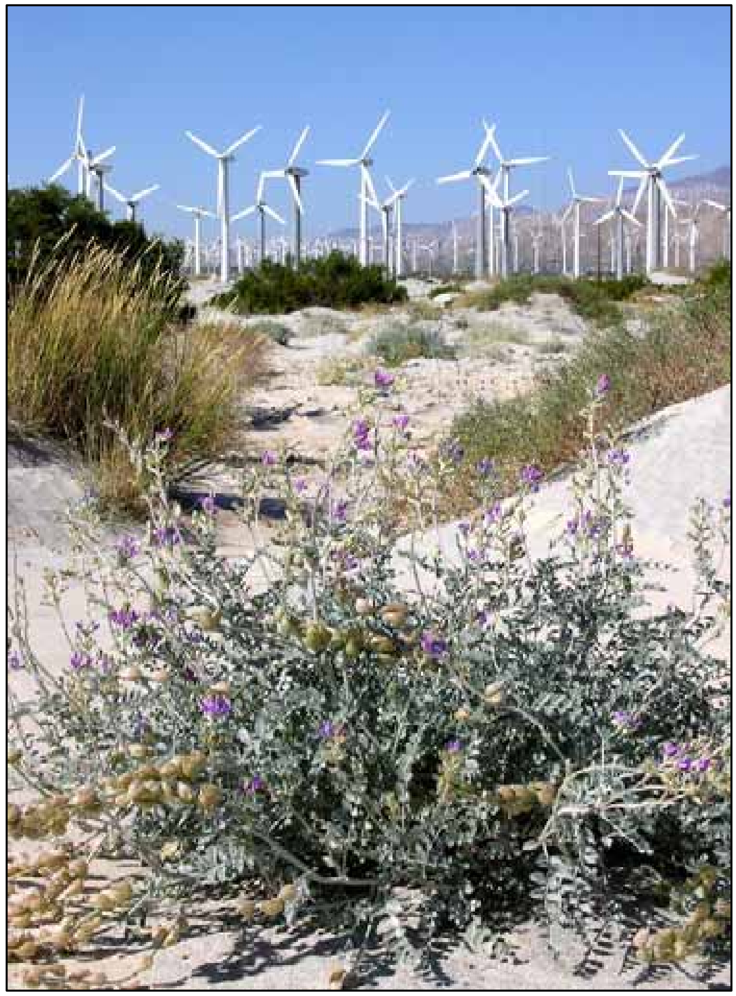

Fig. 22. Perennial Coachella Valley milkvetch plant on low dune near the Garnet study site, just south of the Palm Springs Amtrak Station.

For each of the study sites, 20 randomly assigned reproductive plants (40 at the Coachella Valley Refuge site, which was represented by two subpopulations) were marked with stakes and flagging in early February, 2005 (Fig. 23). Tagged plants were revisited in March and May, 2005, and then February and April, 2006. The five rounds of data collection focused on mortality (i.e., whether plants tagged in 2005 survived until the next visit), demographic stage, and various measures of fecundity and reproductive output (to be discussed in the following sections). Supplemental data was collected from other plants within the study sites for certain data categories.

Survival of monitored milkvetch plants between the 2005 and 2006 field seasons varied appreciably among study sites (Fig. 24), supporting prior observations that some populations are principally "annual" (Fig. 21), while others support at least some perennial plants (Fig. 22). During the two study years, perennials flowered as early as mid-December in the San Gorgonio Pass, and were developing initial fruit by January. Annual reproductive plants (i.e., first-year plants that germinated early enough in the fall to flower, but retained vestiges of embryonic leaves) started blooming as early as January, although for most individuals the phenological peak was sometime in February or even early March. Sporadic flowering continued through late April at all sites, but by this point the populations were largely in fruit (94.6% as measured on April 29-30, 2005; N=20 plants per study site, six inflorescence branches censused for each; pooled data for seven study sites).

Figure 23. Rather than use set plots for demographic evaluations, the scattered nature of milkvetch plants on the dunes made it more practical to simply tag individuals, using flagging, wooden or PVC stakes, and aluminum tags held in place with long wires. Shifting sand made relocating plants challenging at times, especially at the Garnet study site where all of the plants tagged in 2005 had disappeared by February, 2006. GPS measurements and photographic records aided in relocation.

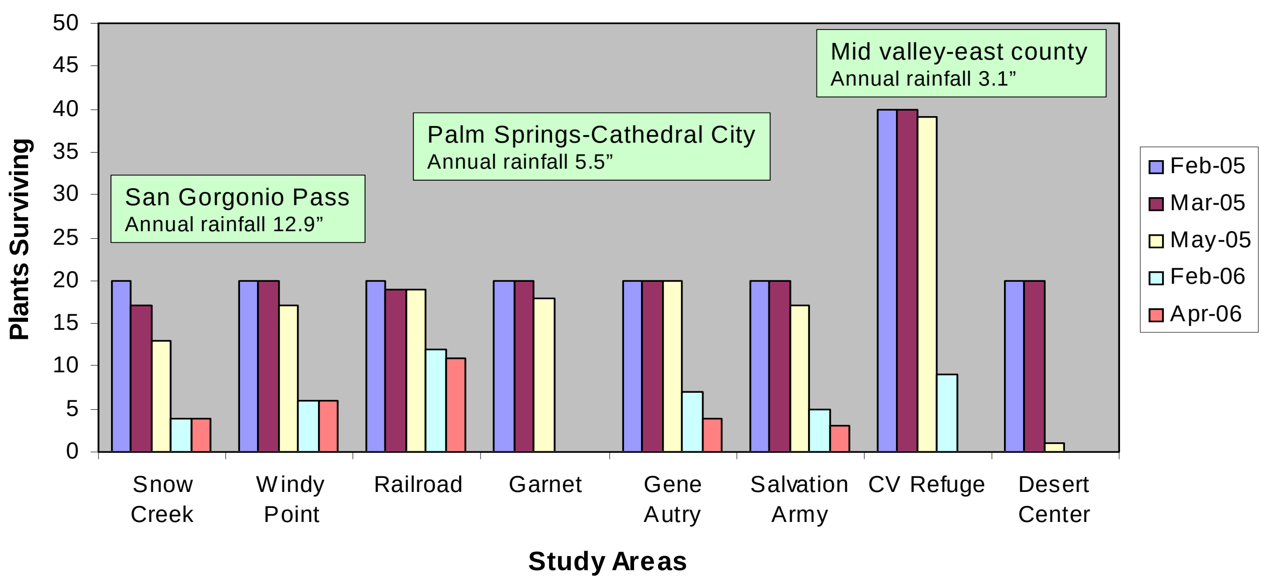

Figure 24. Overall rates of survival for randomly selected *Astragalus lentiginosus* plants (including first-year and perennial plants) from each study population that were tagged and then tracked through April, 2006. Sites around San Gorgonio Pass (Snow Creek, Windy Point, and Railroad) showed higher retention rates, with a pooled total of 33% of tagged plants surviving to reproduce in 2006 in these areas. Drier sites in and near Palm Springs exhibited 8% survival, and the driest sites (i.e., CV Refuge and Desert Center) had less than 2% survival. The data support prior impressions that var. *coachellae* is a facultative perennial, more likely to overwinter and reproduce again in areas with higher rainfall.

Average yearly precipitation figures have not been recorded for the entire range of *Astragalus lentiginosus* study areas. However, the local data that were available (12.93 inches a year for Snow Creek, 5.53 for Palm Springs, 3.11 for Indio, and 3.62 for Desert Center) imply that the ability of a given plant to survive and reproduce for two or more successive years after germination is likely related to rainfall distribution (Fig. 24).

By subdividing the mortality data presented in Fig. 24 into size classes (i.e., small reproductive plants with 1-5 racemes that appeared to be in their first year of growth in 2005 *versus* large, many-stemmed plants with >10 racemes that had already reproduced for at least two seasons), we can see that larger and presumably older plants had significantly better survival odds, with 62% surviving (Fig. 25) to flower again in 2006 (excluding the Garnet study site – see caption for explanation). Since rainfall was well above average in 2005, we might have expected comparably robust survival rates for the younger plants, yet this was not the case – 86% of the plants we considered to be first-year reproductive annuals died, even though they had all become established enough in 2005 to have flowered and set fruit. This suggests that mortality may be generally high

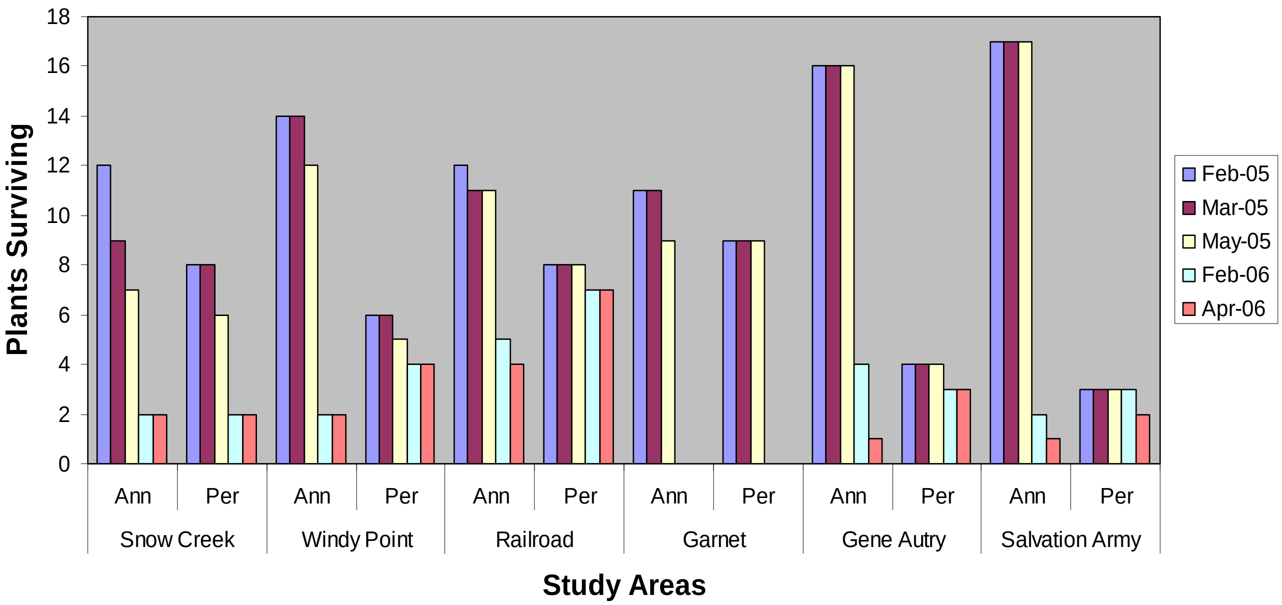

Fig. 25. The relationship between plant age/size class (see text) and mortality at study sites with both year-old reproductive individuals (1-5 racemes) and second-year or older reproductive plants (>10 racemes). (This excluded the Coachella Valley Refuge study area, which had no multi-stemmed perennials in 2005). Significant differences in survival rates exist over time and between demographic classes (χ^2=7.922, p<0.0001; data pooled between sites). There was no difference in overall survivorship between one year-old plants (**Ann**) and older plants (**Per**) by the end of the first season (May, 2005), but by the end of the second year of observations, the proportion of perennial plants that had survived to reproduce again (as measured in April, 2006) was far greater than that of the year-old plants, which had mostly died off (χ^2=0.277, p<0.0001). (Note that the Garnet site was excluded from the analyses, since the 100% mortality it experienced by late 2005 appeared caused by road maintenance and work on a nearby wind farm fence, which resulted in complete burial of tagged plants by diverted sand flow.) As with many herbaceous species with labile life histories, milkvetch populations are disproportionately dependent upon selected individuals, whose chance occurrences in favorable niches promote greater reproductive contribution through increased size and longevity.

among first-year milkvetch plants, even in favorable years, implying that transitioning from first-year reproductive plant to highly fecund perennial (as depicted in Figs. 4 and 22) is uncommon, especially if one assumes that in years with average or below average rainfall the mortality among first-year plants would be even greater. The data also seem to confirm prior observations that perennial var. *coachellae* plants are generally not long-lived, since 38% of perennials that were monitored between 2005 and 2006 died as well.

Since the current study did not directly measure the proportional representation of all age/size classes within the populations, it's difficult to speculate how the different survival rates observed between older and younger plants may be affecting population dynamics. For example, we didn't evaluate seed banks, and we largely ignored the fate of non-reproductive juveniles, defined here as first-year plants (generally smaller and often more "seedling-like") that had germinated and leafed out, but did not flower for whatever reason (possibly due to late germination, unfavorable microsite, etc.). A one-time evaluation of such non-reproductive plants at the Windy Point study site showed that only about 5% (3 plants out of 58, scattered among 5 plots) survived from May, 2005 to April, 2006, suggesting that the inclusion of this size class in the main study would have further skewed the survival ratios in favor of the perennials. And are all the plants we considered annual *really annual*? It's possible that some of the monitored plants we counted as first-year reproductives in 2005 were small because they were in fact non-reproductive the year before (see the 5% survival rate mentioned above) – they could have managed to overwinter and reproduce, yet didn't have enough resources to become large and obviously "perennial-looking" the following year.

Although we have confirmed some basic life history traits of var. *coachellae*, our knowledge of long-term population trends remains limited. The next step could involve a multi-year population viability analysis (PVA) (Caswell, 2001), a popular but usually labor-intensive tool for providing quantitative estimates of the likelihood of population persistence (Menges, 2000; Brigham and Schwartz, 2003). The short-lived perennial life history of var. *coachellae* is particularly suited to the transition matrix modeling approach of PVA, which might serve to help pinpoint those milkvetch populations with long-term vulnerabilities, as well as any that are especially resilient, thereby assisting with conservation decision-making. However, not all at-risk plant species require this level of research commitment to move forward with recovery efforts, and a clearly defined set of objectives would be needed before determining if PVA is appropriate in this situation.

So to summarize, the odds of an average milkvetch plant surviving to reproduce again the following year are enhanced if (1) it has reproduced previously and has multiple stems (mostly >10 in our samples), and (2) it grows in an area of the valley that receives greater annual precipitation. Plants germinating on the hot, exposed dunes above Indio may very well lead an annual lifestyle most seasons. Those occurring to the north, closer to San Gorgonio Pass (Fig. 7), have a somewhat better chance of surviving more than a year (Fig. 24), a factor that promotes population stability and reduces local extinction probabilities. Larger, more robust plants are more apt to survive multiple seasons, and thereby contribute more to subsequent generations through greater reproductive yield (Fig. 25). Reliance on a few dominant individuals to maintain constancy in population structure is a common strategy among herbaceous perennials, and has been noted for a number of other rare species (Charron and Gagnon, 1991; Dammon and Cain, 1998; Sinclair et al., 2005). Such plants characterize a core group of milkvetch populations near the Windy Point and Snow Creek study sites that may be especially worth preserving.

Reproductive output and life history. Not unexpectedly, productivity among milkvetch plants is not randomly distributed among or within populations. Plants from northern populations produce, on average, greater floral displays, with more racemes per individual and more flowers per raceme (Fig. 26), attributes that are directly related to the larger proportion of perennials in these areas. Racemes were defined as a terminal or sub-terminal inflorescence branch with a segregated subset of flowers subtended by a naked peduncle (see example in Fig. 27).

And within milkvetch populations, larger perennials (as measured by the number of racemes produced) tended to cluster together (Fig. 28), indicating, not unexpectedly, that favorable microsites and successful dispersal events are patchily distributed within sites. Although not specifically evaluated here, the clumping of large milkvetch plants to create showy floral displays likely enhances the genetic consequences of pollination and improves overall seed set. Plant density is known to have strong positive effects on both insect visitation and reproductive success in a wide range of species (Kunin, 1997; Roll et al., 1997; Kirchner et al., 2005).

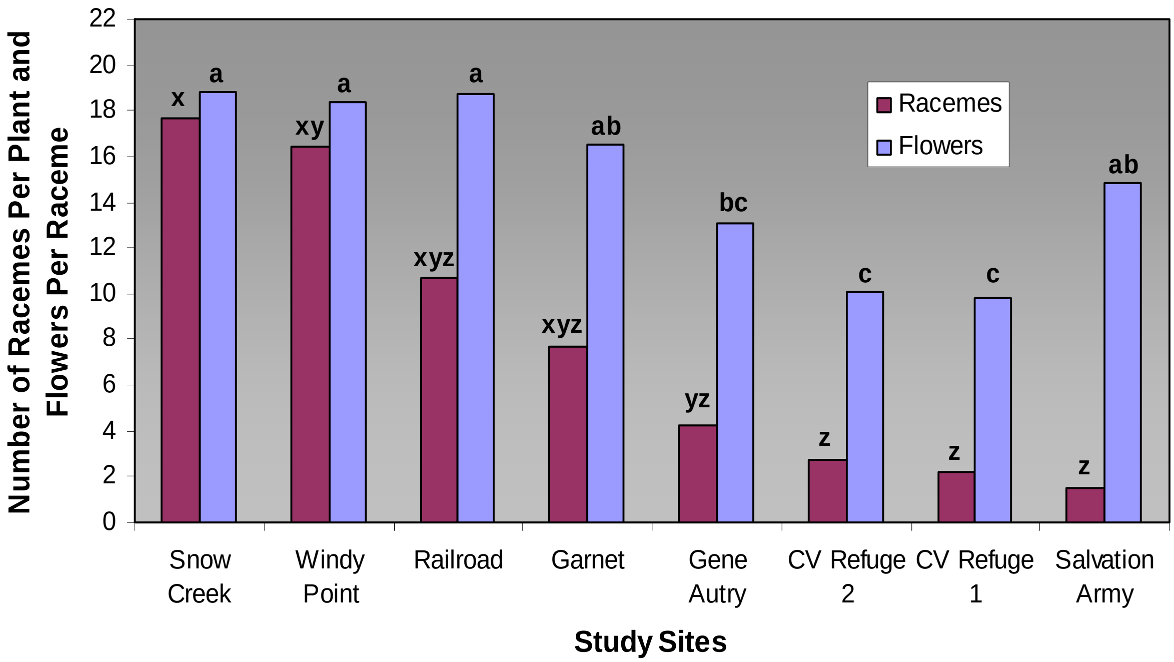

Figure 26. The average number of racemes produced per plant and flowers produced per raceme, recorded from a randomly identified group of 20 milkvetch plants (of mixed reproductive size classes) at each study site (April, 2006). The Coachella Valley Refuge site is split into two subsamples here (N=20 each). A "raceme" was defined as any terminal or sub-terminal inflorescence branch that, by virtue of being subtended by a naked peduncle, supported a segregate array of flowers (see Fig. 27). The geographic location of a sample population (with "study site" as the explanatory variable in one-way ANOVAs) had a significant influence on the production of inflorescences per plant (F=5.021, $p<0.0001$) and flowers per raceme (F=12.025, $p<0.0001$). Although the geographic trend is clear (i.e., more reproductive effort per plant in the northern portion of the range versus the southern), only those bars not sharing superscripts (**a**, **b,** or **c** for the flower data and **x**, **y**, or **z** for raceme data) were significantly different in pairwise comparisons (Tukey's HSD, significant interactions ranging from $p<0.019$ to $p<0.0001$; 95% confidence interval).

Maximizing genetic diversity by preserving a wide range of populations is a critical management consideration for many rare plant species. Focusing on population quality, in terms of vigor and reproductive output, is also an important consideration. The data here again suggest that plants from the more northerly populations of var. *coachellae* may have more conservation value, based on their greater average longevity and superior reproductive effort. Populations on public lands that tend to support masses of large perennial plants (such as the populations at Windy Point, Garnet, and Snow Creek), may be particularly worth conserving, and special effort should be made to insulate these from future development and habitat conversion, and direct impacts from OHV traffic.

Fig. 27. An individual raceme, as described in the text and in Fig. 26.

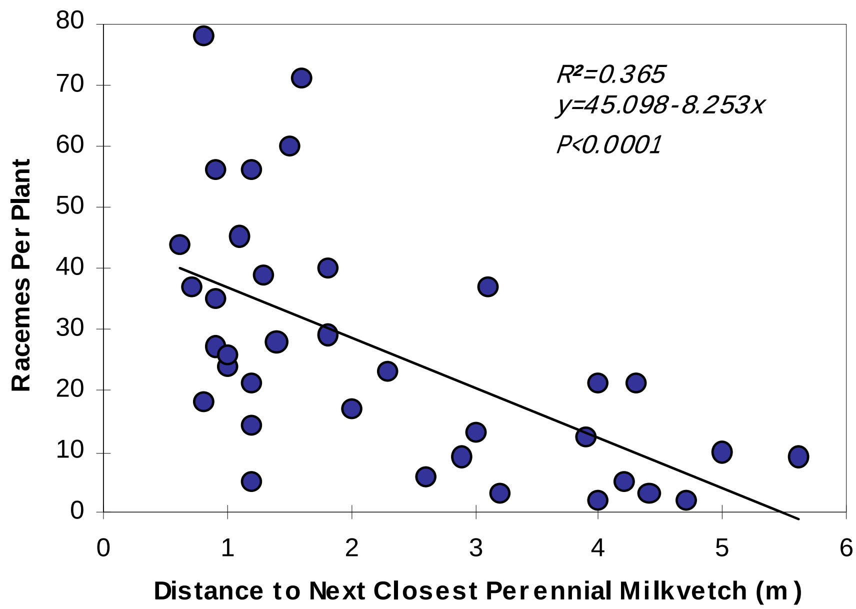

Fig. 28. Observations of perennial plants (i.e., defined here as overwintering individuals with >10 separate racemes) at Snow Creek and Windy Point sites (N=18 randomly selected plants from each location; sampled March, 2005). A significant correlation existed between the number of racemes (and hence flowers) a plant produced, and its proximity to its nearest perennial neighbor. Plants tended to clump up, presumably a response to patchy distribution of resources coupled with chance dispersal events. Clumped perennials formed large floral displays that may help attract pollinators to a population.

Pollination and breeding system.. *Astragalus lentiginosus* var. *coachellae* is a facultative outcrosser. Bagging experiments on field plants (inflorescences bagged with breathable mesh when the entire raceme was still in bud – see Fig. 29) show that flowers were capable of setting fruits and viable seed without pollinators, but at very low rates (1.9% pods containing mature seed out of 1,155 flowers bagged on 43 plants, data pooled from Railroad, Windy Point, Garnet, and the Salvation Army study sites). Manual tripping of milkvetch corollas to effect self-pollination produced only modest improvement (14.5% fruit with some seed out of 110 flowers). And in a field test set up to directly evaluate potential pollinator limitation, five bagged inflorescences on separate plants at the Railroad study site (a total of 144 flowers on 9 racemes) produced two fruits with 11 seeds total, while an equal number of paired inflorescences on the same plants (138 total flowers) that were left open to pollination set 72 fruits with a total of 596 seeds. Since abundant seeds are produced in nature, it was clear that some type of insect pollinators were necessary for effective reproduction.

Fig. 29. Example of polypropylene bag used in pollinator exclusion tests.

The flowers of var. *coachellae* appeared suitable for a range of native pollinators, yet virtually none were observed during this study. Only seven individual native bees (possibly representing a single *Anthidium* species, which was not collected) were recorded on milkvetch flowers over approximately 112 hours of observation in 2005 and 2006 (ca. 8 hours per year per study area, during the height of flowering in February and March). Conversely, over a thousand visits to var. *coachellae* flowers by honeybees (*Apis mellifera*) were observed during this same period. The honeybees were presumably feral, and nests were noted in close proximity to three study areas, including Coachella Valley Refuge and Windy Point (in tamarisk trees and discarded tires), and at the Garnet site (under a nearby bridge). Honeybees started foraging early in the morning and continued late into the evening, and seemed largely unfazed by the high winds that routinely buffet most sites. They were tireless workers in *Astragalus* populations, focusing particularly on the floriferous perennial plants, and appeared very efficient at tripping corollas (Fig. 30).

Even though pesticides and general urbanization have surely taken a toll on the native bee fauna of the Coachella Valley, it seems unlikely that the indigenous pollinators of the milkvetch have been wiped out. Another explanation is that they simply do not compete well with honeybees on *Astragalus lentiginosus* in the valley, and have shifted to different plants. On warm, less windy days, several native bees were noted visiting flowers of other species that were at the time ignored by honeybees (for example, *Baileya pauciradiata*, *Camissonia* species, *Lotus strigosus,* and even *Dalea molissima*), though whether any of these would work *Astragalus* flowers in the absence of *Apis* is unknown.

Fig. 30. Honeybees were the most prolific pollinators of *Astragalus lentiginosus* var. *coachellae* plants in 2005 and 2006. Fewer than 1% of observed floral visits were by native bees, which have potentially been excluded from milkvetch flowers by honeybee competition, habitat loss, pesticides, or a combination of these factors. Despite their exotic status, honeybees were very efficient at effecting pollination and seed set in var. *coachellae*, which is genetically self-compatible but only minimally autogamous.

Based on the current study, it is unknown if the reproductive gain afforded by open-pollination is linked to pollen quality (i.e., whether outcrossed pollen offers a genetic advantage that results in greater seed set than geitonogamy or autogamy), or if insect vectors simply improve the mechanics of pollen transfer. Suffice to say that seed set is dramatically enhanced by insect pollination. If pollen source is an issue, then honeybees may actually benefit var. *coachellae*, since they tend to forage over longer distances and wider areas than most of the native hymenopterans one might expect to visit *Astragalus* flowers. Since corollas are evidently not very capable of self-pollination, isolated milkvetch plants with otherwise low reproductive output could be visited by far-ranging honeybees and outcrossed (assuming they had already been working milkvetch patches in the area), potentially helping to produce more and better quality seed. This may be important in facilitating the establishment of new, genetically diverse populations after long-distance dispersal.

Seed production. The information presented thus far indicates that fruit and seed production by Coachella Valley milkvetch plants are a function of plant size (including life history stage), plant positioning (including geographic location in the valley as well as within-population microsite), and the availability of pollinators (almost exclusively honeybees, at least in 2005 and 2006). At the outset of the study, a critical issue was whether or not var. *coachellae* plants suffer seed loss due to some form of pollinator- or pollination-limitation. This question seems to have been answered. The large numbers of fruits that result (see Fig. 31, and also Fig. 4) when plants are exposed to honeybee pollination, as described above, coupled with a high rate of honeybee visitation, suggests that pollinator-limitation is not a serious obstacle to reproduction.

Fig. 31. Coachella Valley milkvetch pods from a perennial plant at the Snow Creek study site. A single perennial can produce hundreds of fruit (also see Fig. 4) and thousands of seed in a growing season after pollination by honeybees (with final seed crop numbers for a given year also subject to predation – see following section).

Evaluation of seed set data indicate that milkvetch plants produced more seed per fruit in 2005 than in 2006. Pooled data from all seven study areas (minimum of N=20 arbitrarily selected pods from different plants for each site) show that plants produced a mean of 7.2 dark seeds per ripe, unopened pod in 2006 (N=163), and 8.9 seeds per pod in 2005 (N=184). Pre-dispersal seed and ovule predation played a major role in reducing seed set (see next section). Viability was 98% (49 out of 50 seeds germinated in a moist petri dish three to seven days after scarification). Plants from the Windy Point and Snow Creek sites produced, on average, more seeds per fruit than those from the other sites, but the differences were not significant (one-way ANOVA; Tukey's HSD).

In 2005, 60 plants were randomly selected (from across all life history stages) for a *seed crop estimate*, including 20 each from the Snow Creek, Windy Point, and Railroad study sites. The pooled mean number of inflorescences per plant for the three sites was 14.63, the mean pod number per inflorescence was 12.7 (N=5 inflorescences per plant), and the mean number of seeds per pod was 9.2 (N=6 pods sampled per plant). The Snow Creek *study area* (i.e., that portion of the population at the site that we used for sampling, in this case about 12 acres) was estimated to have 850 reproductive plants in 2005, the Windy Point study area (covering ca. 8 acres) 1,400, and Railroad 620 (over ca. 6 acres). Calculating all this out, the Snow Creek plants in our 12 acre study area dispersed about 1.46 million seeds into the seed bank in 2005, Windy Point 2.39 million, and Railroad 1.06 million, or roughly 189,000 apparently viable seeds per acre. As seed banks go that may not be especially prolific, particularly compared to an exotic like Sahara mustard, but it is still a substantial annual output for a species with hard-coated, presumably long-lived propagules. It also indicates that var. *coachellae* can probably sustain a reasonable level of harvest, for seed storage and possible cultivation and reintroduction work, should that be considered necessary at some point. For the number of plants in its populations, Coachella Valley milkvetch is doing a reasonable job of producing seed.

But is the seed getting where it needs to go? The ability to convey seeds long distances may be an important issue for urban interface taxa such as var. *coachellae*, which are regularly subjected to habitat fragmentation and population losses. Despite the inflated fruits (Figs. 31, 32, and 33), presumably an adaptation for movement by wind as

Figure 32. Detached pods and seeds accumulate in soil depressions and at the base of shrubs within existing milkvetch populations, where most seeds are probably dispersed. However, some of the dehisced, dried pods undoubtedly become wind-blown at some point. This may then result in seed movement over considerable distance, a possible mitigating mechanism for the problem of habitat fragmentation. Even modest-sized milkvetch populations can potentially produce millions of seeds annually under favorable conditions (see text), helping to maintain substantial, if localized, seed banks.

pods dry out, numerous milkvetch populations are now surrounded by development and other obstacles to easy dispersal. Even in more natural settings, the majority of seeds appear to be locally distributed, with many pods partially dehiscing and shedding seeds while still on the plant. And when dried fruits finally drop, they often accumulate in temporary blow-outs at the base of nearby shrubs (Fig. 32), and frequently end up buried. However, since pods seldom spread completely open, some seeds manage to stay in them over time, and this may help facilitate eventual wind dispersal. A sample of detached milkvetch pods collected in late February, 2006 (comparable to those in Figs. 32 and 33), which had evidently been produced the previous year, still contained an average of 1.84

Figure 33. One year-old milkvetch pods with exit holes made by pre-dispersal seed predators (in this case, probably a weevil – see Fig. 34.C). A diverse range of insect larvae destroy significant numbers of seeds and ovules while maturing inside the pods.

seeds per fruit (N=56 pods, examined at the Salvation Army study site). The heavy wind gusts common to the valley could certainly move these at some point, assuming they avoid burial or post-dispersal predation, suggesting that at least a small fraction of a crop may remain available for long-distance dispersal months (or perhaps even years) after seeds mature.

Pre-dispersal seed predation. During field work, the most commonly observed pre-dispersal seed predator on *Astragalus lentiginosus* var. *coachellae* was *Bruchophagus mexicanus* (Fig. 34.A and B), a widespread species of chalcid wasp known to infest pods of various native legumes, especially *Astragalus* (including *A. bisulcatus* in Wyoming, *A. utahensis* and *cibarius* in Utah, and the rare *A. sinuatus* in Washington state—Trelease and Trelease, 1937; Green and Palmbald, 1975; Combs, unpubl.). *Bruchophagus* females

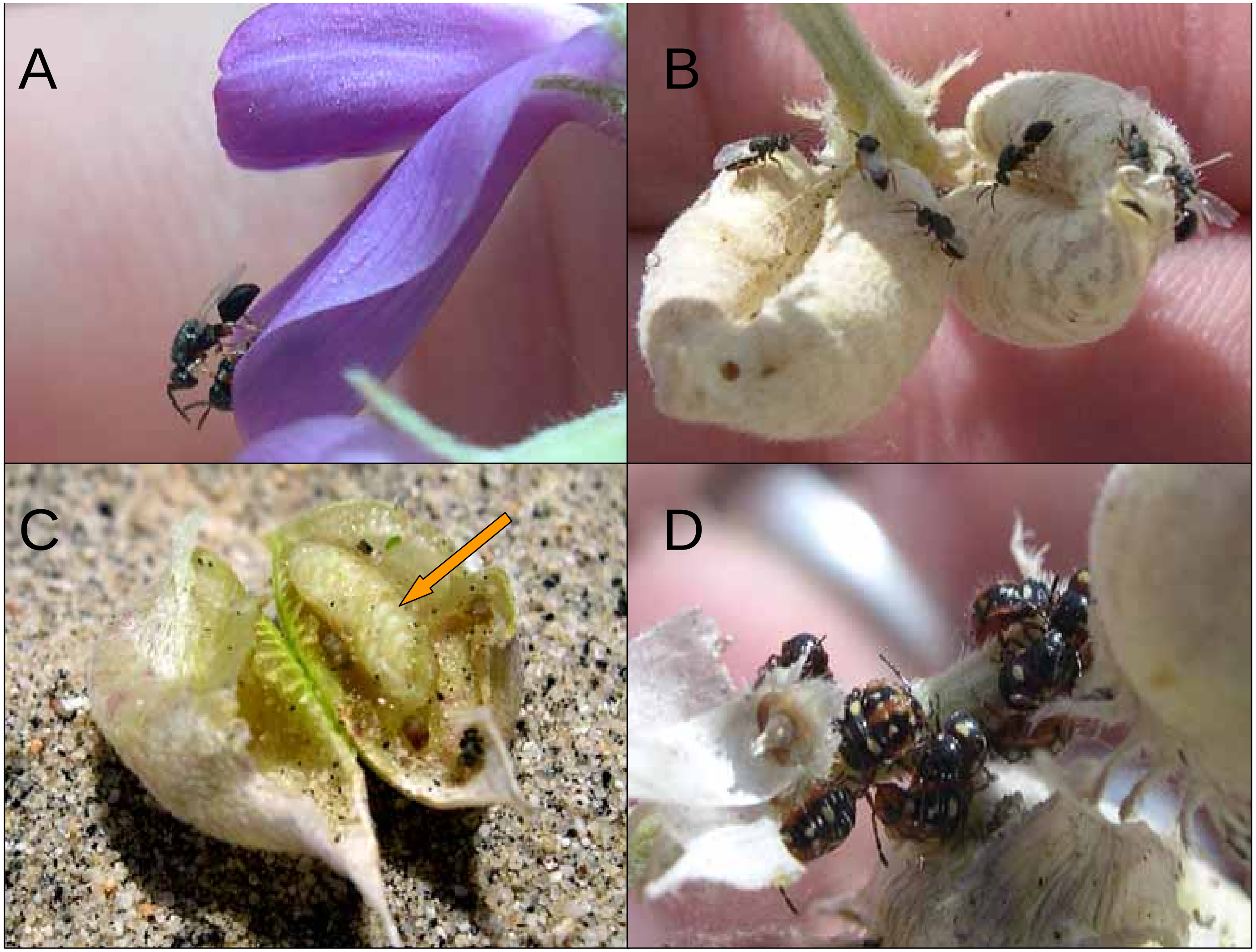

Figure 34. A. *Bruchophagus mexicanus* copulating on corolla of var. *coachellae* after emerging from opened pod. **B.** Recently liberated *Bruchophagus* wasps on pods they may have previously infested as larvae, where they would have fed on ovules and ripening seeds. The small dark spot at the end of the left-hand pod is an exit hole made by a seed beetle (*Acanthoscelides* sp.; Bruchidae), which was common at most sites. **C.** Weevil larva (possibly a *Tychius* sp.), recorded as a significant pest in ripening milkvetch pods, and the source of larger exit holes seen in many fruit. **D.** Predatory stinkbug nymphs (likely *Chlorochora* sp.), on *Astragalus* infructescence after emerging from dehisced pods.

oviposit on var. *coachellae* plants when fruits are young (probably as early as December or January, depending on the site), with larvae infesting and destroying the developing seeds. The wasps evidently exit fruits upon dehiscence – they appeared incapable of chewing their way out, and were often noted congregating on inflorescences with recently opened pods (Fig. 34.B). Further support for this conclusion were the occasional mature wasps discovered inside of drying but unopened fruits. Early emergents may also mate and oviposit if ovaries or young pods are still available (Fig. 34.A), with the species evidently capable of completing more than one generation per season within the same population of plants. *Bruchophagu*s was most common in milkvetch populations with large numbers of perennial individuals, and was most prevalent in the 2005 study season.

The large exit holes on pods in Fig. 33 were probably created by an exiting weevil (Curculionidae), possibly in the genus *Tychius*, although this could not be confirmed as adults were never located or reared out. *Tychius* species have been reported as significant predators in a wide range of other milkvetches (Green and Palmbald, 1975; Kaye, 1999; Isaev, 2001; Johnson et al., 2005). Fig. 34.C shows a large seed predator, believed to be a mid-stage weevil larva, which was regularly observed in green pods. The presence of this larval type in pods typically resulted in a complete loss of seed set.

Another common larval predator that impacted var. *coachellae* were seed beetles (unidentified to species) in the genus *Acanthoscelides* (Bruchidae), which were noted within the developing seeds of many fruit. Adults eventually emerge as the pods open naturally upon ripening, or from a small, circular exit hole chewed in the fruit wall (see Fig. 34.B). *Acanthoscelides* spp. are listed as common pests for other *Astragalus* species (Johnson, 1970; Green and Palmbald, 1975; Combs, unpubl.), so to assess the extent of this beetle in var. *coachellae*, a random sample of nearly ripe, undehisced pods without exit holes was gathered from 60 plants at the Windy Point, Railroad, and Garnet study sites (2 pods each from 20 plants per site; March, 2005). The 40 pods from each site were placed in separate, breathable, insect-proof bags, anchored with stakes, and allowed to dry out and dehisce on site. They were examined in early May, and showed a pooled, minimum infestation rate of 68.3%, based on the presence of small exit holes that had appeared while pods were drying in the bags. This is undoubtedly an underestimate since at least some beetles are believed to leave pods via the dehisced end, without chewing a hole. The bags contained a total of 205 adult beetles, indicating more than one larva can be present in a pod. There were no significant differences in infestation rates between sites (Fig. 35), suggesting that bruchid seed beetles may be successful predators across a wide range of milkvetch populations in favorable years.

Yet another potential source of pre-dispersal seed loss in var. *coachellae* is predation by stinkbug nymphs in the widespread genus *Chlorochora* (Pentatomidae), many species of which require in-fruit seed feeding to complete their life cycle (Panizzi, 1997). Immatures of this insect (not identifiable to species) were regularly spotted on var. *coachellae* inflorescences near ripe pods (Fig. 34.D). Representatives of the genus have been reported from other *Astragalus* species as well(Green and Bohart, 1975).

Based on our sampling, it was not possible to determine the relative contributions to overall seed loss made by the different larval predators we observed. Fruits at all study sites were commonly infested, however, and pods could contain one or multiple species, with the seed beetles (*Acanthoscelides*) and chalcid wasps (*Bruchophagus*) the most commonly observed taxa. In 2005, 78.4% of mature pods sampled one to two weeks prior to dehiscence (N=50 arbitrarily selected fruit per study site, from a minimum of six plants at each) were or had been infested with some type of pre-dispersal seed predator, evidenced by exit holes on the pericarp (such as in Figs. 33 or 34.B), entry marks left by ovipositing insects, or internal damage to ovules or septum. In 2006, the percentage had dropped to 64.2% (based on N=40 fruit per study site). The inside of most infested fruit were characterized by larval frass, torn ovules, and seed fragments (mostly empty testae) scattered among whole seeds, or in some cases all seeds and ovules were destroyed. In a number of instances, fungi were introduced by the infestation, inflicting further damage on developing ovules.

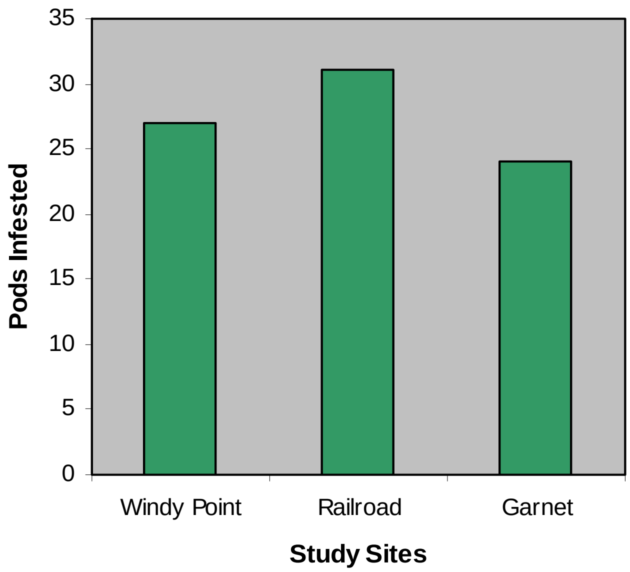

Fig. 35. Number of pods infested with seed beetle larvae at three study sites (N=40 pods sampled per site). Logistic regression indicates infestation rates were not significantly different among sites [Windy Point *vs.* Railroad (1, χ^2 =0.994, $Pr>\chi^2$=0.319); Windy Point *versus* Garnet (1, χ^2=0.485, $Pr>\chi^2$=0.486); Railroad *versus* Garnet (1, χ^2= 0.095, $Pr>\chi^2$ = 0.095)].

A sampling of 40 undamaged pods (20 each from the Salvation Army and Gene Autry sites) revealed a mean ovule number of 32.3±3.8 per pod. So assuming an average of 32 *potential seeds* per pod, and an average seed production per pod of 7.2 (in 2006) and 8.9 (in 2005 – see previous section), we see that the *realized seed set* per year was only about 22.5% and 28.4% of the total number of available ovules. The proportion of this reduction attributable to seed predators is not known (other causes of ovule loss or abortion could conceivably include drought stress, nutrient limitation, lack of fertilization, etc.), but considering our observations, and the number of fruit infected with various larvae, the impact is probably significant. All of the pest insects described here are natural predators indigenous to the Coachella Valley.

Non-insect herbivory. Herbivory by rodents was also observed during the study, primarily involving foliage. It was a less common phenomenon than floral predation by insects, but could be intensely destructive on a local scale. Browsing by rodents was more common in 2006 (a dry year) than in 2005 (an above average rainfall year). While floral damage from larvae was slightly down in 2006 (78% of pods infected in 2005 versus 64% the following year – see previous section), a possible result of greater insect mortality over the drier winter, incidents of foliar damage attributed to rodents was much higher during the 2006 growing season. The reduction of available biomass that year, especially for spring annuals (in contrast to the comparatively lush spring of 2005), seems a likely cause for the elevated interest in *Astragalus lentiginosus* plants.

Instances of herbivory (or fructivory) by mammals were recorded for milkvetch plants during the demographic assessments at each study site (103 observations from randomly selected plants, pooled from all sites, were available for March, 2005, and 155 for February, 2006). In 2006, a number of sampled plants showed signs of herbivory by rabbits and possibly ground squirrels, with some branches stripped clean of leaves (Fig. 36). Far fewer plants were affected in 2005. Of a total of 2,103 flowering stems on the

155 plants sampled in 2006, 780 (or 37.1%) showed obvious signs of browsing. There were 1,335 flowering stems on the 103 plants assessed in 2005, and only 88 of these (or 6.6%) showed evidence of browsing.

Destruction of green pods by rodents also occurred at some sites, but it was uncommon overall (most of this was observed at the Garnet, Railroad, and Windy Point study areas). Since pods were often detached from plants prior to being chewed open to access green seeds (Fig. 37), it was not possible to determine the level of impact in a given population. Similar to rabbit herbivory, most instances of pod predation were observed in 2006. Kangaroo rats (*Dipodomys*) or ground squirrels (*Spermophilus*) were most likely responsible for the damage noted in Fig. 37, both of which have been reported to consume the seeds and fruit of *Astragalus lentiginosus* elsewhere (Henderson, 1990; Best, 1995). It may be that small mammals can constitute a significant threat to var. *coachellae* in certain years, as when drought and large rodent concentrations happen to coincide. But *A. lentiginosus* is generally considered to be toxic (Molyneux and James, 1982; Pfister et al., 2003) and significant herbivory is likely to occur only in situations such as droughts, when green biomass in general is at a premium. In years when ample quantity and assortment of spring forage is readily available (as in 2005), var. *coachellae* foliage and fruits are probably largely ignored.

Figure 36. Rabbits were occasional defoliators of milkvetch plants in the winter and spring of 2006.

Figure 37. Green pods were occasionally removed from milkvetch plants by small rodents and chewed open, presumably to access the young seeds and ovules inside. Although the contents of pods were evidently targeted by the herbivores, this type of granivory was not regularly observed at the study sites, and the vast majority of fruit were left untouched.

Pathogens. Although the wet winter and spring in 2005 may have served to reduce herbivory in var. *coachellae*, due to the greater availability of preferred forage species, the constant rains and damp, cool conditions may have facilitated fungal disease. Plants at several study sites, but particularly at the Coachella Valley Refuge, were impacted by a fungal wilt in 2005, possibly a *Fusarium* species (Zhou et al., 2004) that may be transmitted by insects such as chalcid wasps and aphids (both observed on milkvetch plants). Symptoms included yellowing leaves, flaccid, drooping racemes, and flowers that shrivel at or prior to anthesis (Fig. 38), preventing pollination. Infected stems do not set fruit. The disease was not recorded at any of the study sites in March, 2006 (N=155, from plants used in demographic sampling), but was found on 41 of 180 plants sampled across the range of var. *coachellae* in February, 2005 (this also included the var. *variabilis* Desert Center population). Demographic stage and likelihood of infection were not correlated.

Figure 38. Unidentified fungal or viral disease wilts inflorescences of first-year milkvetch plant at the Coachella Valley Refuge study site. The wilt was not observed in 2006, but affected about 23% of 180 randomly sampled plants from all study sites in 2005 (most evident at the Coachella Valley Refuge populations). The difference between the sample years may have been related to the wetter conditions in the winter and spring of 2004-05. All flowers on infected racemes are destroyed, and some plants are killed outright.

Life cycle summary. Fig. 39 summarizes, in the form of a conceptual model, the life history data and observations reviewed in the preceding sections (i.e., *Demographic overview*, *Reproductive output and life history*, *Pollination and breeding system*, *Seed production*, *Pre-dispersal seed predation*, *Non-insect herbivory*, and *Pathogens*). The model identifies the strengths of the milkvetch life cycle (i.e., heavy fruit production when pollinated by insects, the likely maintenance of a potentially large seed bank, and the ability to perennate) as well as potential weaknesses (apparent reliance on an exotic pollinator known to be vulnerable to population crashes [Doebler, 2000], inability to effectively self-pollinate, high mortality among young plants, and significant levels of pre-dispersal seed predation). Management of var. *coachellae* would benefit from direct research on seed bank ecology (including actual data on seed bank sizes), impacts of particular types and intensities of disturbance on specific life history phases, and whether native pollinators still play a meaningful role in reproduction.

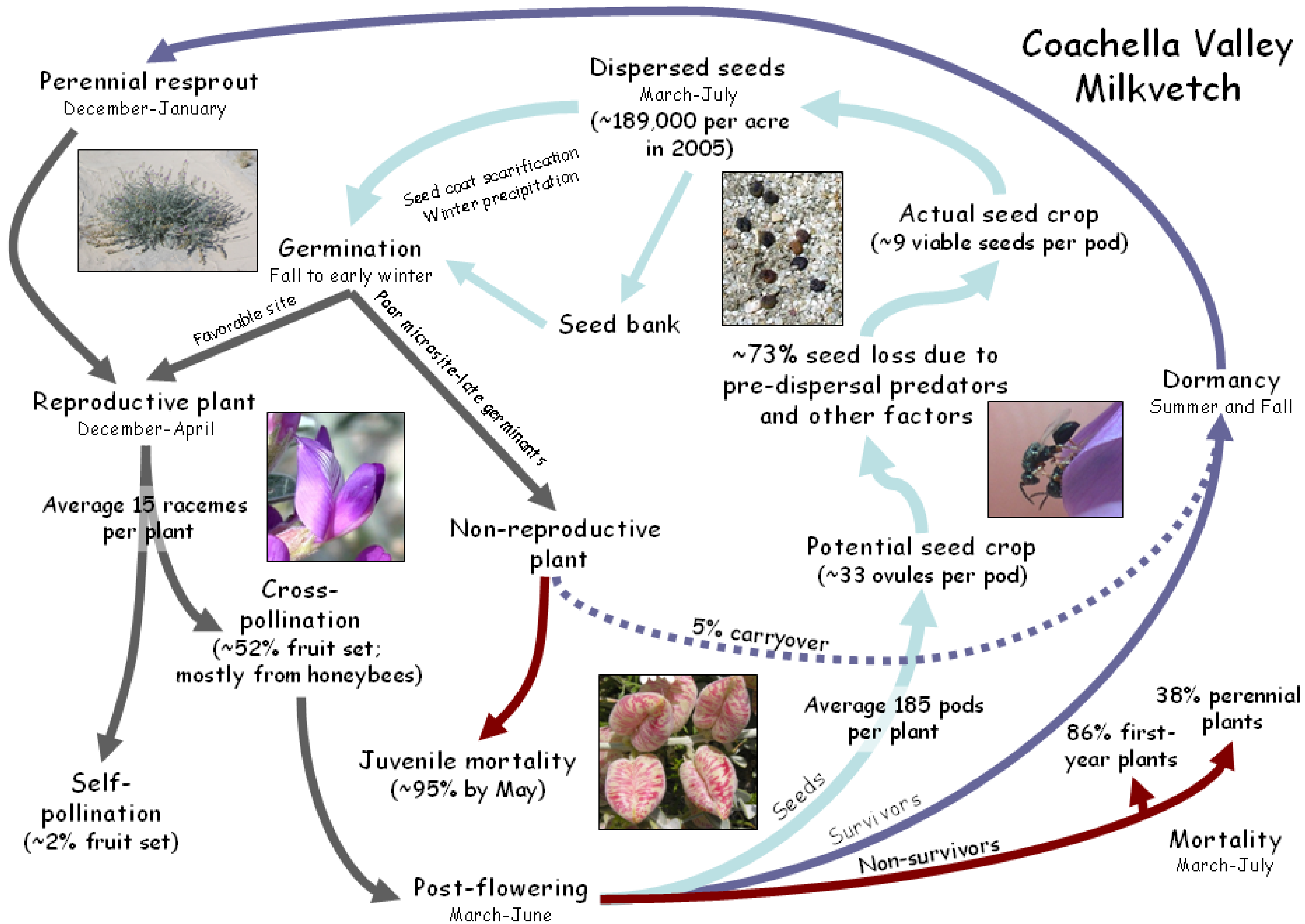

Figure 39. Conceptual model summarizing the annual life history stages expected for a typical mixed annual-perennial population of *Astragalus lentiginosus* var. *coachellae*. Quantitative estimates are based on plant averages from data recorded during the 2005 and 2006 field seasons, and may not reflect actual survivorship or reproductive output observed in future years.

Disturbance relationships. Habitat loss and disturbance are frequently cited as threats to endangered species. However, while conversion or outright destruction of habitat undeniably lead to local extirpations, responses to disturbance are less predictable, and depend on the nature of the perturbation and the life history of the species. The draft Coachella Valley Multiple Species Habitat Conservation Plan cites several disturbance-related threats to *Astragalus lentiginosus* var. *coachellae*, including indirect impacts from developments that stabilize nearby dunes and washes, as well as direct effects from OHV activity and trampling (CVMSHCP, 2007). Another consequence of such disturbances can be the settling and compaction of sandy substrates, which could negatively affect population dynamics over time as sand transport is redirected or reduced (Sharp, 1964; Griffiths et al., 2002) and vegetative cover is altered.

But is var. *coachellae* truly intolerant of disturbance? A previous report suggests otherwise (Stevens and Pearson, 1984), and observations at several of our study sites showed that milkvetch plants were often present along the ubiquitous trails and sandy thoroughfares resulting from off-road activity. Under certain scenarios, could moderate disturbances mimic the natural conditions necessary for certain demographic stages to thrive? Although the Coachella Valley Refuge study area was effectively fenced and largely unaffected by human activities (aside from the introduction of exotics), areas within each of the other six study populations showed ample evidence of trampling, OHV traffic, or right-of-way maintenance, and sand here was frequently compacted relative to adjoining, less disturbed plots of ground. At four study sites (i.e., Gene Autry, Salvation Army, Railroad, and Windy Point) the disturbance was clearly on-going and regular, while at the others (Garnet and Snow Creek) it appeared less frequent. Although the sites were far from pristine, impacts from trampling or vehicular traffic were usually localized, and trail networks and tracks were typically interspersed with comparatively undisturbed patches of habitat.

To evaluate the local distribution of populations, belt transects were established within four of the study areas (Railroad, Gene Autry, Windy Point, and Salvation Army) to measure plant frequencies relative to substrate disturbance. Belt transects were most convenient, since the impact areas for the disturbances we were sampling tended to be narrow and elongate (e.g., an extended trail, a straight OHV track, etc.). The set-up for each study site involved establishing an initial *disturbance line* parallel with the trail or track, using a meter tape oriented lengthwise along the approximate middle of the disturbance polygon (Fig. 40). The tape was extended 50 or 100 meters, depending on the extent and orientation of the sample site, and secured with surveyors pins. All milkvetch plants that occurred within two meters of either side of the mid-line were then recorded for the entire transect (data were taken by establishing a contiguous series of 1 x 2 meter plots on either side of the tape – see Fig. 40). In addition to collecting presence-absence data for each plot, the demographic stage of any recorded milkvetch plant (i.e., juvenile non-reproductive, first-year reproductive, or perennial reproductive) was also noted. To complete a transect series, the sampling procedure was then repeated for two additional transects of equivalent length, one set out 10 meters from (and parallel to) the initial line, and then another at 20 meters out. Starting points of the initial transect lines were randomly chosen along disturbance features occurring within the sample areas.

The nature of the disturbances sampled were similar yet different for the three study sites. The Salvation Army study area was criss-crossed with a complex of foot and bicycle trails that received heavy use (Fig. 40) – motorized vehicles were rare, probably due to the fact that the site was essentially a neighborhood lot frequented by children and pedestrians. Two 50 meter transect series were set up here. The Gene Autry site was not near homes, and had a single, essentially straight sand track (see Fig. 12) that ran immediately east of Gene Autry Trail (a busy, hard-surface road). It was commonly used

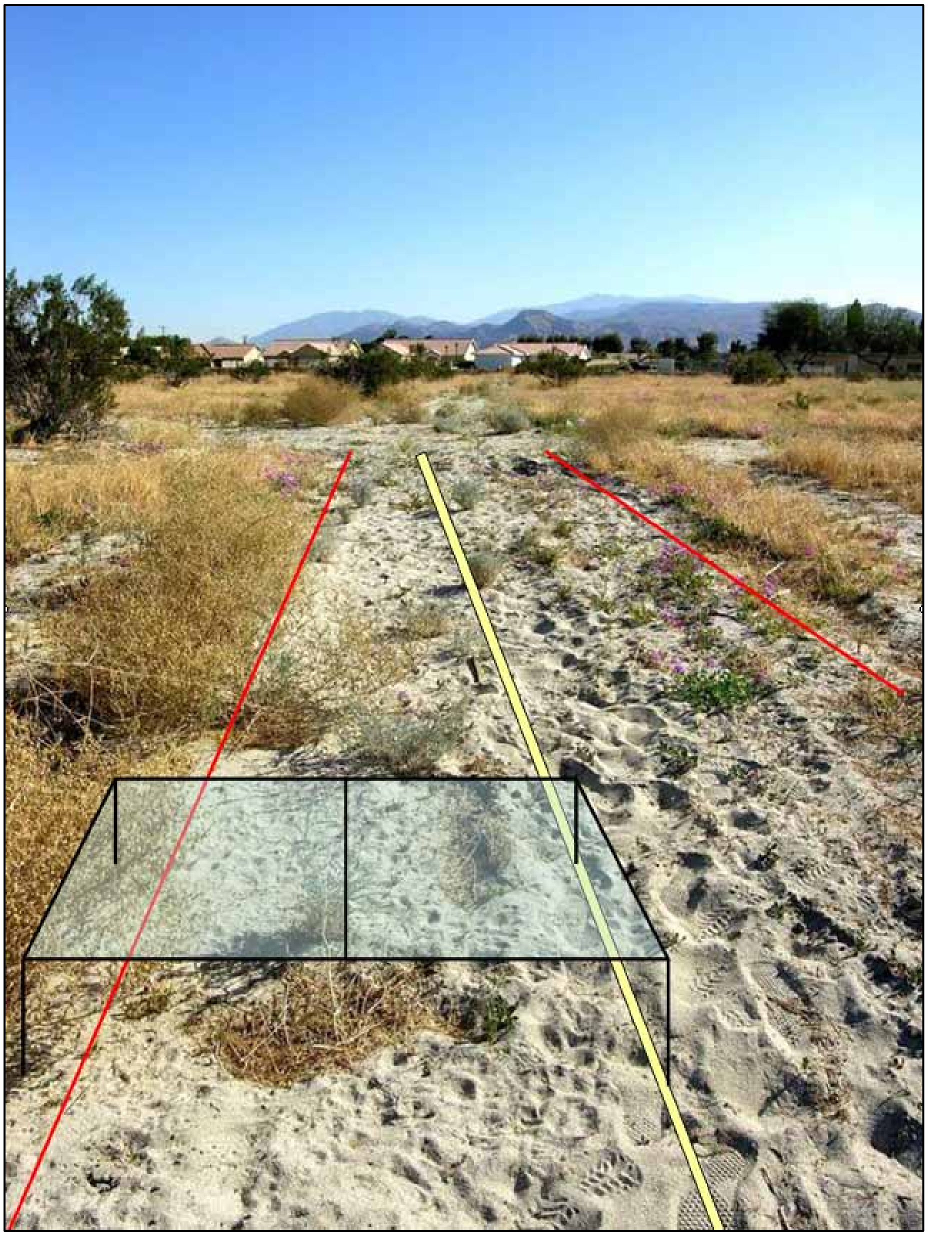

Figure 40. Disturbance-frequency sampling in milkvetch population along a high traffic foot and mountain bike path at the Salvation Army study site. The middle (yellow) line represents a meter tape used to establish the *mid-line* for a 4 x 50 or 4 x 100 meter belt transect (see text for details). The outer (red) lines represent the estimated boundaries of the "disturbance polygon" (the area where disturbance is most prevalent, used in estimating the mid-line). Milkvetch frequency was recorded at every meter along the tape by counting the plants in a 2 x 1 meter plot frame extended on either side of the mid-line (as shown above). To contrast disturbed with less disturbed areas, the process was then repeated for two additional transect lines, situated 10 and 20 meters away from (and parallel to) the original tape position.

by OHV enthusiasts, landscapers collecting rocks and sand, and others with business in the desert. A 100 meter disturbance transect line was laid down the center of the road, with the secondary transects set up to the left (east) of Gene Autry Trail (seen at the far right in Fig. 12). The west edge of the Railroad study area is impacted by maintenance vehicles (and recreational OHVs) that regularly drive along the train tracks running parallel to Tipton Road. The several meter wide strip immediately east of the tracks (Fig. 10) is highly disturbed, and as a result remains more or less clear of vegetation. It leads up to a sandy berm that opens to a flat, much less disturbed stretch of public land adjacent to Tipton Road. A 100 meter disturbance transect line was set along the base of the berm, with the secondary lines situated to the east (i.e., towards the left in Fig. 10). The Windy Point study area is administratively off-limits to off-road vehicles, but that hasn't managed to exclude them (Fig. 9). The disturbance line here (100 meters) was set up within an active OHV track, situated just inside a tamarisk windbreak running parallel to Highway 111. The secondary transects were set up to the west of the disturbance line, in the heart of the milkvetch population among low dunes.

All transects were set up and read in March, 2005. After data collection a chi-square test of independence was performed to assess the relationship between disturbance and plant distribution within a population. The association between these variables was significant at each study site (Fig. 41.A), indicating that plants were more likely to occur in or along the sandy roads and trails than they were in undisturbed areas 10 or 20 meters

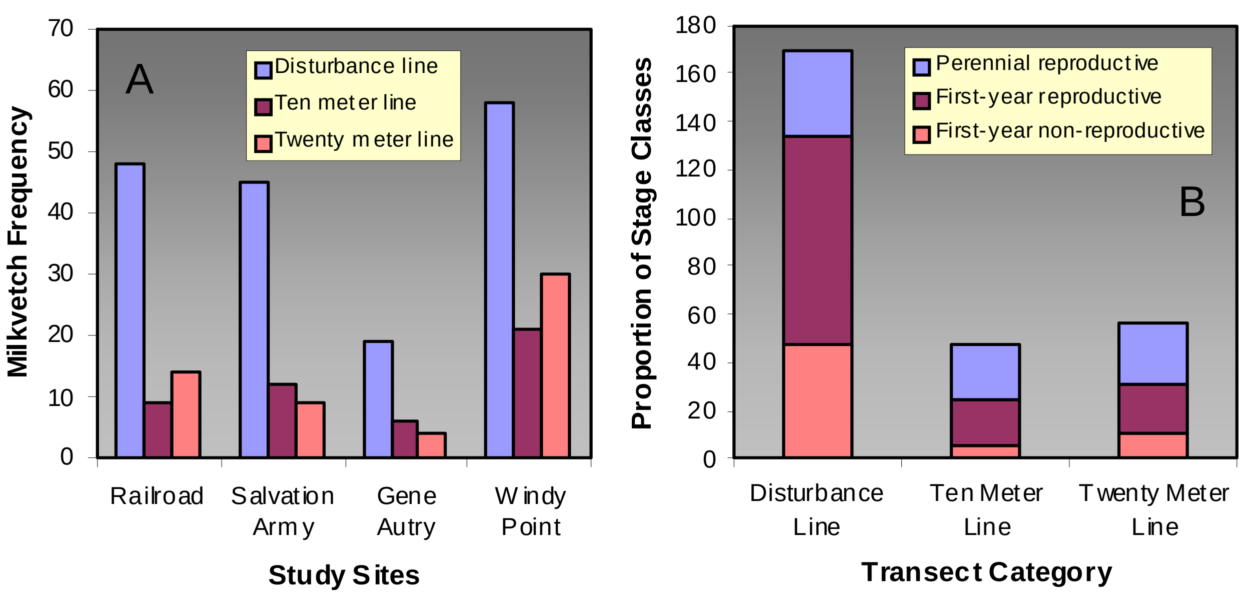

Fig. 41. A. The frequency of milkvetch plants along transects in locally *disturbed areas* versus frequency along parallel transects in *undisturbed areas* 10 or 20 meters away. The relationship between frequency and habitat quality was significant for all study sites [Railroad: $\chi^2(2, N=900) = 41.32$, $p<0.0001$; Salvation Army: $\chi^2(2, N=900) = 39.14$, $p< 0.0001$; Gene Autry: $\chi^2(2, N=900) = 14.18$, $p = .0008$; Windy Point: $\chi^2(2, N=900) = 21.32$, $p<0.0001$]. Plants ranged from 59.6% (Windy Point) to 104.5% (Salvation Army) more likely to occur along disturbed tracks within the areas sampled. **B.** Relative numbers of first-year plants versus perennials associated with the three transect types (pooled for the four study sites). The distribution of first-year plants was proportionately greater along the disturbance transects [χ^2 (2, $N=275$) = 19.81, $p<0.0001$].

away. In addition, the proportion of first-year plants (reproductive or non-reproductive) was significantly greater along the disturbance transects than those located in undisturbed habitat (Fig. 41.B), implying that recruitment may be related to environmental conditions associated with disturbance.

So is var. *coachellae* tolerant of disturbance? Possibly, at least at early stages in the life cycle (Fig. 41.B). Although many desert species are considered highly sensitive to disturbance (Guo, 2004), germination and recruitment of certain dune annuals or short-lived perennials is often related to a dynamic substrate environment (Klinkhamer and De Jong, 1988; Weller, 1989; Maron and Simms, 1997; Milton and Dean, 2000), similar to what is reported here for var. *coachellae*. Moreover, in one of the few ecological evaluations of var. *coachellae*, Stevens and Pearson (1984) reported that milkvetch plants may respond favorably to low-levels of artificial disturbance, but that their long-term response in these situations was unknown. Whether or not the plants actually *require* some level of disturbance to establish is also unknown. However, at least at the four sites we sampled, milkvetch distribution clearly appeared influenced by proximity to trails, etc. Also worth mentioning here is the fact that the association with disturbance was largely with first-year plants (Fig. 41.B), most of which die before becoming established as perennials (Fig. 25). Perennials, in contrast, were more evenly distributed among the transects (Fig. 41.B), and proportionately more common away from disturbed areas. This suggests that whatever factors promote initial milkvetch establishment along trails and OHV tracks may be less likely to favor the perpetuation of plants for multiple years. Reasons for this may include the destruction of plants by passing traffic, a focus on disturbed areas by herbivores, or simply increased stress in harsher, less vegetated sites. On the other hand, even if first-year plants show low transition rates to perennials, the fact that many of them flower and produce seed before expiring may very well represent an overall net gain for the population in disturbed zones, if we assume that germination rates across the site are equivalent.

While disturbance-dependent (or at least disturbance-facilitated) recruitment is a trait often associated with so-called ruderal (i.e., weedy) plants (Grime, 1977, 1979), such behavior has also been previously reported for other rare (and non-weedy) psammophytic species (Petrů and Menges, 2004), where shifting sands play an important role in creating appropriate microsites for germination and establishment. So even though var. *coachellae* plants are sometimes noted along busy roadsides and near commercial centers, characterizing the taxon as ruderal is probably inappropriate, as it seems such individuals are simply more opportunistic than truly weedy. The milkvetch plants occasionally seen thriving near developments or along highway verges presumably arrived as isolated, wind-blown seeds, and seldom form integrated populations. In densely urban areas, such strays often germinate and then persist as a result of irrigation runoff associated with lawns and other landscaping. Another boon to vagrant milkvetches comes from the dust abatement efforts in the valley, which result in the frequent soaking of streets and open ground near active construction areas to reduce air-borne particulates. Even in drier seasons (such as the spring of 2006), repeated dust abatement waterings of construction sites and nearby lots can activate lingering seed banks and result in amazing, if localized, wildflower displays within city limits (which may include the occasional milkvetch). But as a rule, var. *coachellae* populations occur well away from the urban core, or when not, they're found on residual, sandy patches of native desert (such as at the Salvation Army study site) that for some reason have escaped development.

In areas where milkvetch habitat has become fragmented and urbanized, most notably in parts of Palm Springs, Thousand Palms, and Cathedral City, the normal aeolian processes are often stymied. The negative impact this is likely to have on var. *coachellae* and other dune endemics has been addressed earlier (Griffiths et al., 2002; CVMSHCP, 2007), and indicates that the establishment of large conservation areas with contiguous, open corridors is most likely the best alternative for maintaining milkvetch populations. But remnant populations occurring outside these areas – in urban open space such as parks or along bike paths, for example, or around wind energy facilities – may also have certain conservation value, even if not specifically managed for. The data presented here suggest that var. *coachellae* is compatible with moderate levels of human-caused disturbance, which may be mimicking the natural habitat fluctuations believed to promote germination and establishment in more unspoiled environments. Even if populations end up isolated from the reserve areas described in the HCP (CVMSHCP, 2007), moderate disturbances that inhibit substrate stabilization (including trampling, biking, or limited OHV traffic) could conceivably help maintain milkvetch seed banks by promoting localized recruitment and reproduction, to the point where patches of plants might reappear at sites indefinitely even if aeolian sand transport was limited or cut off. The level and intensity of disturbance are key issues here, of course, and would need further evaluation.

Observations of Sahara mustard relative to milkvetch populations. As noted above, the Coachella Valley Multiple Species Habitat Conservation Plan designates a number of specific habitat reserves for conserving vulnerable species and their habitats. Assuming the plan is approved, this should in theory insulate var. *coachellae* (as a whole) from future urbanization. So although a few remnant populations may persist within urban settings (see above), the Coachella Valley milkvetch will evidently make its stand in the habitat reserves situated in the Snow Creek area, the Whitewater River Floodplain, the Edom Hill-Willow Hole Preserve and ACEC, and the Thousand Palms Conservation Area east of Interstate 10 (which includes the Coachella Valley Preserve populations near Indio) (see part 9.0, CVMSHCP, 2007). To quote the conservation plan (CVMSHCP, 2007), these sites were selected to safeguard "essential ecological processes" for var. *coachellae* and other taxa, in part by promoting normal "evolutionary processes and natural population fluctuations."

Regrettably, these same conservation areas also support some of the worst local infestations of Sahara mustard (*Brassica tournefortii*), an aggressive weed increasingly recognized as a serious threat to desert ecosystems across the western U.S. and Mexico (Sanders and Minnich, 2000; Trader et al., 2006; Sánchez-Flores, 2007). The wet winter of 2005 resulted in extraordinary levels of Sahara mustard germination across the Coachella Valley, demonstrating the invasive capabilities of a highly competitive exotic with a potentially massive, long-lived seed bank (Fig. 42). Even if infestations are reduced or all but disappear in intervening dry years, the seed bank ensures that mustard populations will reappear when conditions are favorable, and at a time when most native species are also germinating and attempting to reproduce. As the cycle continues, milkvetch populations and other natives (especially annuals) are eliminated or reduced by shading, competition for moisture and nutrients, lowered reproductive output (Barrows, 2005), and possibly even allelopathy (Lovett and Jackson, 1980).

So how much hard information is available regarding the threat posed by Sahara mustard? Not much at this point. The flowers are reportedly self-incompatible (Plitmann,

Fig. 42. A Sahara mustard-dominated landscape in late February, 2005. The photopoint is east of Interstate 10, immediately west of the intersection of Washington Street and 38th Avenue (west of the Mountain Vista Golf Club north of Bermuda Dunes). *Brassica tournefortii*, which comprises virtually all the green biomass in the photo (to the distant horizon), extended for thousands of acres across the refuge in 2005, often occurring as vast monocultures in areas that would have otherwise consisted of open, sandy terrain populated by native annuals and short-lived perennials. Most milkvetch plants in this part of the refuge occurred well up on the dunes in 2005 (see Figs. 14 and 20), where the loose, deeper sand seemed to check mustard establishment. On the sandy flats below, *Brassica* plants blanketed considerable habitat, including areas that presumably would have been suitable for *Astragalus* populations – this was based on the presence of scattered individual milkvetch plants in these areas, co-occurring below the mustard canopy with handfuls of other surviving natives (*Abronia*, *Oenothera*, *Camissonia*, *Baileya*, etc.). Repeated cycles of heavy mustard encroachment may eventually deplete or extirpate milkvetch populations through resource competition, shading, and other factors (see text).

1993), but since the species usually grows in large, congested populations, this is unlikely an obstacle to successful pollination. In our area, Sahara mustard flowers are readily pollinated by the feral honeybees common throughout the Coachella Valley – based on what we've learned during this study, this probably results in competition for pollinator service between var. *coachellae* and *Brassica tournefortii* wherever the species overlap. The seriousness of this problem is expected to vary considerably by population, with milkvetch plants at the weedy Coachella Valley Refuge (Fig. 42) more likely to be affected than say, those at the Garnet study site or the Windy Point population complex, where loose, shifting sand fields are more resistant to mustard encroachment.

Sahara mustard plants can range in size from a few centimeters to somewhat over a meter when reproductive, with the timing and amount of flowering and seed production dependent on substrate moisture. Seeds are hard and durable, easily dispersed (especially when senescent plants break off and tumble in the wind), and readily accumulate in the soil, making the species extremely difficult to eradicate once established. Germination is inhibited by light, yet is also restricted by even shallow burial (Thanos et al., 1991; Chauhan et al., 2006), perhaps explaining the difficulty the species appears to have in establishing on steep, active dunes. As a result, most recruitment takes place on lower dunes, coppice mounds, sandy flats, and dry washes, substrates that, while not stabilized *per se*, are better at retaining moisture at the one to three cm depth that mustard seeds prefer for germination (Chauhan et al., 2006).

When fall and early winter conditions are right, as they were in late 2004 and early 2005, *Brassica tournefortii* germinates en masse (Fig. 42). The majority of plants in these cohorts may grow for three to four months or more and produce hundreds of flowers each, only senescing as sands dry out and temperatures rise in April. In years with minimal precipitation, germination may or may not be extensive, depending on the timing and location of whatever rainfall does appear, as well as the last year the seed bank was heavily replenished. So although 2006 was comparatively a much drier year (2.18 inches of rain measured at Palm Springs from October 2005 through February 2006, compared with 12.77 inches for the same period the previous season), enough precipitation fell at the appropriate time in late fall to again initiate heavy Sahara mustard germination in many areas, an event that was probably also facilitated by the large seed crop produced the previous spring. However, a lack of follow-up precipitation in January and February resulted in considerable early mortality in 2006, with most germinants dying before attaining any significant size (Fig. 43). As a result, much of the seed bank produced in 2005 was re-invested in 2006 with little return. With this sort of boom and bust strategy, periodic high rainfall years are particularly important in maintaining year-to-year seed banks for Sahara mustard, so that even though large fractions of these are occasionally lost to inopportune germination (Fig. 43), there is enough carry-over to support future recruitment. The explosion of mustard populations around the Coachella Valley in 2005, after several years of near absence (Cameron Barrows, pers. comm.), would seem to confirm that a base seed bank sufficient enough to take advantage of infrequent wet years is now more or less permanently established.

The amount of seed produced by individual mustard plants varies tremendously. Most mature only a few hundred, although large plants are capable of producing many thousands in favorable years. In mid-March 2005, we estimated how much mustard seed was being released into milkvetch habitat in areas where Sahara mustard densities were especially high. Using the Coachella Valley Refuge (Figs. 20 and 42) for the sample area,

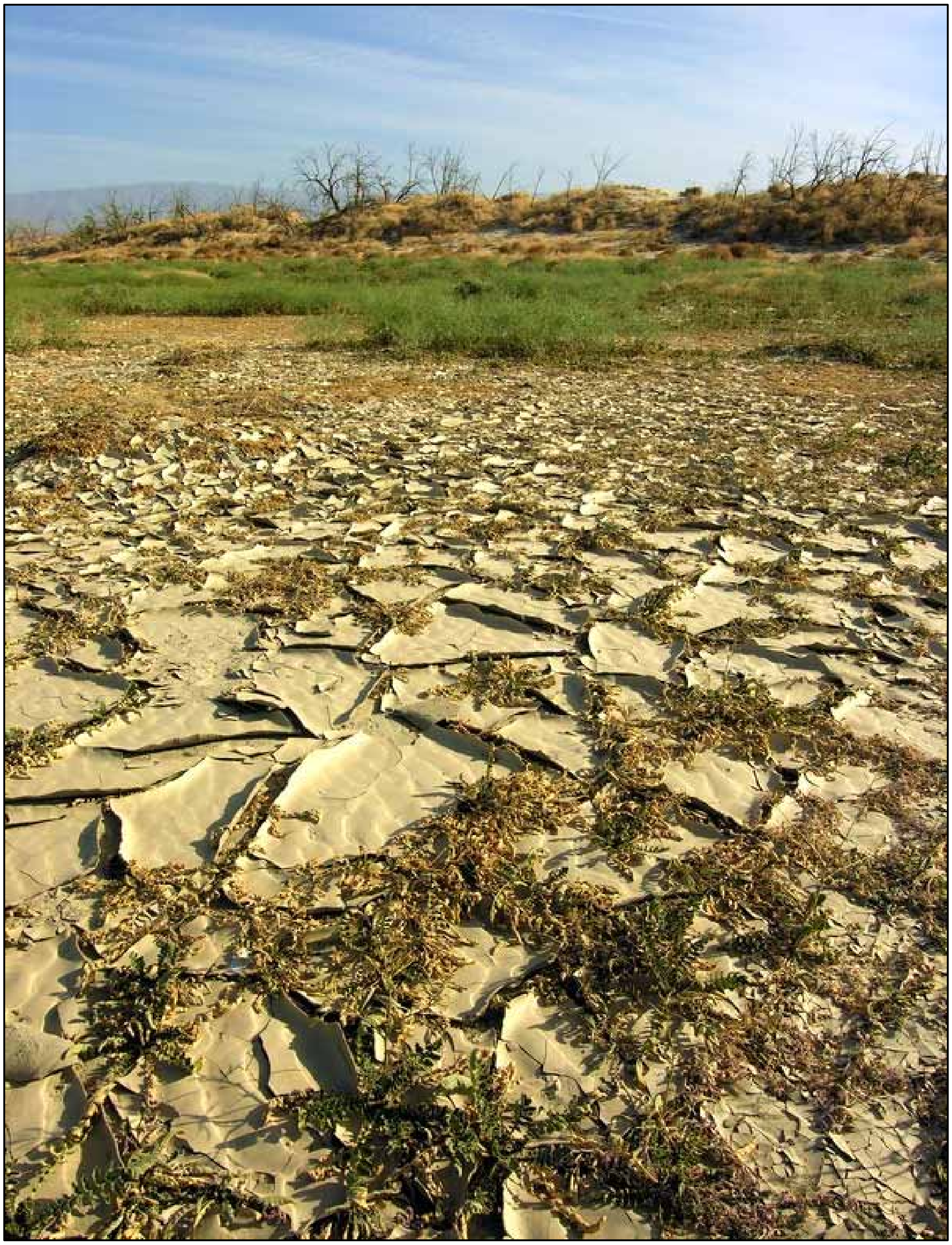

Fig. 43. Large numbers of Sahara mustard plants died without reproducing in 2006, a result of fall rains (that stimulated germination) being followed by a mid-winter drought. Although mustard seed banks are subject to rapid depletion cycles, enough seeds are produced in occasional high rainfall years to maintain a widespread, permanent presence across the Coachella Valley.

a single linear transect (32 meters long) was randomly placed within a dense patch of *Brassica tournefortii* located on a flat, sandy field just west of the Coachella Valley Refuge study site. Every other meter, the mustard plant rooted closest to the tape was measured for size and fecundity. *Plant size* was measured as an index, where the crown diameter of the plant (recorded in dm) was multiplied by the height of the main stem axis.

Fecundity was based on an estimate of the total seed crop of the plant. The exercise was repeated at roughly the same time and location in 2006, which permitted a comparison of seed production during a very wet spring versus a drier than average year.

Although the sample size was not large (counting thousands of seeds in the field was time-consuming), the data (Fig. 44) clearly show a tight positive correlation between

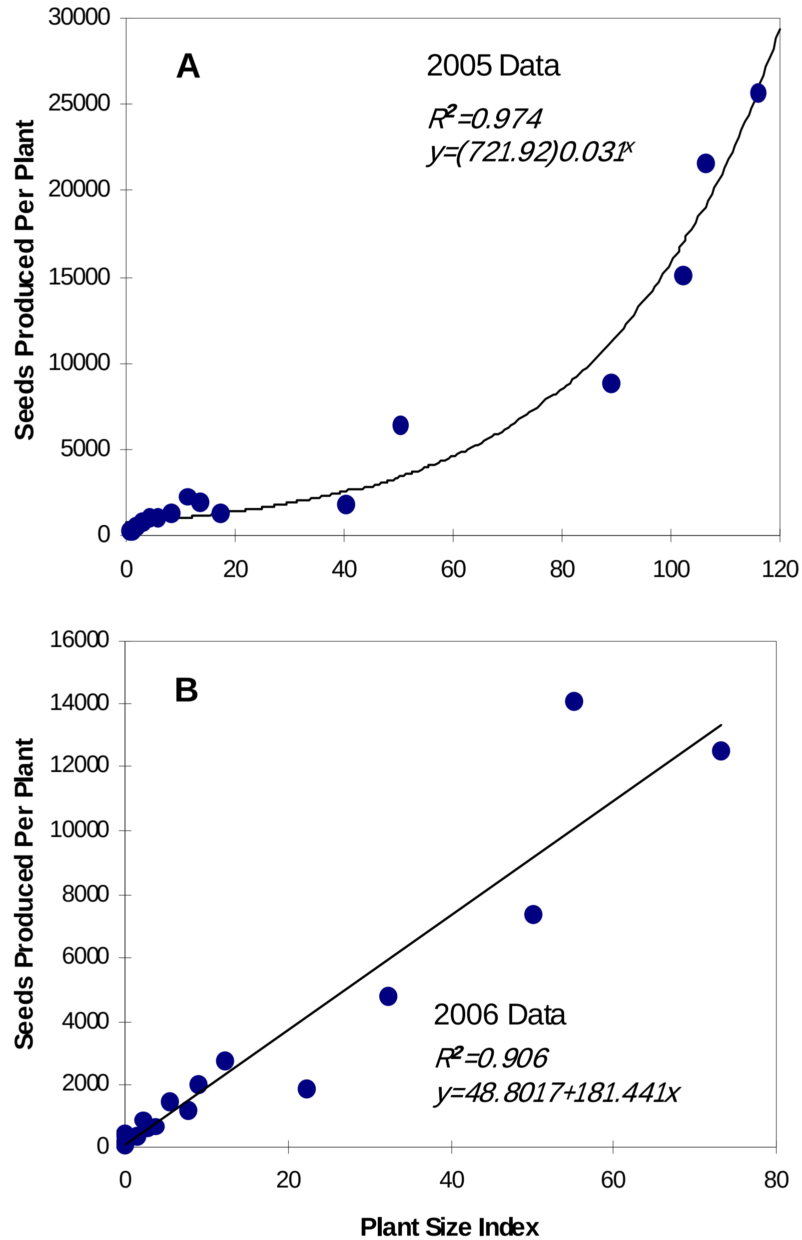

Fig. 44. A. The relationship between *Brassica tournefortii* plant size and fecundity at the Coachella Valley Refuge study site during the week of March 14th, 2005. The *size index* represents crown diameter times the length of the main stem axis (in dm). Seed production for plants under 3 dm tall was determined by a direct count. For larger plants, we randomly selected five primary branches and counted all mature fruit, and then counted all seeds in 100 randomly designated fruit. Seed production was estimated by multiplying the number of primary branches by the mean siliques per branch, and then by the mean seeds per silique. **B.** Data from the same location recorded the week of March 6th, 2006.

plant size and seeds produced. Not surprisingly, bigger plants produce more seed. In fact, in 2005 the data suggest an exponential relationship between seed production and plant size index (Fig. 44.A) – even in favorable microsites, plants that year seemed to max out at a little over a meter in height, yet they would continue to add biomass and develop increasingly congested inflorescences as long as soil moisture held out.

In 2005, the reproductive output of the largest Sahara mustard plants we sampled exceeded 20,000 seeds, though most were much smaller, with a transect mean of 5,597 seeds per plant (Table 2.). The record for seed production by a single plant is evidently much greater, however, and an exceptional individual located near Washington Street at the south end of the CV refuge was estimated to have produced about 130,000 seeds! Mustard plants at the study site were only about half as large in 2006, with an individual average seed yield of 3,193 (Table 2). Seed set data collected in 2005 are comparable to seed crops recently reported for *B. tournefortii* in other areas of the Mojave and Sonoran Deserts (Trader et al., 2006).

TABLE 2. Averages for seeds produced and plant size (= *size index*, defined in Fig. 44) along Sahara mustard sample transects in 2005 and 2006. Plants were larger and produced more seeds in 2005 than in 2006.

2005

Variable	Observations	Minimum	Maximum	Mean	Std. error
Seeds	16	192.0	25700.0	5597.5	2026.5
Size Index	16	0.9	115.8	35.7	10.7

2006

Variable	Observations	Minimum	Maximum	Mean	Std. error
Seeds	16	84.0	14100.0	3193.4	1098.9
Size Index	16	0.6	73.3	17.4	5.8

Finally, to estimate Sahara mustard density, forty one-meter^2 plots were randomly scattered in mid-March, 2005 within the area sampled for seed production (above). The number of live, reproductive plants present in each plot was recorded, without regard to plant size. Based on this sampling scheme, mean density was calculated at 10.73±0.98 (S.E.) plants per square meter. Being cool-season annuals, plants senesced and dispersed seeds in mid- to late-spring (Fig. 45).

So how much mustard seed can be released in var. *coachellae* habitat in a high rainfall year? This obviously depends on a range of local climatic and edaphic factors. However, if we assume the site we sampled is representative (and it appeared so, looking very much like the scene in Fig. 42), we conservatively estimate that in heavily infested areas, Sahara mustard populations can produce 243 million seeds or more per acre (based on 4046.85 square meters per acre *times* 10.73 plants per square meter *times* 5597.5 seeds per plant). Considering that thousands of acres at the CV Refuge were essentially covered by mustard populations in 2005, the enormity of the problem becomes evident.

Little direct work has been completed on competitive interactions between Sahara mustard and other plant species. In some initial evaluations, Barrows (2005) and Trader et al. (2006) describe reduced vigor for several Mojave Desert taxa that co-occurred with *Brassica tournefortii*, while Chauhan et al. (2006) have reported significant reductions in

Fig. 45. Density of Sahara mustard averaged 10.73 plants per square meter during our sampling at the Coachella Valley National Wildlife Refuge in 2005 (it was higher in this photo). Adult plants generally senesced in late March through early May – seeds were dispersed locally, or over longer distances if plants broke off and tumbled in the wind. Estimates in 2005 indicated that in areas with heavy concentrations of the species (as in Fig. 42), about 243 million seeds per acre may be produced (see text). There appeared to be few checks on mustard seed production in 2005, with reproductive success high (pollination was largely by honeybees) and pre-dispersal seed predation very low to non-existent (based on observations at several study sites).

crop yield on Australian farms due to Sahara mustard infestations. Although formal studies are only just getting underway, there is little doubt that *B. tournefortii* represents a serious obstacle to recovery for var. *coachellae* (and potentially other threatened dune endemics, as well).

***Ex situ* seed banking and reintroduction potential.** Augmentation of existing populations or the creation of entirely new populations (via seed sowing or outplanting) are commonly used methods in plant conservation biology (see chapters in Falk et al., 1996), and may at some point be appropriate for Coachella Valley milkvetch in certain portions of its range. Reintroduction is often viewed as a last ditch approach, commonly used in those situations where populations or species are truly threatened with extinction (Maunder, 1992; Krauss et al., 2002; Jusaitis et al., 2004). While the concept is, in theory, a simple one, many plant reintroduction projects fall well short of their objectives, and the attainment of viable, self-sustaining populations based on translocated individuals or seeding is not easily achieved. Problems typically stem from a minimal understanding of the demographic and biological requirements of most endangered plants (Pegtel, 1998; Lofflin and Kephart, 2005), combined with a lack of coordination with habitat management (Maunder, 1992).

Rare plant reintroduction work requires the use of plant materials (i.e., seeds, tubers, rootstocks, rhizomes, or cultivated plants) originating from wild populations of the target species. Rather than collect from extant populations for every project, *ex situ* seed banking offers the opportunity to gather seed during highly favorable reproductive years (such as 2005 for var. *coachellae*) and stockpile it for later use. Organizations such as Rancho Santa Ana and Berry Botanic Gardens (in Claremont, California and Portland Oregon, respectively) have freezers specifically designed for long-term storage of a wide range of native plant seed, although many academic institutions have suitable facilities for small-scale storage as well. In addition to being directly utilized in recovery efforts, stored seed can periodically be used to cultivate plants for "bulking up" seed accessions, reducing the need to repeatedly recollect from wild populations.

A critical question often asked for rare and endangered species is how much seed can be gathered in the field without adversely affecting population dynamics (Menges et al. 2004)? Seed set in many rare plant species can be severely limited, resulting from inbreeding or outbreeding depression (Fischer and Matthies, 1997; Kephart et al., 1999; Carlson, 2002), hybridization-related compatibility issues (Amsberry and Meinke, 2007), isolation and population size (Kéry et al., 2000), competition for pollination (Karron, 1987; Brown and Kephart, 1999), and other factors. If the objective is to merely collect and preserve an appropriate genetic representation, particularly for extremely rare or reproductively limited taxa, then very few seeds per population may be an adequate goal (Lawrence et al., 1995; Lawrence, 2002). But *Astragalus lentiginosus* var. *coachellae*, although local, is not extremely rare, and as pointed out earlier, plants are highly fecund despite often occurring in fragmented habitats and being poor self-pollinators – our 2005 sampling at the Windy Point, Snow Creek, and Railroad study sites estimated roughly 4.91 million seeds (after pre-dispersal predation losses) were produced by 2,870 plants. Even if we restricted seed collection to 5% of the crop of just these three populations, we would have acquired over 245,000 seeds from the 2005 season alone. Clearly, reproductive output is not a limiting factor in *ex situ* seed banking and future recovery work for var. *coachellae*.

Since ample seeds could be made available for recovery-related reintroduction work, if needed, the next step is to consider whether seed sowing or the transplanting of whole, cultivated plants would be a better option for var. *coachellae*. Arguments for and against both methods have been reviewed in other studies (Maschinski et al., 1991; Pegtel, 1998; Lofflin and Kephart, 2005; Guerrant and Kaye, 2007), but without specific field research are difficult to apply here. Using whole plants (i.e., well-rooted, pre-reproductive juveniles) could provide for immediate establishment, and eliminate the need to expose large numbers of sown seed to potential pre-recruitment mortality. Difficulties could arise, however, in terms of selecting the right microsites for transplants, as well as the logistic problem of providing irrigation if the weather turned dry at a critical time.

And work also remains to determine if large numbers of plants could reliably be grown in a greenhouse setting, a potentially problematic environment for var. *coachellae*, since even under a xeric cultivation protocol it would likely be more humid and prone to various pathogens than native conditions. *Astragalus* species also occasionally need soil symbionts for growth and reproduction (Zhao et al., 1997; Barroetavena et al., 1998), and at least one other arid dune endemic in the genus is known to require a mycorrhizal association (Rose, 1981). In *Astragalus applegatei*, an endangered species from the

Great Basin that is highly dependent on endomycorrhizae, growing plants without their symbionts was shown to be virtually impossible (Barroetavena et al., 1998).

So alternatively, if many thousands of var. *coachellae* seeds can be collected with minimal impact to wild populations, then the inevitable propagule losses associated with field sowing might be a reasonable trade-off if we can immediately create a seed bank in areas when none previously existed. One advantage to sowing is that advance knowledge of the microsite requirements of the species becomes less important, since the propagules will presumably locate these on their own (just as they would do if dispersed from wild plants). While Pegtel (1998) was dubious about generating new populations of rare species from artificially created seed banks, our experience has been that this approach can be successful (Roberts, 2003), and that most reintroduction projects that focus on sowing tend to suffer from not using enough seed (a problem we can presumably avoid in var. *coachellae*). Consider that the three sample milkvetch populations (above), with just a few thousand plants combined, produced nearly 5 million seeds in 2005, yet there is no evidence that these or comparable populations in the area are rapidly expanding (based on our 2005 and 2006 field observations; Cameron Barrows, pers. comm.; and Cox, 2005). Clearly, a large, persistent seed bank is essential for such populations to take advantage of the few patchy and unpredictable opportunities for establishment that characterize most desert habitats. It's no wonder that reintroduction attempts using small numbers of seed or other propagules often show poor or uncertain results (examples in Guerrant and Kaye, 2007).

CONCLUSIONS AND MANAGEMENT RECOMMENDATIONS

Taxonomic Evaluation

Key points. Work reported here by Knaus (2007), on the taxonomic status of var. *coachellae*, indicates the Desert Center populations of *Astragalus lentiginosus* are best treated as var. *variabilis*, a taxon otherwise known from in and north of Joshua Tree National Park. The differences between var. *coachellae*, var. *variabilis*, and related taxa are not morphologically profound, but appear consistent. On-going work by Knaus (chloroplast microsatellites and amplified fragment length polymorphisms) is expected to shed additional light on the taxonomy and phylogeny of the *A. lentiginosus* complex.

Recommendations. *Astragalus lentiginosus* var. *coachellae* should be considered endemic to the Coachella Valley and the east end of the San Gorgonio Pass. The reputed Desert Center populations, which have been widely cited in habitat planning documents (USFWS, 2005; CVMSHCP, 2007), should be excluded from conservation strategies and critical habitat designations for var. *coachellae*.

Demography

Key points. Previous reports indicating that var. *coachellae* has an adaptable life history, with annual plants dominating arid dunes to the south and perennials frequenting more mesic areas nearer the mountains, were substantiated. The distribution of var. *coachellae* appears to terminates just north of Indio, and may be restricted by yearly rainfall totals that fall below around three inches. Northern populations, benefitting from greater annual precipitation, produce more seed and are demographically more stable due to the higher proportion of perennial individuals.

Recommendations. The Conservation Areas designated in the Coachella Valley Multiple Species Habitat Conservation Plan (CVMSHCP, 2007) appropriately include sites with a demographically diverse selection of milkvetch populations. Although no genetic data are available to explain the life history differences observed within var. *coachellae*, a genetic basis for comparable developmental flexibility has been reported for other desert annuals (Fox, 1990), so it is sensible to include a wide range of milkvetch populations in protected areas. But given a choice, northern populations should be given conservation preference, due to their less transient nature (easier to delineate protective boundaries) and overall higher fecundity. Northern populations would also be the best candidates for long-term monitoring studies using population viability analysis (PVA) (Caswell, 2001), which could be potentially valuable in predicting demographic trends if habitat disturbances (i.e., OHV activity and exotic species establishment) continue to expand within Conservation Areas.

Habitat Fragmentation

Key points. While *Astragalus lentiginosus* var. *coachellae* is known from over a hundred populations (CVMSHCP, 2007), many are small, subject to disturbance, and effectively isolated by urbanization. Prior to development, var. *coachellae* would likely have existed as a series of population arrays across the valley, presumably occurring in discrete habitat patches and prone to local extinction as dune systems ebbed and flowed. Conforming to the concept of *metapopulation* (Hanski, 1998; Freckleton and Watkinson, 2002), the maintenance of such arrays, and the regional persistence of the variety as a whole, would have depended (more or less) on overall stability in patch occupancy rates, even as the patches themselves shifted in time and space.

With the advent of urbanization, habitat fragmentation has not only interrupted the aeolian sand flow that sustains dune systems, it disrupted metapopulation dynamics by blocking milkvetch migration routes. Emigration and colonization in var. *coachellae* is entirely by wind-blown seed, and plants hemmed in by housing tracts and golf courses have difficulty dispersing seeds into suitable habitats elsewhere. As a result, extinctions of milkvetch patches, whether natural or through human disturbance, can no longer be balanced by the founding of new population groups. Although we've shown that isolated milkvetch patches in fragmented habitat can still produce large quantities of seed if left unmolested, their long-term prospects are generally poor. For most of them, even if they avoid development, the important processes associated with metapopulation ecology have been irreparably altered.

Recommendations. Preserving the larger milkvetch populations that persist on administratively protected land outside the urban core areas remains the best conservation option for var. *coachellae*. Functioning metapopulations are probably present only in certain of the extended Conservation Areas identified in the draft Habitat Conservation Plan (CVMSHCP, 2007) – during our work, the population complex in the Windy Point area (west of Highway 111) seemed to be the best example.

Management of these sites with the goal of preserving their "essential ecological processes" (CVMSHCP, 2007) is essential to the self-sustainability of the taxon. At the least, this should involve (1) vigilance in assuring that migration corridors between conservation areas remain open; (2) careful regulation of unauthorized trespass (OHVs in particular); (3) establishing a program to compare disturbance levels and exotic species encroachment in conservation areas against habitat baseline data (pre-HCP, if available, or gathered as soon as possible); and (4) monitoring of milkvetch metapopulation health, using PVA or a comparable approach (see Demography section, above).

And even if most urban milkvetch populations are considered expendable by the HCP, they may still have a role to play as donors for *ex situ* seed banking efforts. Potentially cooperative landowners should be contacted to see if they would permit salvage seed collection, especially on sites slated for development, which would reduce the need to gather seed from protected areas. Agua Caliente tribal lands in the so-called "Big Dune" area near Interstate 10 would be an especially good choice, although attempts to work with the tribe during this project were unsuccessful. Hundreds of reproductive milkvetch plants were scattered here in 2005 and 2006 (observed from the streets and sidewalks bounding the property). Destruction of this population by development, before at least some of the available seeds are collected, would be a wasted opportunity.

Breeding System and Reproductive Ecology

Key points. *Astragalus lentiginosus* var. *coachellae* is largely an outcrosser, and requires insects for effective fertilization. While hand-pollination slightly improved seed set over autogamy (from roughly 2% in bagged, unmanipulated flowers to just under 15%), it never produced the high levels of pod production seen in open-pollinated plants. It is unknown if the low selfing rates have a genetic basis, or if the reproductive success of wild plants simply results from better pollination technique by bees, although mixed-mating systems based on partial self-incompatibility are known for other milkvetch species (Karron, 1987, 1989; Kudo and Molau, 1999).

Fertilization of var. *coachellae* flowers does not require native pollinators – most pollination was carried out by honeybees during this study, with fewer than 1% of floral visits by native bees. Contrary to the opinion that honeybees are poor pollinators of most native species (Westerkamp, 1991), they appeared extremely effective in fertilizing milkvetch flowers in 2005 and 2006. Whether or not this is a consistent (or desirable) trend, or if native pollinators yet play an important role in var. *coachellae* reproduction, requires further evaluation.

Recommendations. Additional surveys may help establish if native pollinators have been mostly replaced by honeybees. It is possible that native bees still frequent milkvetch populations in areas we didn't visit, or may be prevalent in different years. Since honeybees are eusocial and vulnerable to population crashes (Doebler, 2000; Oldroyd, 2007), it may be useful to know more about the status of native pollinators.

Habitat fragmentation and the suppression of metapopulation dynamics (discussed earlier) is resulting in smaller, isolated milkvetch patches, increasing the potential for inbreeding depression as increased geitonogamy and mating with close relatives occurs. Although little can be done about this problem in terms of practical management, it is another argument in favor of maintaining large, contiguous population reserves as advocated in the HCP (CVMSHCP, 2007).

In some mixed-mating milkvetch species, where flowers are at least moderately autogamous (*A. applegatei* in Oregon, for example), bagging racemes when in early bud has been a productive method for gathering seed, by helping to exclude ovipositing seed predators and increasing seed yield. However, since var. *coachellae* flowers rarely self-pollinate, they are unable to produce much seed when flowers are bagged. As a result, bagging inflorescences for seed collection should only be attempted after fruits are forming.

Seed Production

Key points. Coachella Valley milkvetch populations produce more seed in wet years than in years with below average precipitation, particularly in populations with a high proportion of perennials. As with most legume species, populations require a seed bank to persist. Plants are also are capable of long-distance dispersal via anemochory, a key feature in establishing new populations. During this study, an "average" milkvetch plant dispersed roughly 1,700 viable seeds in 2005, suggesting that harvesting a small percentage of seeds for use in *ex situ* seed banking or other recovery work would not negatively impact populations.

However, pre-dispersal predation was shown during our work to reduce potential seed crop yield in var. *coachellae* by over 70%. Post-dispersal predation and general herbivory also affected fecundity, though to a much lesser degree. Although seed loss to predators is common among the Fabaceae (Auld, 1983), its impact is probably magnified when the host-predator equilibrium, established through co-evolution, is disrupted by anthropogenic factors that may also lessen seed production (such as habitat modifications from development or competition with invasive exotics). As a result, even though a few hundred reproductive milkvetch plants can disperse a million or more seeds annually, the post-dispersal fate of those seeds is now far less certain than it would have been prior to settlement times. And with most development in the valley rather recent (at least from the standpoint of a plant species with a long-lived seed bank), the degree to which predation and habitat modifications may be interacting to suppress seed production below normal levels has yet to be fully appreciated.

Recommendations. Despite not knowing how much new seed is needed each year to replenish and maintain seed banks in var. *coachellae*, it would be irresponsible not to move forward with a seed collection program considering the immediate threats facing most populations. We advocate an aggressive agenda to comprehensively collect seed from multiple populations across the valley. At least some seed from each locality should be collected and kept separate along maternal lines. However, a larger quantity could also be bulked (by population), with the goal of amassing a significant quantity of mixed parentage seed for use in sowing projects or experiments. Assuming permission is obtained, initially collecting from private or other unprotected lands is recommended (as discussed earlier under Habitat Fragmentation). An inventory of milkvetch populations on property scheduled for development should be maintained, if possible, and a protocol developed that prioritizes collection sites based on population quality and construction timetables. Where possible, collections should be emphasized in wet years. Seed should be stored at the Rancho Santa Ana repository, or a comparable CPC-affiliated facility.

Seed type (Thompson, 1987) and field observations clearly support the presence of dynamic seed banks in var. *coachellae*, yet overall, there is little empirical evidence available to evaluate them. Quantifying the seed bank is especially important in areas that have been hardest hit by disturbance. Although we don't have any baseline data to assess how these areas may have changed since substrates were stabilized or Sahara mustard arrived, we can at least compare the less disturbed habitats (such as the Windy Point metapopulation, for example) with heavily impacted areas. Topics for investigation might include (1) contrasting the number of *Astragalus* versus exotic propagules in the sand; (2) assessing genetic diversity levels present in milkvetch seed banks at different populations; (3) correlating annual germination and recruitment with factors such as precipitation and associate vegetative cover; and (4) evaluating the germinability of seeds occurring in stabilized habitat, versus shifting dunes and sand fields, versus moderately disturbed areas (do some types of sites limit or facilitate seed coat scarification, thereby affecting germination opportunities?).

Substrate Disturbance Ecology

Key points. While heavy disturbance may destroy or seriously impact milkvetch populations (see Groom et al. [2007], regarding the effects of OHV traffic on *Astragalus magdalanae* var. *peirsonii*), light disturbance may actually promote recruitment and seed production. Establishment of first-year reproductive plants was shown to benefit from, or at least be compatible with, modest levels of artificial disturbance (i.e., trampling, biking, light OHV traffic, etc.), which may mimic the natural substrate instabilities that appear to promote germination in more pristine environments. Higher amounts of seed may be produced per unit area in lightly disturbed habitat versus other areas. This effect may be particularly important for stagnant populations that mostly occur in urban settings, where substrates have begun to stabilize and sand transport is compromised due to habitat fragmentation.

Recommendations. Excessive ground disturbance (e.g., braided road complexes resulting from heavy and repeated OHV use) that results in widespread destruction of established plants is a serious threat to milkvetch populations, and should be discouraged. However, recreational activities at moderate levels, particularly if focused (i.e., scattered trails, bike tracks, occasionally used access roads, etc.), do not constitute a significant threat. For instance, extrapolating from data gathered at the four study sites, milkvetch populations occurring on wind energy facilities are probably not impacted by the level of disturbance necessary to maintain turbines, and may very well benefit from it in areas where substrates have been previously compacted during construction. The wind farms near Garnet (Fig. 6) provide a working example of where development and long-term milkvetch conservation are probably compatible.

As discussed earlier, fragmented populations in urban areas may have value in the short-term (before their habitat is developed) as seed donors for future reintroduction and recovery efforts. Moderate disturbances at such sites (for example, the tracks and trails scattered across the "Big Dune" area owned by the Agua Caliente) may actually increase milkvetch seed crops, by slowing or reversing the trend towards substrate stabilization

Considering that Sahara mustard, Russian thistle, and other exotics are similarly attracted to disturbed areas (Malusa et al., 2003), the direct use of disturbance as a tool to improve *Astragalus* habitat or enhance populations should be approached with caution. It may be appropriate as a temporary fix in some cases, where small populations in urban settings are being drastically reduced due to substrate stabilization or competition, and where weeds are already widespread anyway. But using disturbance as a means of habitat enhancement should be applied only on a small scale, and in conjunction with strong weed control measures.

Exotic Species

Key points. Sahara mustard (*Brassica tournefortii*) is the primary threat to remaining Coachella Valley milkvetch populations, including all of those within the conservation areas identified in the HCP. In 2005 and 2006, it was quantitatively and visually dominant at all study sites (with the possible exception of the Windy Point series of populations). *Brassica* populations regenerate from long-lived seed banks that respond to winter precipitation (Trader et al., 2006). Estimates during our study showed that billions of mustard seeds were added to seed banks within milkvetch population areas after the wet winter of 2004–05. Sahara mustard is well entrenched in the Coachella Valley and is unlikely to be eradicated.

Recommendations. Reducing or locally eliminating mustard infestations from milkvetch habitat should be a top priority, although it is probably not feasible without considerable resources. Biocontrol is not an option, since there are too many economically important crop plants in the genus *Brassica* grown in California. Herbicide application has drawbacks as well, as it would be difficult to target mustard populations without impacting the many native species struggling to persist in the same areas. However, the use of herbicides to knock out large infestations, even if some natives are lost, may be preferable to continuing to allow the steady build-up of massive seed banks, as occurred in 2005 (Fig. 42).

Hand-pulling (before seed release) may be the most feasible control approach, yet would be expensive and require a long-term commitment, since mustard seed banks are well established and keeping target areas cleared would be an annual challenge. Considering the magnitude of the problem, the most feasible option may be to prioritize the highest quality *Astragalus* populations (such as the plants on the shifting sand fields near Garnet, the metapopulation northwest of Windy Point, and elements of the Snow Creek complex), where mustard populations are presently less vigorous, and aggressively work to keep those areas from deteriorating further. Land managers should also consult annually with state and federal agencies, the California Invasive Plant Council, and academic groups (e.g., the Holt Lab in the Dept. of Botany and Plant Sciences, UC-Riverside) to keep abreast of current thoughts on dealing with Sahara mustard.

Reintroduction as a Recovery Strategy

Key points. Population augmentation or creation is a commonly used method for stabilizing declining species. For this approach to work, enough seeds or other propagules must be available in the wild to permit at least limited collection. *Astragalus lentiginosus* var. *coachellae* produces enough seed to support an *ex situ* storage program, which could be used to explore the potential for greenhouse cultivation and outplanting as a recovery option. Reintroduction level cultivation protocols for var. *coachellae* have not yet been established, and may require knowledge of soil symbionts (probably endomycorrhizae) to be successful.

Recommendations. Reintroduction of var. *coachellae* is considered unnecessary at this time, based on the number of extant populations on various administratively protected sites. However, populations are expected to continue to decline, in response to further development and increased competition with exotic species. Research focusing on cultivation requirements would therefore be useful, to ensure that transplant stock could be created if needed. Towards this end, a range-wide seed collection program should be implemented now (discussed earlier), to facilitate greenhouse research and to develop a genetically diverse store of seeds for possible recovery work in the future.

SUGGESTED FUTURE STUDIES

- Develop a disturbance index for all populations on public or otherwise conserved lands, to help prioritize population and habitat quality
- Conduct a range-wide evaluation of the role that disturbance plays in facilitating milkvetch population maintenance, with a focus on how and where particular types of disturbance may impact specific life history phases
- Explore the use of directed disturbance as a recovery tool in augmenting stagnant populations or re-establishing extirpated populations, focusing on areas becoming stabilized by weed encroachment or urbanization
- Develop a seed collection plan for var. *coachellae*, that (1) takes into account the potential genetic composition of accessions, (2) determines whether or not 5% of a seed crop is a reasonable collection goal, and (3) attempts to organize a seed salvage program, emphasizing populations on land slated for development
- Evaluate the potential competitive effects of Sahara mustard on recruitment and reproduction in var. *coachellae* populations, including the relative germination phenology of the two species, the potential for pollinator competition, and any evidence for allelopathy
- Determine whether and where native pollinators still play a meaningful role in milkvetch reproduction, and estimate how seed production in var. *coachellae* might be affected if honeybee populations crashed
- Establish baseline data on the genetics, ecology, and size of milkvetch seed banks, including how mustard infestations may be affecting seed bank dynamics
- Investigate factors related to successful cultivation of var. *coachellae*, including possible mycorrhizal relationships
- Assess the feasibility of mass production of Coachella Valley milkvetch plants, for use in possible reintroduction work at a later date

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