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Lake Mead National Recreation Area Vegetation Monitoring and Management: Year-End Progress Report, October 1, 2006 to September 30, 2007

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YEAR-END PROGRESS REPORT
University of Nevada, Las Vegas
Time Period: October 1, 2006 to September 30, 2007

Cooperative Agreement Number  H8R07060001
Task Agreement Number  J8R07060011
Lake Mead National Recreation Area
Vegetation Monitoring and Analysis

Executive Summary

- The Weed Sentry program surveyed more than 750 miles of federal lands in Clark County for invasive, exotic plant species.
- Weed Sentry also removed more than 600,000 individual invasive plants from federal lands. These removals represent pro-active efforts that may have forestalled large infestations difficult and costly to eradicate.
- In response to a request by the manager of the Fish and Wildlife Service Desert National Wildlife Refuge, a major effort of surveying springs for plant community composition and invasive plants provided unique knowledge services by the Weed Sentry program. No such baseline information existed for the Sheep Range. This knowledge service and extensive roadside surveys were provided on the refuge.
- Monitoring protocols were developed by Research Assistant Dianne Bangle, a botanist, for key rare plant species. These protocols were implemented, and meet technical requirements for county Multiple Species Habitat Conservation Plan (MSHCP) funding.
- Preliminary plot sampling was conducted, and a proposal for the Federal Highways Administration was prepared in collaboration with ATR Alice Newton to guide ecological restoration efforts of gypsum habitat at Lake Mead.
- A nationally competitive Joint Fire Science grant ($179,000) was secured to support efforts in this Task Agreement to provide knowledge services to resource managers for mitigating community invasibility. ATR Alice Newton was the federal cooperator on this grant and made a major contribution to the proposal.

Program Activities

The task agreement was awarded to UNLV on October 1, 2006. This report covers the period October 1, 2006 to September 30, 2007. The following activities have been conducted toward meeting or exceeding deliverables in the statement of work.

Invasive Plant Monitoring and Treatment (Weed Sentry Program)

Research assistants in the Weed Sentry Program are tasked with mapping and treating incipient populations of exotic species on targeted federal lands throughout Clark County. Surveying activities for invasive species that took place from October 1, 2006, to September 30, 2007, are
divided into sections by federal agency, and are summarized in Table 1. More than 750 miles and 5,500 acres were surveyed for exotic, invasive species during this period. This effort was clearly an interagency effort, with at least 30 miles being surveyed on lands of each of the four federal agencies—NPS, Bureau of Land Management (BLM), U.S. Forest Service (USFS), and U.S. Fish and Wildlife Service refuge (USFWS). The Weed Sentry Program also submits trip reports to federal managers that show maps of where exotic species occur, estimate which species are likely to be most problematic, and provide recommendations for treatment. These trip reports were sent to managers shortly after a given area was surveyed to provide timely, up-to-date information.

**Table 1. Summary of miles and acres surveyed, Weed Sentry Program, October 1, 2006-September 30, 2007, by federal agency.**

<table>
<thead>
<tr>
<th>Agency</th>
<th>Miles</th>
<th>Acres</th>
</tr>
</thead>
<tbody>
<tr>
<td>National Park Service</td>
<td>484</td>
<td>3573</td>
</tr>
<tr>
<td>Bureau of Land Management</td>
<td>84</td>
<td>655</td>
</tr>
<tr>
<td>Forest Service</td>
<td>34</td>
<td>252</td>
</tr>
<tr>
<td>Fish and Wildlife Service</td>
<td>155</td>
<td>1207</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>757</td>
<td>5687</td>
</tr>
</tbody>
</table>

**A. Locations surveyed: National Park Service**

Surveys on land managed by the NPS occurred in the following locations: Lakes Mead and Mohave shorelines, approved roads along the Northshore Road, approved roads near Nelson, approved roads surrounding Cottonwood Cove, approved roads surrounding Temple Bar, and approved roads south of Willow Beach in both Arizona and Nevada.

**B. Locations surveyed: Bureau of Land Management**

Surveys on BLM holdings were scaled back to include only the areas around Searchlight based on guidance provided by the BLM Weed Manager, Las Vegas Field Office. Surveys were also limited due to lack of precipitation.

**C. Locations surveyed: Forest Service**

Areas surveyed on USFS lands included the Cold Creek area, Highway 157, approved roads on the south side of the Spring Mountains, and new trail systems.

**D. Locations surveyed: Fish and Wildlife Service**

Surveys on the Desert Range National Wildlife Refuge included Alamo Road and its tributaries, Mormon Well Road, Pine Nut Road, and many backcountry areas surrounding Hayford Peak.

**E. Small Incipient Population Treatment**

In addition to surveying, the Weed Sentry staff are tasked with treating upon discovery (often hand pulling) small, incipient populations of invasive plants. This represents a pro-active effort to remove invasive species before they become larger infestations and, therefore, increasingly costly and difficult to eradicate. During the term of the task agreement, a total of 652,516
individual invasive plants were removed by Weed Sentry staff from federal lands in Clark County. These removals are summarized by agency lands in Tables 2-5 below.

Table 2. Number of individual invasive plants removed, Weed Sentry Program, October 1, 2006-September 30, 2007, National Park Service lands.

<table>
<thead>
<tr>
<th>Species</th>
<th>Number of Plants Treated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avena fatua</td>
<td>658</td>
</tr>
<tr>
<td>Brassica tournefortii</td>
<td>632,460</td>
</tr>
<tr>
<td>Bromus tectorum</td>
<td>46</td>
</tr>
<tr>
<td>Lepidium latifolium</td>
<td>134</td>
</tr>
<tr>
<td>Malcolmia africana</td>
<td>5</td>
</tr>
<tr>
<td>Nerium oleander</td>
<td>5</td>
</tr>
<tr>
<td>Nicotiana glauca</td>
<td>6</td>
</tr>
<tr>
<td>Parkinsonia aculeata</td>
<td>8</td>
</tr>
<tr>
<td>Pennisetum setaceum</td>
<td>176</td>
</tr>
<tr>
<td>Sisymbrium irio</td>
<td>1,214</td>
</tr>
<tr>
<td>Sisymbrium orientale</td>
<td>9</td>
</tr>
<tr>
<td>Tamarix aphylla</td>
<td>1</td>
</tr>
<tr>
<td>Tamarix ramosissima</td>
<td>147</td>
</tr>
<tr>
<td>Tribulus terrestris</td>
<td>46</td>
</tr>
<tr>
<td>Washingtonia filifera</td>
<td>130</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>635,045</strong></td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Species</th>
<th>Number of Plants Treated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brassica tournefortii</td>
<td>3</td>
</tr>
<tr>
<td>Parkinsonia aculeata</td>
<td>1</td>
</tr>
<tr>
<td>Peganum harmala</td>
<td>289</td>
</tr>
<tr>
<td>Solanum elaeagnifolium</td>
<td>1</td>
</tr>
<tr>
<td>Tamarix ramosissima</td>
<td>3</td>
</tr>
<tr>
<td>Tribulus terrestris</td>
<td>3,292</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3,589</strong></td>
</tr>
</tbody>
</table>

Table 4. Number of individual invasive plants removed, Weed Sentry Program. October 1, 2006-September 30, 2007, on Forest Service land.

<table>
<thead>
<tr>
<th>Species</th>
<th>Number of Plants Treated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marrubium vulgare</td>
<td>672</td>
</tr>
<tr>
<td>Sorghum halepense</td>
<td>4</td>
</tr>
<tr>
<td>Tamarix ramosissima</td>
<td>1</td>
</tr>
<tr>
<td>Tribulus terrestris</td>
<td>13,151</td>
</tr>
<tr>
<td>Verbascum thapsus</td>
<td>2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>13,830</strong></td>
</tr>
</tbody>
</table>
Table 5. Number of individual invasive plants removed, Weed Sentry Program, October 1, 2006-September 30, 2007, Fish and Wildlife Service land.

<table>
<thead>
<tr>
<th>Species</th>
<th>Number of Plants Treated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bromus diandrus</td>
<td>1</td>
</tr>
<tr>
<td>Bromus tectorum</td>
<td>6</td>
</tr>
<tr>
<td>Centaurea melitensis</td>
<td>42</td>
</tr>
<tr>
<td>Descurainia sophia</td>
<td>3</td>
</tr>
<tr>
<td>Sisymbrium irio</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>53</strong></td>
</tr>
</tbody>
</table>

The map (Fig. 1) on the next page shows the general locations of where Weed Sentry activities occurred in Clark County.
Fig. 1. Locations of Weed Sentry surveys in Clark County, October 1, 2006-September 30, 2007. The tracklog represents GPS routes of surveys along roads and trails.
The Weed Sentry program also provides knowledge services in addition to baseline weed mapping. These knowledge services include, for example, studies of community invasibility and assessments of treatment effectiveness. These other knowledge services are equally as important as mapping is for ecologically based exotic plant management, and are documented in later sections of this report.

**Sahara Mustard Research**

Research assistant Dianne Bangle submitted a manuscript for review to the peer-reviewed journal Western North American Naturalist in March 2007 and awaits reviewer’s comments. The title for this manuscript is: “Seed germination in the Mojave Desert invasive plant *Brassica tournefortii* (Sahara mustard).”

Ms. Bangle has completed three *B. tournefortii* experiments (seedpod/resource filling; effectiveness of herbicide on seed development; rosette reburial in sand dune habitat) and started a fourth experiment, (self-pollinating study). The self-pollinating experiment was not completed, but was attempted four different times this past year. Ms. Bangle has evaluated the causes of each failure and is confident the experiment will be completed this winter. A fifth experiment (seed burial/longevity) was postponed from last quarter, but is scheduled for the coming year.

**Survey for effect of Brassica tournefortii on plant community composition**

Cayenne Engel conducted a plant community assessment on April 3, 2007 to investigate the impact of Sahara mustard on native plant species (particularly native annual establishment). Transects were established along a plant density gradient of *B. tournefortii* in an early successional community at a restored landfill site west of the NPS plant nursery. Data indicate a negative relationship between *B. tournefortii* and the dominant native annual *Phacelia crenulata*. This was the strongest relationship among species within this site, and no other species had a negative relationship with *B. tournefortii*. However, density of *Chaenactis fremontii* was positively related to density of *B. tournefortii*. The presence of *B. tournefortii* did not affect community diversity or richness at this site.

**Rare Plant Monitoring and Research**

**Monitoring and mapping of shoreline populations of rare plants**

New monitoring protocols were implemented in the spring of 2007 for the four MSHCP covered species (*Arctomecon californica*, *Anulocaulis leiosolenus*, *Eriogonum viscidulum*, *Astragalus geyeri* var. *triquetrus*). All newly implemented protocols include randomization in positioning sampling units as well as good interspersion of sampling units throughout the population.

**Sticky buckwheat**

Three macroplots (50 × 100 m) were randomly placed in high density sticky buckwheat habitat along the Overton Arm of LMNRA. Five 100 m transects were laid out at each 10 m interval within each macroplot starting at high water and running perpendicular to the shoreline for 100 meters. Twenty plots (1 × 1m) were placed along each 100 meter transect in 5 meter intervals.
Data collected from these transects included: associated plant species, cover estimates of all plant species occurring within plots, threats, disturbance (type, amount, possible cause), and number of sticky buckwheat plants and their specific locations.

Data were entered into an excel spreadsheet, and frequency, species richness, and relative cover analyses were performed (Figures 2-5, Table 6) with the intention of running more detailed analyses after consultation with a UNLV statistician. The data show that exotic plant species occur more frequently within the monitored areas and suggest that as relative cover of exotics increases, natives including *Eriogonum viscidulum* decrease. Consecutive years of data will provide further information and more detailed analyses.
Figure 2. Number of plant species in each of five frequency classes based on percentages of occupancy of 100, 1-m² plots. These patterns suggest that within these communities a few species are dominant whereas most species are uncommon to rare. The dominant species in all three plots was the exotic species *Schismus arabicus* occurring in 74-93% of plots. The rare plant *Eriogonum viscidulum* occurred in 10, 12, and 33% of plots monitored.
Figure 3. Relative frequency of natives versus exotic species at each of three monitoring sites. Data are shown as percentages of occurrence in 100, 1-m² plots.

Figure 4. Relative cover of natives, exotics, and *Eriogonum viscidulum*. Data are presented as a percent of total per macroplot.

Table 6. Species richness at three *Eriogonum viscidulum* monitoring sites. Data are presented at plot, transect, and site levels.

<table>
<thead>
<tr>
<th>AREA</th>
<th>MACROPLOT 1</th>
<th>MACROPLOT 2</th>
<th>MACROPLOT 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plot</td>
<td>0.0001 (1 m³)</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Transect</td>
<td>0.04 (400 m²)</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td>Site</td>
<td>1 (10,000 m³)</td>
<td>24</td>
<td>24</td>
</tr>
</tbody>
</table>
Figure 5. Distribution of *Eriogonum viscidulum* along each of five transects within Macroplot 3. Distribution patterns support previous observations that this species repopulates overtime from plants occurring above high water down to exposed sandy areas towards the shoreline.

**Ervi locations - Macroplot 3**

![Graph showing the distribution of *Eriogonum viscidulum* along five transects within Macroplot 3.](image)

**Threecorner milkvetch**

Eight 20 × 20 m grid plots were randomly placed in key areas on the dunes at Sandy Cove in historically high density threecorner milkvetch areas. Quadrats (5 × 5 m) were laid within the grid and data collected included presence/absence for spatial patterning, plant species composition, an estimate of cover for each species, disturbance, threats, and target species counts and specific locations. Data from the 2007 season have been entered into an Excel spreadsheet and preliminary analyses are completed (Figures 6 and 7, Table 7). Data show that within the study area, native species have higher cover than exotic species. Consecutive years of data will provide additional information and more detailed analyses.

Habitat monitoring in select years is recommended for tracking changes in sand dune stabilization by invasive species such as *Schismus arabicus*, *S. barbatus*, *Brassica tournefortii*, and *Salsola tragus*. Habitat monitoring could also include monitoring sand movement on the dunes.
Figure 6. Relative cover of natives, exotics, and Astragalus geyeri var. triquetrus. Data are presented as a percent of the total across all eight grids at Sandy Cove.

Figure 7. Distribution map for Astragalus geyeri var. triquetrus showing slight clumping. Data shown are from Grid 6 (area = 400m²).
Table 7. Species richness within *Astragalus geyeri* var. *triquetru* monitoring plots on Sandy Cove. Data are presented at cell, grid, and site levels.

<table>
<thead>
<tr>
<th>Area (ha) m²</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell 0.0025 (25 m²)</td>
<td>14</td>
<td>8</td>
<td>7</td>
<td>6</td>
<td>9</td>
<td>10</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Grid 0.04 (400 m²)</td>
<td>33</td>
<td>22</td>
<td>26</td>
<td>19</td>
<td>27</td>
<td>24</td>
<td>21</td>
<td>19</td>
</tr>
<tr>
<td>Site 0.32 (3200 m²)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>72</td>
<td></td>
</tr>
</tbody>
</table>

**Monitoring and mapping of populations of other rare plants**

**Las Vegas** bearpoppy and ringstem
A stratified random approach to monitoring two rare plant species (bearpoppy and ringstem) was implemented this year. Three sites (Echo Wash, Road 100, and Rainbow Gardens) were chosen for annual monitoring. Within each site, disturbance trails (burro trails, ORV tracks, and drainages) were walked with a GPS unit collecting track log data. Random points were generated along these track lines using GIS software. Four 20 × 20 m plots divided into four 10 × 10 m quadrats were established at each site. Data gathered included plant community composition and cover, number and location of LV bearpoppy and ringstem individuals, as well as disturbance and invasive species threats. Data from the 2007 season have been entered into an Excel spreadsheet and preliminary analyses are completed (Figures 8, 9, Table 8). The data show that Road 100 has the highest occurrence of exotic species and that Rainbow Gardens and Echo Wash had little or no exotic species within the monitoring plots. Exotic species do occur outside the study area and remain a threat to both rare plant species.

Table 8. Species richness in monitoring plots across three sites based on mean species densities in quadrats, per plot, and per site.

<table>
<thead>
<tr>
<th>Average species richness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area ha (m²)</td>
</tr>
<tr>
<td>quadrat 0.01 (100 m²)</td>
</tr>
<tr>
<td>plot 0.04 (400 m²)</td>
</tr>
<tr>
<td>site 0.16 (1600 m²)</td>
</tr>
</tbody>
</table>
Figure 8. Distributions of *Arctomecon californica* and *Anulocaulis leiosolenus* var. *leiosolenus* at Road 100 monitoring site (plot 1).

Figure 9. Relative cover of exotics, natives, and two rare plant species (*Arctomecon californica* and *Anulocaulis leiosolenus* var. *leiosolenus*) as a percent of the total across three monitoring sites.
Anulocaulis leiosolenus *phenological study*

D. Bangle and C. Engel designed a monitoring strategy for vegetative and reproductive phenological development of *Anulocaulis leiosolenus* var. *leiosolenus* (sticky ringstem). Observations are conducted on 21 individuals at each of three sites in the rare plant habitat in the vicinity of Northshore Road. Monitoring is designed to follow the development of the plants from the rosette stage through bolting, flowering, and fruit development. Plants are observed weekly when populations are in the vegetative rosette stage, and twice a week when individuals within the populations flower. Plant phenological stage and floral phenological stage are recorded. Data collected to date have been entered into Excel spreadsheets. Data collection is expected to continue throughout the summer and fall in concordance with the flowering period of *A.I. leisolenus*.

To date, we have observed a significant amount of chewed or broken stems across all three sites. We suspect rabbits are impacting this species, but the degree of impact is unknown. It is possible that a field camera placed on site may provide answers concerning the routine loss of ringstem reproductive branches.

**Herbarium**

The new herbarium cabinet arrived in the third quarter of this year and a good portion of time was spent re-organizing specimens from the previous two cabinets to the current three cabinets. Dividing the specimens between the three cabinets will likely help in the preservation of the plant specimens housed in the Lake Mead study collection herbarium as they are no longer overcrowded on each shelf. Plant collection and identification occurred this past year with approximately 75 plants identified. Of these plants, one new grass species (*Crypsis schoenoides*-Muddy-Virgin Rivers confluence) was added to the LMNR A plant species checklist and two additional grass species (*Koeleria macrantha*, and *Elymus trachycaulus ssp. trachycaulus*-Shivwits Plateau) were collected for the first time. Assistance was provided to the weed sentry and EPMT groups with plant identifications. Assistance was also provided to the wildlife division for plant identification from the Snowy Plover (Nevada State bird species of concern) site near the confluence of the Muddy and Virgin Rivers and the Las Vegas Springs Preserve.

**Conservation Planning and Monitoring Technical Assistance for Rare Plants**

Ms. Bangle communicated via phone and email correspondence with BLM botanist Christina Lund and USFWS Fred Edwards in the third quarter to discuss the Nevada State listing of *Eriogonum corymbosum* var. *nilesii* and future conservation efforts. They agreed that survey effectiveness would be increased by conducting helicopter aerial surveys in prime habitat areas over NPS and BLM lands. Ms. Bangle proposed the aerial survey to the LMNRA management staff on 9/18/2007 to obtain permission to fly over designated wilderness areas. Surveys are scheduled to take place in late October (based on the species flowering phenological stage) after compliance and flight plans are complete and filed. A NPS letter of support was prepared in support of listing this rare species on the Nevada State list of protected species.

Ms. Bangle attended the Nevada Rare Plant Meeting held in Las Vegas at the Barrick Museum on the UNLV campus on April 3-4, 2007. She reported on the status of rare plants at LMNRA including a new addition to the NNHP watch species list *Lorandersonia salicina*. 
All members of the UNLV vegetation group attended a rare plant meeting on April 25, 2007 in St. George, Utah, which included presentations on dwarf bear poppy and Holmgrens milkvetch.

A meeting with a county representative (Sonja Kokos) on May 18, 2007 was attended by Ms. Bangle and Dr. Scott Abella concerning county funding for rare plant monitoring projects. Research assistant Bangle attended the Lower Colorado River Terrestrial and Riparian Biology Meeting on January 24, 2007. The meeting focused on past, present, and future research concerning biota that occur along the Lower Colorado River.

**Cattle Cove Eriogonum viscidulum exclosures**

Ms. Bangle assisted ATR A. Newton and P. Baird (Cultural) in the Lime Cove area to familiarize them with the plant *Eriogonum viscidulum* and its habitat. She flagged locations for temporary placement of cattle exclosures, which were installed the following week.

**Mapping and treatment of invasive plants:**

*Brassica tournefortii* was re-located at the Overton Arm rare plant site which supports the rare plant *Eriogonum viscidulum* (sticky buckwheat). All *B. tournefortii* plants found within the initial infestation area were removed totaling 3,059 plants. Additional surveys were conducted throughout *E. viscidulum* habitat and five additional *B. tournefortii* infestations were mapped. This information was passed on to Carrie Nazarchyk and a weed crew was sent to the site where an additional 19,265 plants were removed. (Surveys and initial weed removal were conducted by Ms. Bangle and Jessica Spencer).

**Training and professional development:**

Research assistant Bangle attended the Motorboat Operator Certification Course (MOCC) held from March 12-16, 2007. This course enables individuals (for work-related purposes) to operate watercraft for the National Park Service, Department of the Interior. The course provided students with motorboat handling techniques and knowledge of safe operation utilizing the rules of the road, emergency operations/self rescue, and night operation. Coursework included both practical (on the water) and lecture sessions. A passing score on both the practical and written test was required for certification.

Research assistant Dianne Bangle received informal training on decontamination procedures for NPS boats that may transport Quagga mussels from contaminated areas to uncontaminated areas, and subsequently, decontaminated two NPS boats.

Research assistant Dianne Bangle completed a graduate-level course titled Restoration Ecology for 3 credit hours. The course focused on the science of restoring damaged ecosystems as well as, theoretical and applied restoration ecology in a variety of ecosystems. Ms. Bangle is currently attending a graduate level course titled ‘Biostatistics Methods for public health’ for 3 credit hours.
Weather Stations at Rare Plant Sites

Weather station data were collected at LV bearpoppy sites by research assistants Jessica Spencer and Dianne Bangle. Ms. Bangle met with a NPS data manager for instruction on the completed weather database. Weather data were summarized from all remaining sites (Figures 10, 11, Tables 9, 10). Dr. Abella, Alice Newton, and Ms. Bangle agreed that dismantling some of the weather stations was acceptable due to malfunctions and difficulty in accessing sites. Ms. Bangle is researching new weather stations and is summarizing the results of her research to present to NPS for purchase. The new weather stations will be more advanced models and will ideally be capable of direct satellite transmission of data, which will eliminate the possibility of losing data because of malfunctions. Seven rare plant sites (supporting the 4 MSHCP covered species) are proposed for the new weather station locations.
Figure 10. Rainfall data gathered at six *Arctomecon californica* sites in 2006. Rainbow Gardens showed consistently higher rainfall July through August. Sunrise Hills weather station was dismantled in April 2006.

![2006 Rainfall across sites](image)

Figure 11. Rainfall data gathered at six *Arctomecon californica* sites in 2007. Again, Rainbow Gardens showed consistently higher rainfall April through August.

![2007 Rainfall across sites](image)
Table 9. Temperature from 2006 at select *Arctomecon californica* sites.

<table>
<thead>
<tr>
<th>Site</th>
<th>Max of Temp</th>
<th>January</th>
<th>February</th>
<th>March</th>
<th>April</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>August</th>
<th>September</th>
<th>October</th>
<th>November</th>
<th>December</th>
</tr>
</thead>
<tbody>
<tr>
<td>BitterSprings</td>
<td>Max of Temp</td>
<td>34.48</td>
<td>40.04</td>
<td>35.78</td>
<td>50.94</td>
<td>57.4</td>
<td>53.13</td>
<td>0</td>
<td>0</td>
<td>48.09</td>
<td>42.19</td>
<td>38.29</td>
<td>27.25</td>
</tr>
<tr>
<td></td>
<td>Min of Temp</td>
<td>-4.58</td>
<td>-0.89</td>
<td>-0.41</td>
<td>6.77</td>
<td>10.92</td>
<td>18.57</td>
<td>0</td>
<td>0</td>
<td>11.82</td>
<td>7.38</td>
<td>-3.79</td>
<td>-3.38</td>
</tr>
<tr>
<td>BluePoint</td>
<td>Max of Temp</td>
<td>0</td>
<td>0</td>
<td>35.73</td>
<td>53.13</td>
<td>61.29</td>
<td>65.59</td>
<td>0</td>
<td>60.85</td>
<td>62.37</td>
<td>53.35</td>
<td>0</td>
<td>24.49</td>
</tr>
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Table 10. Temperature from 2007 at select *Arctomecon californica* sites.

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**Additional Rare Plant Research and Surveys**

A draft version of data-sharing protocols for rare plants and animals within LAME was written by GIS staff with assistance from Ms. Bangle and NPS wildlife staff this past year.

Ms. Bangle has written a research proposal for *Anulocaulis leiosolenus* var. *leiosolenus* (ringstem), which will be expanded after attending the Clark County sponsored rare plant workshops.

Several surveys of the Overton Powerline Road were conducted in order to evaluate any specific potential damage or destruction of rare plants and rare plant habitat during replacement of the powerline. Data were also gathered on several uncommon plant species (in addition to several rare plant individuals) likely to be destroyed, with intentions of coordinating efforts with Lake Mead nursery staff for plant salvage or at least minimal seed collection before construction begins. A report was prepared outlining each survey and recommendations concerning rare plant and weedy species.

Research assistant Bangle and three members of the Lake Mead nursery crew spent three days surveying rare plant sites and select high diversity areas for habitat conditions on the Shivwits Plateau.

**Gypsum Soil Seed Bank Assay**

Originally intended as a graduate student project, we collected soil seed bank samples from 10 sites in gypsum habitat. These samples were started in the UNLV greenhouse in May, and monitoring is ongoing. To date, two *Phacelia* species have emerged, and other species of interest have been detected.

**Technical Assistance/Synergistic Work**

*A. Community invasibility experiment*

Maintenance of this experiment at the landfill near the NPS nursery has been conducted primarily in the form of weekly water application and periodic mortality monitoring. Unfortunately, plant survival has been much lower than was hoped for using the transplants, so we must decide whether to terminate or continue this project.

*B. Desert burn revegetation*

A site on the BLM Goodsprings burn was visited for post-planting monitoring and assessment on April 9, 2007. At this time, Ms. Engel took pictures of each of the plants for foliar cover estimation and a live plants status report, replaced any broken or missing plant shelters and re-seated any disturbed driwater applications. Mortality appears to have been very heavy, most likely due to record-high temperatures and no precipitation since the planting.
C. **Springs Rana onca habitat restoration project (Jef Jaeger, PI)**

At the request of NPS ATRs Kent Turner and Alice Newton, as well as wildlife PI Dr. Jef Jaeger, we established plant community monitoring plots and protocols to investigate the response of plant community composition to vegetation removal at Rogers Spring and Blue Point Spring. The vegetation removal was conducted in an effort to create better habitat for the relict leopard frog (*Rana onca*). We participated in all aspects of the vegetation manipulation including placement of plot locations, pre-treatment data collection, participating in and oversight of the physical vegetation removal, and we are currently planning for the ongoing monitoring (approximately four times annually) of these plots. We established 148, 0.5-m² plots (60 at Blue Point Spring, 88 at lower Rogers Spring) for plant community monitoring. Within each of these plots we monitored for plant species composition January 30-31, 2007. We then clipped and collected the plant biomass February 2-3 and 6, 2007. Biomass samples have been weighed and data entered at UNLV with the help of two research assistants under the guidance of Dr. Jaeger. Ms. Engel will run statistical analyses comparing the clipped and control plots and analyze the data for variation in site responses. Plant community composition was assessed again on May 1-2, 2007, with a third monitoring scheduled for mid-October, 2007. We will continue monitoring the response of the plant communities including species abundance and rate of regrowth, with emphasis on encroachment of any exotic species.

D. **Germination studies for species common to gypsum soil habitats**

Dr. Abella and Ms. Engel initiated investigations into the germination ecology of species common to the gypsum soils in LMNRA. C. Engel collected seeds periodically throughout May and June for use in germination trials to be conducted in the germination chambers at NPS headquarters and at UNLV. To date, germination trials of *Aristida purpurea, Astragalus prussii, Enceliopsis argophylla, Malcomia africana, Phacelia crenulata, Plagarto ovata,* and *Pleuraphis rigida* have been conducted. We are testing several temperature and light combinations to find out which conditions are most preferable for the germination of each species. Information gained from these investigations will aid studies of rare plant seed banks and be useful in revegetation with the restoration necessary for the Northshore Road realignment. Trials will be continued in upcoming months as space in the growth chambers becomes available. Each trial runs for two to three weeks.

E. **Cattle Cove Eriogonum viscidulum exclosures**

S. Abella and C. Engel accompanied several NPS employees (including ATR A. Newton) and a volunteer who installed fencing for cattle exclosures along the sandy shore at Lime Cove on the Overton branch of Lake Mead on May 20, 2007. The fencing is designed to exclude cattle from patches of dense *E. viscidulum*. C. Engel monitored the plots for *E. viscidulum* abundance and disturbance on one date, and performed statistical analyses on the compiled data for the park fencing personnel.
F. Northshore Road realignment project

On June 13, 2007, Ms. Engel and ATR Newton accompanied three NPS and FHA representatives involved with restoration plans and funding of the Northshore Road realignment to scout all construction sites and discuss plans for restoration in conjunction with the Northshore Road realignment.

The Weed Sentry crew, along with input from ATR Newton, Dr. Abella, and Ms. Bangle, created a proposal for research to be conducted relating to restoration of gypsum habitat with the Northshore Road realignment. We propose to research methods of plant establishment (including transplanting container plants and seeding), the role of biological soil crusts in plant re-establishment, methods for storage and establishment of biological soil crusts, and fertile island establishment. Much of this research will be performed prior to the obliteration of the current Northshore Road such that the research can then inform managers about the most effective restoration practices to implement.

We will also assess small mammal populations and conduct insect surveys (requested by ATR Newton) to better understand the ecological systems in these unique gypsum soil habitats. Additionally, we will characterize the existing soil seed bank to investigate which seeds we can expect to be redistributed with the topsoil salvage that will take place with the construction. We will be collecting seed bank samples in early October, 2007. At that time we will also collect soil samples for analysis of soil characteristics which may help inform best restoration practices. To date, we have established 23, 10 × 10 m plots along the length of the path scheduled for realignment. Within these plots we assessed the density of shrubs and perennial plants to provide target plant species and densities in our plant establishment trials. ATR Newton requested a line item budget on the estimated direct expenses we will request from FHA related to the various projects related to the gypsum research. Ms. Engel and J. Spencer have provided technical assistance to Tracy Cudworth, NPS landscape architect, by performing analyses of the proposed Northshore realignment route to determine how often and where construction machinery will need to be cleaned to prevent transfer of weeds along the realigned road corridor.

G. Nevada Test Site FACE site seed bank sampling

On May 7, 2007, members of the UNLV vegetation group, together with ATR Newton, sampled soil seed banks with Stan Smith at his long-term FACE site on the Nevada Test Site. These samples were started on the UNLV greenhouse on May 9, 2007, and monitoring is ongoing.

H. Teaching

As part of his joint appointment with UNLV School of Life Sciences, Dr. Abella completed teaching BIO 420x/730A (Restoration Ecology) this spring. This course was attended by 36 students, including several members of the NPS and UNLV vegetation groups. Extra-credit field trips were run on Lake Mead NRA land (e.g., native plant nursery) and on BLM land to provide students exposure to these agencies.
I. Red Rock Canyon post-fire monitoring

As part of interagency work in collaboration with Christina Lund, BLM botanist, monitoring of 20 plots was conducted on the Loop Fire. Sixty plots were established, but not yet monitored, on the Goodsprings Fire, which also was seeded by BLM.

J. Microsite invasibility study

Weed Sentry staff initiated a study considering the invasibility of native desert shrubs. This study was designed to determine whether certain dominant plant species are stronger facilitators of weed invasion than others. This year, four focal species within undisturbed sites and seven species installed in a post-fire restoration planting were assessed for invasibility. In the future, it is expected that additional species and habitat-types will be added to the study.

K. Fish and Wildlife Service springs

The Weed Sentry program is designed to be responsive to the needs and requests of resource managers. At the request of the FWS refuge manager, who wished to assess the condition of springs (including exotic invasive plants), Weed Sentry staff sampled springs and seeps within Desert National Wildlife Refuge for plant community composition and the presence of weeds. Further information regarding vegetation change at the springs will be gathered using historic photos and repeat photography. This spring surveying was a large effort that involved visiting more than 15 springs in remote terrain, providing the first inventory of its kind in the Sheep Mountain range at lower elevations.

L. Las Vegas Wash

At the request of ATR Alice Newton, UNLV provided a monitoring protocol to assess the success of revegetation on a bank stabilization project mandated by the Army Corps of Engineers. This mitigation project is detailed in “Proposed compensatory mitigation plan NV LAME 1 (5a). It is expected that UNLV will be involved with analysis of monitoring data in future years.

M. Cacti poaching

The NPS vegetation manager is interested in the status of natural barrel cacti populations and possible increased mortality rates in cacti included in a poaching prevention project previously implemented within LAME. Jill Craig conducted initial assessments of the condition of more than 100 PIT tagged cacti. Additionally, assistance with gathering baseline population data was provided by developing a demographic/ plant association study of barrel cacti populations within the park. It is expected that the study will be initiated early in the next quarter.

N. Pipeline restoration research project

We finished data collection and installation of permanent plots to monitor plant community and soil changes on a water pipeline right-of-way through Lake Mead NRA. This project was
requested by ATR Alice Newton and had substantial involvement from her in the participation of a research protocol and analysis mechanisms as well as participation in the presentation of results in publications. A presentation on this work was delivered during a Southern Nevada Restoration Team field workshop, and a manuscript has also been submitted for review to a peer-reviewed journal:


O. Plant salvage

With substantial involvement from ATR Newton in the form of directly participating in methods, organization of personnel, and coordinating the NPS nursery, we performed a significant plant salvage in Las Vegas Valley, which took place on a privately owned site with permission of the land owner. Dr. Abella initially located the site and contacted the owner. The site is for sale and will likely be developed soon. Using a Nevada Conservation Corps crew coordinated by ATR Newton, we salvaged ~ 1,000 purple three awn (Aristida purpurea) and deergrass (Muhlenbergia rigens) plants, along with seed, which were transported to the LAME nursery. A second salvage conducted December 18, 2006, is estimated to have recovered more than 1,000 plants with a total of nine species. This salvage unfortunately had only mixed success, as a phenology study of several of the salvage species (such as purple three awn) should be undertaken.

P. Las Vegas Valley grassy remnant vegetation assessment

Also with support and substantial involvement from ATR Newton, we sampled three 0.25-ha plots on remnant grassy sites in the Las Vegas Valley. One of the sites was the plant salvage site noted above. The purpose of this assessment was to document vegetation on these unique sites before they are destroyed, to identify additional species for salvage, and to make herbarium collections for both the Lake Mead and UNLV herbariums. About 40 plant species were on each plot and provided our research assistants with a unique opportunity to become familiar with some species they had not seen before.

Q. Disturbance project set up – not completed

A deliverable in the Task Agreement was to provide technical assistance to NPS ATR Newton for establishing a road disturbance project through MSHCP funding. Dr. Abella provided suggestions for study design, and set up a meeting with UNLV engineering for suggestions on designing a traffic counter. NPS has not received MSHCP funding to initiate this project, so, in consultation with NPS, no further technical assistance was provided for this project.

R. Other

Dr. Abella was invited by the University of Leuven (Belgium) to serve on a review panel for internal funding proposals, which was completed in April 2007.
He also reviewed manuscripts for Forest Ecology and Management, Soil Science Society of America Journal, Diversity and Distributions, and other journals.

Dr. Abella reviewed the Environmental Assessment for BLM-Parashant for a proposed forest thinning and spring restoration project on Upper Langs Run Watershed.

On May 3, 2007 J. Spencer with Dr. Abella had a media event “photo shoot” for UNLV Magazine on the plant salvage work that has been undertaken in Las Vegas Valley. These plants have been used for restoration experiments at Lake Mead and on BLM land, and have had substantial involvement from ATR Newton. She also attended the photo shoot on May 3. A popular article about the project has been produced by UNLV media.

**Papers Published/Submitted**

*Papers that were previously submitted during prior work that were published or accepted this year:*


Manuscripts from previous work submitted for review this year:


Manuscripts from this Task Agreement submitted this year:

Abella, S.R. A systematic review of burro grazing effects on Mojave Desert vegetation, USA. Environmental Management (in review).

Internet publication detailing plant salvage work:


Funding Proposals

Two competitive grants submitted this year were not funded:

Abella, S.R. Where have the native species gone? A pilot study to develop techniques for reconstructing historical vegetation change in southern Nevada. Competitive President’s Award, University of Nevada Las Vegas, Las Vegas, NV. $49,999. (not funded).
Another competitive grant was funded:

Abella, S.R., S.D. Smith, A.C. Newton, and C.L. Lund. 2007. Revegetating burned arid lands: identifying successful native species using trait and competition analysis. Joint Fire Science Program, Manager’s Request, competitive grants. $179,000. (This project is being conducted at the NPS Lake Mead nursery facility, with substantial involvement from ATR Alice Newton for experimental planning).

Presentations

Earlier this year, Dianne Bangle was invited to present summary information about two rare plant covered species, sticky buckwheat and threecorner milkvetch, at the Lower Colorado River Terrestrial and Riparian Biology Meeting on January 24, 2007. The title of the presentation is: “Status assessment of sticky buckwheat and three-corner milkvetch within Lake Mead NRA.”

Dr. Abella was invited to present a systematic review of burro grazing effects on Mojave Desert vegetation at the Society for Range Management annual meeting in Reno on February 15, 2007. The symposium was titled: “Ecology and Management of Wild and Non-Native Equids.”

Dr. Abella was the second author of a presentation at the 2007 annual conference of the Ecological Society of America/Society for Ecological Restoration about modeling patterns of community composition with structural equation modeling. This presentation won the E.C. Pielou award for statistical ecology.

Cayenne Engel submitted an abstract for the 9th biennial Conference of Research on the Colorado Plateau taking place in Flagstaff, AZ on October 29-November 1, 2007. The poster presentation topic will be interpreting patterns of invasive species richness in ponderosa pine forests around Flagstaff, AZ.

Ms. Engel also collaborated with ATR Newton to submit an abstract to the same conference for a project status presentation on gypsum restoration at Lake Mead.

Dr. Abella submitted an abstract, which was co-presented with ATR Newton, on a systematic review of the effectiveness of planting and seeding in the Mojave Desert for the Colorado Plateau Conference.

From previous work, but linked to revegetation efforts at Lake Mead and by BLM in Red Rock Canyon, Dr. Abella submitted an abstract to the Colorado Plateau Conference to present the outcome of a 28-species revegetation seeding on a Sonoran Desert burn. This abstract was submitted in collaboration with a resource manager (John Gunn) with the Maricopa County Parks and Recreation Department and with NAU researchers.

In October 2006, Dr. Abella was selected as a Distinguished Alumnus-In-Residence to deliver three invited seminars to faculty and students at Grand Valley State University in Michigan (see below). He also participated in a day-long field trip to Midewin National Tallgrass Prairie (U.S. Forest Service, near Chicago, Ill.) with a 20-member student chapter of the GVSU Soil and
Water Conservation Society. This trip included three hours of volunteer work collecting seed for prairie restoration, and a tour of the 18,000-acre preserve.


Abella, S.R. Lessons learned: reflections from the field of a 2000 NRM alumnus. Invited presentation to NRM 150 [Introduction to Natural Resources] class, Grand Valley State University, Allendale, MI. 19 October 2006.


**Agency Meetings/Training Attended/Professional Development**

- Meeting with BLM botanist Christina Lund, USGS researchers Leslie DeFalco, Todd Esque, and Sara Scoles, and weed sentry representative Cayenne Engel on July 31, 2007 to coordinate research on burned BLM lands and to discuss their upcoming herbicide and outplanting experimentation.
- National Park Service monthly staff meetings consistently attended by PLI staff.
- Annual National Park Service retreat attended by all staff.
- Attended desert restoration seminar conducted by David Bainbridge on July 16.
- Operational risk management training July 17 (Weed Sentry staff).
- Mojave Network Inventory and Monitoring meeting (all staff).
- UC Davis Weed Science School: September 24 – September 26 (Cayenne Engel, Jessica Spencer).
- Coordination meeting with Christina Lund, BLM botanist, about Weed Sentry staff activities and fire monitoring, September 19, 2007 (Cayenne Engel, Scott Abella)
- Jill Craig completed CPR and Basic First Aid Training, NPS Motorboat Operator Certification Course (and a supplemental Heavy Weather Boating Course), and Tortoise Training. She also completed the online training: Orientation to the Privacy Act, Records Management Awareness, and Discrimination and Whistleblowing in the Workplace (No Fear).
- In March 2007, Jill Craig and Cayenne Engle attended a Watercraft Inspection and Decontamination class which discussed the current threat of Quagga Mussels within LAME NRA.
- Jill Craig attended the joint annual conference of the Ecological Society of America and the Society of Ecological Restoration in San Jose, CA. Many informational workshops were attended at the conference, including: Demography and Dispersal: Analyzing Invasion Wave Speeds, Book Publishing for Ecologists, and What Editors Want: Advice for Submitting your Manuscript. Alex Suazo also attended and presented at this conference.
• Jill Craig also defended her M.S. thesis at the University of Wisconsin on December 6, 2006.
• Carrie Nazarchyk and Jessica Spencer attended the California Invasive Plant Council Conference held October 4-6, 2006, in Rohnert Park, Calif.
• Scott Abella attended the UNLV workshop “Publish and Flourish” in January 2007.
  - Southern Nevada Restoration Team (SNRT), October, 28, 2006. Attended by Carrie Nazarchyk and Scott Abella.
  - BLM and FWS (2 separate meetings), October 30, 2006. The purpose of these meetings was to coordinate Weed Sentry activities on BLM and FWS land. Attended by Carrie Nazarchyk, Scott Abella, and Jill Craig.
  - Dianne Bangle attended a one-day course at UNLV titled “Time Management for Professionals” on April 13, 2007.
  - Dianne also attended a “Desert Survival” class offered by NPS on May 30, 2007.
• All members of the UNLV vegetation group attended a rare plant meeting on April 25, 2007 with NPS ATR Alice Newton in St. George, Utah, which included presentations on gypsum restoration, dwarf bearpoppy, and Holmgrens milkvetch.

Attachments

Appendix 1: Manuscript using Weed Sentry data that was submitted to the journal Environmental Monitoring and Assessment for review in August, 2007.
Appendix 2: Manuscript co-authored by NPS ATR Alice Newton documenting results of a pipeline restoration project, submitted for review to the journal Crossosoma in December 2006. During the writing of this report, we learned that the manuscript is accepted pending satisfactory revisions and scheduled for an October 2007 issue of the journal.

Submitted by:

Margaret N. Rees, Principal Investigator

09/30/2007  Date
Assessing an Exotic Plant Surveying Program in the Mojave Desert, Clark County, Nevada, USA

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Abstract Exotic species threaten native ecosystems and can reduce services that ecosystems provide to humans. Early detection of incipient populations of exotic species is a key step in containing exotics before explosive population growth and corresponding impacts occur. We report the results of the first three years of an exotic plant early detection and treatment program conducted along more than 3000 km of transportation corridors within an area > 1.5-million ha in the Mojave Desert, USA. Incipient populations of 44 exotic plant species were mapped using global positioning and geographic information systems. *Brassica tournefortii* (Sahara mustard) infested the most (47%) of 256 soil types surveyed in the study area, while *Nicotiana glauca* (tree tobacco) and others currently occupy less than 5% of soil types. *Malcolmia africana* (African mustard) was disproportionately detected on gypsum soils, occurring on 59% of gypsum soil types compared to 27% of all surveyed soils. Gypsum soils constitute unique rare plant habitat in this region, and by conventional wisdom were not previously considered prone to invasion. While this program has provided an initial assessment of the landscape-scale distribution of exotic species along transportation corridors, evaluations of both the survey methods and the effectiveness of treating incipient populations are needed. An exotic plant information system most useful to resource mangers will likely include integrating planning oriented coarse-scale surveys, more detailed monitoring of targeted locations, and research on species life histories, community invasibility, and treatment effectiveness.

Keywords Distribution · Invasibility · Landscape · Mapping · Monitoring · Roads · Transportation corridor
1 Introduction

Exotic species in general are threats to native ecosystems and to ecosystem services provided to human societies (Higgins et al. 1999; DiTomaso 2000). For example, *Tamarix ramosissima* (saltcedar) invasion of riparian areas in the western United States often depresses plant diversity (Busch and Smith 1995). Dense stands of this deep-rooted exotic tree with high leaf area also can usurp more water than native riparian vegetation of lower leaf area, reducing available water for native wildlife and for human populations in the arid West (Shafroth et al. 2005). Estimated economic impacts of exotic *Tamarix* species to agriculture and other resource values in the western United States range from $133-285 million (1998 U.S. dollars) annually (Zavaleta 2000). Another example is the establishment of exotic annual grasses (e.g., *Bromus rubens* [red brome]) in western deserts, which has fueled wildfires not thought to have been prevalent before invasion (D’Antonio and Vitousek 1992). These wild fires kill long-lived native plants such as *Yucca brevifolia* (Joshua tree), increase soil erosion, reduce air quality, threaten or burn human habitations, and may cost millions of dollars to attempt to suppress (Brooks and Pyke 2001).

As opposed to attempted eradication of established populations, preventing undesired exotic species from arriving to an area in the first place is considered the most economical and ecologically viable means for limiting exotic species impacts (Moody and Mack 1988; Davies and Sheley 2007). Prevention is not currently completely feasible, however, because expanding human populations in the arid West increase dispersal vectors and disturbance, combined with “natural” dispersal mechanisms such as water, wind, or animals (Rejmánek 1996). Furthermore, Levine et al.’s (2004) meta-analysis found little evidence that any native ecosystem can completely repel invasion given intense propagule pressure from potential invaders. Failing prevention, the next most cost effective and feasible strategy is the early detection and treatment
of exotic species populations when they are still small (Davies and Sheley 2007). Exotic species frequently exhibit a lag time between introduction and the occurrence of explosive population growth and corresponding impacts (Hobbs and Humphries 1995). However, treating exotic species populations during this lag time requires that the species are first detected and mapped (Dewey and Andersen 2004; Underwood et al. 2004; Barnett et al. 2007).

We document an early detection system, known locally as the “Weed Sentry” program, operating in Clark County, Nevada, USA, in the Mojave Desert. This program presupposes that knowing the exotic species present in an area and their distribution is an important step for forestalling widespread infestations and for developing a long-term exotic species management plan. While this program recognizes that not all potential exotic invaders will have large impacts, not all invaders may be able to be stopped, and that ideally more research would be available on invasion ecology in this region, this program assumes that “doing nothing” or waiting for more research violates precautionary principles (Underwood 1997). Thus, this program detects and facilitates the eradication of small, incipient exotic plant populations to make every attempt, in accordance with precautionary principles, to preclude additional widespread infestations. The Weed Sentry program is implemented by the University of Nevada Las Vegas through a cooperative agreement with the U.S. National Park Service, and operates on an interagency basis on federal lands in southern Nevada managed by the National Park Service, Bureau of Land Management, Fish and Wildlife Service, and the Forest Service. We report the first three years of exotic species survey data collected by this program, assess methods and assumptions of the program, and suggest future work for advancing exotic species information systems in this region.
2 Materials and Methods

2.1 Study area

Clark County, Nevada is in the eastern Mojave Desert and encompasses a wide elevational range from 137 m near the Colorado River to 3634 m in the Spring Mountains (Lato 2006; Fig. 1). Precipitation varies sharply from year to year, with long term (1937-2006) averages of 11 cm/yr at 662 m elevation in the city of Las Vegas (Western Regional Climate Center, Reno, Nevada, USA). High temperatures average 14°C in January and 41°C in July. At a shorter term (2005-2006) weather station in the county at a higher elevation of 2195 m in Kyle Canyon of the Spring Mountains, annual precipitation ranged from 35-60 cm, average January high temperatures from 7.6-8.3°C, and average July high temperatures from 29-30°C (Doug Merkler, U.S. Natural Resources Conservation Service, unpublished data). Predominant plant communities from low to high elevation include *Larrea tridentata* (creosote bush) desert scrub, *Coleogyne ramosissima* (blackbrush) shrubland, *Pinus-Juniperus* (pinyon-juniper) woodland, and higher elevation *Pinus ponderosa* (ponderosa pine) or mixed conifer forest (Rowlands et al. 1982). More than 1.5-million ha of federal land reside in Clark County, including Lake Mead National Recreation Area (National Park Service), Desert Range National Wildlife Refuge (Fish and Wildlife Service), Spring Mountains National Recreation Area of the Humboldt-Toiyabe National Forest (Forest Service), and Bureau of Land Management holdings. Human visitation is intense on some of these federal lands. For example, an average of nine million people visited Lake Mead National Recreation annually between 1995-2006 (Inside National Park Service, Washington, D.C., USA). Las Vegas, the largest metropolitan area in Clark County, experienced an 83% population growth from 1990-2000, which was the most rapid growth of any U.S. metropolitan...
area during that time period (Perry and Mackun 2001). By 2006, Las Vegas contained an estimated 1.8 million people (Southern Nevada Regional Planning Coalition 2006).

2.2 Field procedures

More than 3000 km of roadsides, trails, and shorelines (Lakes Mead and Mohave, formed when the Colorado River was dammed) were surveyed by vehicle, on foot, or by boat in a 35-month period from 2003-2006 (Table 1, Fig. 1). Roads, trails, and shorelines were chosen as survey areas because it was believed these areas would serve as establishment points and dispersal corridors (Tyser and Worley 1992; Gelbard and Belnap 2003; Hansen and Clevenger 2005).

Survey routes and exotic plant species were recorded using a Global Positioning System (GPS) tracklog in 0.16 km (0.1 miles) increments along roadsides, and in approximately the same increments along irregularly shaped shorelines or trails. Thus, this systematic approach to surveying recorded both species presence and absence, which permits distinguishing between unsurveyed area and true absences at the time of surveying (Barnett et al. 2007). In road surveys by vehicle, both sides of the road were surveyed up to 10 m away from the road edge. This distance was chosen for practical reasons as approximately the greatest distance that surveyors could see and identify plant species. Driving speeds during roadside surveys were approximately 5-15 km/hour. The approximate number of plants of each species in each 0.16 km increment was categorized as <10, 10-100, 101-1000, and >1000 individuals. Unknown plant specimens were collected, pressed, and identified by a botanist. To correspond to periods of active growth for most species, surveys were conducted in fall, winter, and spring in lower elevation desert areas and in spring and summer in higher elevation forests. However, the presence of dead annual species also was recorded for enhancing species detection in dry years or if the period of active growth was missed by surveys. A priori species targeted to look for during surveys were
those suggested by federal land managers in Clark County, state noxious weed lists (Nevada, and
the neighboring states of Arizona, California, Utah, and New Mexico), and weed lists from the
five counties adjacent to Clark County. New species were added to the survey list as they were
detected during surveys. Some exotic species known to occur in Clark County were not
surveyed for because they are ubiquitous in much of the county (e.g., *Bromus rubens*, *Schismus*
spp. [Mediterranean grass]), and, therefore, were not considered relevant to the early detection
focus of the program. Other species (e.g., *Erodium cicutarium* [filaree]) that were not thought to
have high invasive or impact characteristics also were not surveyed. Nomenclature and
classification of species by lifeform and nativity follow USDA NRCS (2007).

2.3 Data analysis

Data were downloaded from GPS units into a database and viewed using a Geographic
Information System. To evaluate species distributions among soil types, we obtained digital data
from soil surveys of Clark County (Bagley 1980; Lato 2006). These surveys typically classified
soils to the association (Lato 2006) or series levels (Bagley 1980). We totaled the number of
kilometers of roadsides, trails, or shorelines on which exotic species were detected in each soil
taxonomic unit and computed the average number of species occurrences per kilometer in each
soil type. Soils classified as “badlands” were included. We descriptively assessed relationships
between species occurrences and soil types, elevation, and the presence or absence of gypsum
(defined as soils containing >5% gypsum in the upper 15 cm of soil according to the published
soil surveys). To evaluate which soil types may be most infested, we calculated the mean
number of species occurrences per kilometer surveyed for each soil type.

3 Results and Discussion
3.1 Survey coverage and conditions

Surveying of more than 3000 km crossed more than 250 soil types (Table 1). Survey coverage was extensive, with most backcountry roads (dirt and gravel surface) being surveyed at least one or two of the three survey years (Fig. 1). Freeways and other high-speed roadways, however, were not surveyed due to safety concerns about a need to travel sufficiently slow to identify species. Annual precipitation during a five-year period encompassing the survey period varied nearly six-fold from 34 to 182% of the long-term average (Table 1). This high inter-annual variation, typical of the Mojave Desert (Rowlands et al. 1982), can have a major effect on plant recruitment, particularly for annual plants where germination and abundance are closely linked to precipitation (Beatley 1974).

3.2 Species distribution and frequency

Occurrences of several of the 15 most frequently encountered species (of 44 total survey species) were related to elevation (Table 2). For example, the only detected occurrences of *Nicotiana glauca* (tree tobacco) and *Lepidium latifolium* (tall white top) were below 915 m, while *Sisymbrium altissimum* (tumblemustard), *Bromus diandrus* (ripgut brome), and *Descurainia sophia* (herb sophia) exhibited their most occurrences/km at elevations above 1830 m. Other species, such as *Hordeum vulgare* (common barley), *Sisymbrium orientale* (Indian hedgemustard), and *Bromus tectorum* (cheatgrass) occurred across a broader range of elevations. With an average of 1.3-1.6 occurrences/km, *Brassica tournefortii* (Sahara mustard) was the most frequently detected species below 915 m elevation. It is important to remember that the nearly ubiquitous *Bromus rubens* and *Schismus* spp. were not surveyed and thus are not included in species frequency rankings.

3.3 Soil relationships
Few relationships between soil types and exotic species distributions were evident. For example, *Brassica tournefortii* occurred on 91% (41/45) of soil types in the <610 m elevation belt for soil types where ≥ 1 km were surveyed. Occurrences per kilometer showed no trend to vary predictability among soil types. The major soil survey in Clark County (Lato 2006) is an order 3 survey, which is relatively coarse, so it may not capture environmental heterogeneity of specific exotic species establishment points. Differences in exotic species establishment can occur on microscales in the Mojave Desert, such as between openings and below shrubs only a few meters apart (Brooks 1999). Soils could be related to exotic distributions if soils serve as an “environmental filter” regulating where species can establish based on species tolerances or dispersal, or if disturbance is correlated with soil types (DeFarrari and Naiman 1994; Stohlgren et al. 1999). However, establishing species-soil relationships would be difficult for most species in our data set, as 59% (26/44) of surveyed species occurred in 2% or fewer (≤ 5/256) soil types. We cannot distinguish whether these species are incapable of growing on other soil types or if propagules have simply not arrived on other soil types.

*Malcolmia africana* (African mustard) was an exception to the trend of species in our data set showing little relationship to the coarse-scale soil survey. This annual forb occurred on more than twice as many gypsum soil types than expected based on its distribution among all soil types (Fig. 2). *Malcolmia africana* is not restricted to gypsum soils, as we recorded it in 50 non-gypsum soil types, consistent with Van Buren and Harper (2003) who recorded the species on limestone and other soils containing <1% gypsum in southwestern Utah. Since many of *M. africana*’s occurrences were near the border of southwestern Utah in northeastern Clark County (Fig. 1), where gypsum soils also are concentrated, it cannot be ruled out that this species’ distribution is correlated with the geographic proximity to other populations that may have
expanding. Regardless, *M. africana*'s preponderance on gypsum soils is a concern because these soils harbor several low-elevation rare plant species such as *Arctomecon californica* (Las Vegas bearpoppy; Meyer 1986). Conventional wisdom in this region also did not consider gypsum soils to be prone to invasion.

3.4 Survey and treatment effectiveness

In evaluating the assumptions and effectiveness of this program, it is important to keep in mind that waiting to take action before thorough and long-term research or monitoring of exotic species ecology in this region are well underway would defeat the program’s goal of providing early detection and treatment of incipient populations. Furthermore, the program was targeted to be adaptive based on the first few years of survey data and can be viewed as a tool for helping to guide research priorities. However, both the survey methods and the effectiveness of early detection and removal of incipient populations require evaluation.

A major assumption of the survey methods is that roads, trails, and shorelines are vectors of exotic species dispersal and establishment. This program concentrated surveys along these corridors, assuming that eradicating incipient populations in these areas forestalls invasion of other corridors and interior areas. Previous studies in southwestern arid lands have found that exotic plants overall are more abundant along roadsides than in interior areas (e.g., Gelbard and Belnap 2003). However, even small populations that establish in interior areas could form nascent foci that expand to infest additional interior area that would be out of view of roadside surveys (Cowie and Werner 1993). Surveying interior areas when an incipient population is found along a roadway, together with surveying other interior areas, may increase the generality of surveys (Barnett et al. 2007).
Qualitative observations about the effectiveness of this program’s early detection and treatment system suggest some encouraging outcomes. For example, in Monkey Cove above the shoreline of Lake Mead, new individuals of *Nicotiana glauca* have been sprayed with herbicide annually from 2003-2005. Observations in 2006 did not reveal any new individuals, although continued monitoring is needed in a moister year (Table 1). As another example, a population of approximately 200 individuals of *Peganum harmala* (African rue) was detected and pulled in 2005. In 2007 only 10 *P. harmala* individuals occurred at this site, which will be re-treated. No other infestations of this species have since been detected in the survey area. Particularly for more widespread invaders, ideally quantitative monitoring could be performed where some populations are treated and some are not to isolate treatment effectiveness, and to monitor surrounding areas to assess any expansion of the incipient populations. Ethically, however, it is difficult to justify not treating all located incipient populations of an exotic species with high potential for damaging native ecosystems. Nevertheless, if the exotic plant is not present on or off-site for several years (including wet and dry years) after treatment, the outcome is successful following precautionary principles (Underwood 1997), whether or not the outcome can be directly attributed to the treatment.

In our view, some changes or additions to this program in species selection for surveying, survey methods, and assessments of exotic species ecology could be considered to advance this exotic species information system. *Bromus rubens* and *Schismus* spp. are considered among the most widespread and high-impact (by changing disturbance regimes from infrequent to frequent fire) exotic plants in the Mojave Desert (Brooks and Pyke 2001), but they were not surveyed because the program focused on detecting new invaders before they are firmly established.
abundance of these exotic annual grasses, however, may vary substantially across the landscape (Beatley 1966). Recording a rapid, coarse measure of abundance (e.g., cover estimation) of these species as part of this program’s surveying may help resource managers plan for potential fire hazards and identify high-impact areas (Link et al. 2006).

The assumption of restricting surveys to transportation corridors could be evaluated to ensure that incipient populations were not missed in interior areas. In particular, washes, animal trails, or other features in interior areas may also serve as vectors (Rejmánek 1996) and could be surveyed. As Dewey and Andersen (2004) note, surveys and monitoring provide complementary, but different, information for exotic species management. A network of permanent monitoring plots could be established at strategic locations and sampled periodically to provide more detailed quantitative information on exotic species abundance than can be provided by coarse surveys (Barnett et al. 2007). These plots may be particularly appropriate in areas where incipient populations have been treated. Given limited budgets, consideration also could be given to how frequently surveys need to be conducted; currently they are conducted annually. Mojave Desert vegetation is closely linked to precipitation, and particularly annuals may not be visible aboveground in dry years (Beatley 1974). Exotic annuals that do germinate in dry years also tend to be smaller in size, and thus may be more difficult to spot during vehicle and boat surveys. Concentrating surveying to wet years may provide the most comprehensive distributional data and represent the most efficient use of resources. On the other hand, the relative benefits of treating species in wet versus dry years is not known. It is possible that treating species in refugium areas (e.g., moist microsites) in dry years may sharply reduce populations. Furthermore, runoff is concentrated along roadsides, which may allow species to persist during dry years (Johnson et al. 1975).
Little published literature or practical knowledge exist about many of the new invaders surveyed (Kemp and Brooks 1998; Bossard et al. 2000), making it difficult to choose and plan containment treatments and develop monitoring programs. Information about seed bank formation, seed dispersal, and propagule pressure (Von Holle and Simberloff 2005) would be particularly valuable for many species, as well as information on the effectiveness of hand pulling, herbicide, or other treatments in a range of potential management situations. In addition, clarifying factors regulating community invasibility requires further work not only in the Mojave Desert, but also in the field of invasion ecology in general (Byers et al. 2002).

This program has produced a map showing species invasion along transportation corridors across a broad landscape (Fig. 1). We believe that periodically resurveying to continue to update exotic species distributions is one of the best known approaches this region has for curtailing widespread infestations by new invaders. Now that a map exists of these species, however, surveying tells little about what to do about current and future incipient populations and larger infestations. A successful exotic plant information system will likely need to go beyond surveying alone, to also incorporate effectiveness monitoring, generate new or synthesize existing published research on invasibility and treatments, and be adaptive to new invaders or to changes in ecosystem invasibility.

Acknowledgements Funding for the Weed Sentry program was provided by the Clark County Multiple Species Habitat Conservation Plan through the Southern Nevada Public Land Management Act and by the National Park Service (Lake Mead National Recreation Area). Funding for the preparation of this manuscript was awarded by the National Park Service through a cooperative agreement, facilitated by Angie Evenden (Research Coordinator, National
Elizabeth Powell provided insight and direction in early phases of the program; Stacey Provencal (Bureau of Reclamation) developed and maintained the data collection and storage system; Kashmira Asnani, Tiffany Finke, James Fitzgerald, and Jennifer Frey helped collect survey data; Dianne Bangle (University of Nevada Las Vegas) identified plant specimens; Joe Hutcheson (Lake Mead National Recreation Area) guided GIS analyses of soil-species relationships; and Doug Merkler (Natural Resources Conservation Service), Alice Newton (Lake Mead National Recreation Area), and Cayenne Engel and Jill Craig (University of Nevada Las Vegas) provided helpful comments on earlier drafts of the manuscript.

References


Table 1 Characteristics of exotic plant surveys along roadways, trails, and lake shorelines in Clark County, Nevada, USA, from November 2003 to September 2006

<table>
<thead>
<tr>
<th>Measure</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total survey distance (km)</td>
<td>3325</td>
</tr>
<tr>
<td>No. soil types surveyed&lt;sup&gt;a&lt;/sup&gt;</td>
<td>256</td>
</tr>
<tr>
<td>Min. elevation (m)</td>
<td>137</td>
</tr>
<tr>
<td>Max. elevation (m)</td>
<td>3634</td>
</tr>
<tr>
<td>No. exotic species surveyed/detected&lt;sup&gt;b&lt;/sup&gt;</td>
<td>50</td>
</tr>
<tr>
<td>Annual precipitation (% of mean)&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>2002</td>
<td>34</td>
</tr>
<tr>
<td>2003</td>
<td>161</td>
</tr>
<tr>
<td>2004</td>
<td>182</td>
</tr>
<tr>
<td>2005</td>
<td>173</td>
</tr>
<tr>
<td>2006</td>
<td>42</td>
</tr>
</tbody>
</table>

<sup>a</sup> No. of soil classification units, including soils classified as badlands, surveyed within two soil survey areas (Bagley 1980; Lato 2006).

<sup>b</sup> Species were based on those chosen <i>a priori</i> to survey for, and new species detected during surveys.

<sup>c</sup> Percent of the 67-year mean (1937-2006) measured at the city of Las Vegas airport (Western Regional Climate Center, Reno, Nevada, USA).
Table 2 Summary of distributions of the 15 most frequently encountered exotic species (of 44 total species) during roadside, trail, and shoreline surveys, Clark County, Nevada, USA, from November 2003 to September 2006. Species are arranged in order of increasing frequency with increasing elevation, with values in bold highlighting the greatest frequencies of species.

<table>
<thead>
<tr>
<th>Species</th>
<th>Elevation class (m)</th>
<th>Mean occurrences/km</th>
<th>Soils infested (%) overall$^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;610</td>
<td>610-915</td>
<td>915-1220</td>
</tr>
<tr>
<td>Nicotiana glauca</td>
<td>0.2</td>
<td>&lt;0.1</td>
<td>0</td>
</tr>
<tr>
<td>Lepidium latifolium</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>0</td>
</tr>
<tr>
<td>Nerium oleander</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>0</td>
</tr>
<tr>
<td>Tamarix ramosissima</td>
<td>0.2</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Malcolmia africana</td>
<td>0.3</td>
<td>0.5</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Brassica tournefortii</td>
<td>1.6</td>
<td>1.3</td>
<td>0.2</td>
</tr>
<tr>
<td>Hordeum murinum</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>0</td>
</tr>
<tr>
<td>Hordeum vulgare</td>
<td>&lt;0.1</td>
<td>0.1</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Sisymbrium irio</td>
<td>&lt;0.1</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Sisymbrium orientale</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Bromus tectorum</td>
<td>0.2</td>
<td>0.9</td>
<td>0.6</td>
</tr>
<tr>
<td>Bromus berteroanus</td>
<td>&lt;0.1</td>
<td>0.1</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Sisymbrium altissimum</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Bromus diandrus</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Descurainia sophia</td>
<td>0</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
</tr>
</tbody>
</table>
Percent of the total number (256) of surveyed soil classification units in which a species was recorded at least once. Soil classification data were obtained from Lato (2006) and Bagley (1980).
Fig. 1 Map of Clark County, Nevada, USA, showing roads and trails surveyed and distributions of three exotic species as examples of low- (Brassica tournefortii, Malcolmia africana) and high-elevation species (Bromus diandrus) of 44 total surveyed species.

Fig. 2 Malcolmia africana occurred on 12/21 gypsum soil types in Clark County, Nevada, more than twice as many as expected by chance.
Abella Figure 1
Figure 2: % occupied by exotic plants in gypsum soils vs. all soils.
Appendix 1  List of 44 exotic plant species surveyed by the Weed Sentry program, Clark County, southern Nevada, USA

<table>
<thead>
<tr>
<th>Species</th>
<th>Family</th>
<th>Lifeform</th>
<th>% soils infested</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Annuals</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Avena fatua</td>
<td>Poaceae</td>
<td>grass</td>
<td>0.8</td>
</tr>
<tr>
<td>Brassica tournefortii</td>
<td>Brassicaceae</td>
<td>forb</td>
<td>46.9</td>
</tr>
<tr>
<td>Bromus bertereanus</td>
<td>Poaceae</td>
<td>grass</td>
<td>9.8</td>
</tr>
<tr>
<td>Bromus tectorum</td>
<td>Poaceae</td>
<td>grass</td>
<td>44.9</td>
</tr>
<tr>
<td>Chorispora tenella</td>
<td>Brassicaceae</td>
<td>forb</td>
<td>2.0</td>
</tr>
<tr>
<td>Halogeton glomeratus</td>
<td>Chenopodiaceae</td>
<td>forb</td>
<td>1.6</td>
</tr>
<tr>
<td>Hordeum marinum</td>
<td>Poaceae</td>
<td>grass</td>
<td>0.4</td>
</tr>
<tr>
<td>Hordeum murinum</td>
<td>Poaceae</td>
<td>grass</td>
<td>7.0</td>
</tr>
<tr>
<td>Hordeum vulgare</td>
<td>Poaceae</td>
<td>grass</td>
<td>7.8</td>
</tr>
<tr>
<td>Malcolmia africana</td>
<td>Brassicaceae</td>
<td>forb</td>
<td>27.3</td>
</tr>
<tr>
<td>Poa annua</td>
<td>Poaceae</td>
<td>grass</td>
<td>0.4</td>
</tr>
<tr>
<td>Polypogon monspeliensis</td>
<td>Poaceae</td>
<td>grass</td>
<td>0.8</td>
</tr>
<tr>
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<td>forb</td>
<td>1.6</td>
</tr>
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<td>forb</td>
<td>31.6</td>
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<td>forb</td>
<td>19.5</td>
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<td>0.4</td>
</tr>
<tr>
<td>Triticum aestivum</td>
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<td>grass</td>
<td>1.2</td>
</tr>
<tr>
<td><strong>Biennials, annual-perennials</strong></td>
<td></td>
<td></td>
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<tr>
<td>Bromus diandrus</td>
<td>Poaceae</td>
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<tr>
<td>Centaurea melitensis</td>
<td>Asteraceae</td>
<td>forb</td>
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<td>Descurainia sophia</td>
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<td>Type</td>
<td>Score</td>
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<tr>
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<td>--------------</td>
<td>---------</td>
<td>-------</td>
</tr>
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<tr>
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<tr>
<td>Pennisetum setaceum</td>
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<td>grass</td>
<td>3.5</td>
</tr>
<tr>
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<td>forb</td>
<td>0.4</td>
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<tr>
<td>Sorghum halepense</td>
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<td>grass</td>
<td>0.4</td>
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<td>Tamaricaceae</td>
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<tr>
<td>Ulmus pumila</td>
<td>Ulmaceae</td>
<td>shrub</td>
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</tr>
</tbody>
</table>

\(^a\) Percent of 256 soil types in the study area on which a species occurred. Soil types were classified in county soil surveys (Bagley 1980; Lato 2006).
PLANT SUCCESSION IN THE EASTERN MOJAVE DESERT: AN EXAMPLE FROM LAKE MEAD NATIONAL RECREATION AREA, SOUTHERN NEVADA

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ABSTRACT: Plant succession remains a poorly understood process in the Mojave Desert, which is disconcerting because increasing human populations may amplify disturbance frequencies and intensities. In a retrospective study, we examined plant communities on two pipeline right-of-ways cleared in 1998 or 1968 to supply water to metropolitan Las Vegas, Nevada. We also evaluated the effectiveness of restoration treatments (raking soil surfaces, spreading artificial desert varnish, and planting four species of native shrubs) applied by the National Park Service on the 1998 right-of-way to enhance recovery of \textit{Larrea tridentata} communities. Plant cover was sparse (<5%) on the untreated 1998 right-of-way eight years after clearing, with a mean shrub density of only 99/ha. On the restoration-treated area, however, \textit{L. tridentata} established at 36% of the density of an adjacent control area. Restoration treatments also made the right-of-way less visually distinct from surrounding \textit{L. tridentata} communities. Even 38 years after clearing, the older right-of-way was dominated by species such as \textit{Stephanomeria pauciflora} and \textit{Encelia farinosa}, which are classified as early colonizers in the Mojave Desert. Our findings concur with long recovery estimates after vegetation-removing disturbances given in the literature, but suggest that ecological restoration has potential for manipulating the speed and trajectory of plant succession in the Mojave Desert.

Mining, military activities, off-road vehicles, agriculture, livestock grazing, and land clearing for linear corridors (e.g., roads, power lines) are some of the many types of human disturbances impacting Mojave Desert ecosystems (Lovich and Bainbridge 1999). Plant succession (rate and species composition) following these disturbances can vary with disturbance type (Webb et al. 1987) and size (Hunter et al. 1987), precipitation (Brum et al. 1983), time since disturbance (Carpenter et al. 1986), and also with other less well documented factors such as soil type (Lathrop and Archbold 1980). Rough estimates of recovery times of *Larrea tridentata* (DC.) Cov. communities, a dominant vegetation type in the Mojave Desert, to approximate pre-disturbance plant composition have generally ranged from decades to more than centuries (Lovich and Bainbridge 1999).

Vasek (1979/1980) documented plant succession in the Mojave Desert nine years after land clearing for a highway borrow pit in southern California. He found that early colonizers included *Ambrosia dumosa* (A. Gray) Payne, *Encelia frutescens* (A. Gray) A. Gray, *Stephanomeria pauciflora* (Torrey) Nelson, and *Porophyllum gracile* Benth. These species exhibited 19-177 times greater densities in the disturbed pit bottom than in adjacent *Larrea tridentata* communities. Vasek (1983) further classified Mojave Desert perennial species into three main successional categories: early colonizers responding strongly and positively to disturbance and that have short individual life spans (e.g., *Hymenoclea salsola* A. Gray, *S. pauciflora*, *Encelia* spp.), long-lived opportunistic species important in mature communities but also exhibiting pioneering ability (e.g., *A. dumosa*, *Opuntia bigelovii* Engelm.), and long-lived perennials that recover slowly from disturbances.
disturbance (e.g., *L. tridentata*). Vasek (1983) also noted that many early
colonizers after human disturbance are abundant in frequently disturbed “natural”
habitats such as washes, and that annual plants occur in both early and late-
successional communities.

Specific questions about succession, such as factors affecting its rate and
trajectory, remain poorly understood in the Mojave Desert (Bolling and Walker
2000). This hinders ecological management in this desert, where increasing
human populations may intensify disturbance levels (Kemp and Brooks 1998;
Lovich and Bainbridge 1999). In a retrospective study in the eastern Mojave
Desert, we assessed plant community and soil characteristics on two water
pipeline right-of-ways (ROWs) cleared of upper soil and vegetation eight (1998)
or thirty-eight (1968) years before this study. The National Park Service also
applied restoration treatments designed to speed recovery of *Larrea tridentata*
communities on part of the 1998 ROW. Both ROWs cross National Park Service
land (Lake Mead National Recreation Area [LMNRA]) and were constructed by
the Southern Nevada Water Authority to supply water to the Las Vegas Valley.
Since further water developments are planned to occur within LMNRA, this study
was intended to evaluate potential for ecological remediation of these
disturbances. Additionally, our study adds site-specific successional data needed
to build general theories of succession for the Mojave Desert. We sought to
answer the following questions at this site: (1) What is species composition, shrub
density, and species richness on ROWs cleared in 1998 or 1968 relative to
adjacent *L. tridentata* communities? (2) On the 1998 ROW, do soil properties
differ among treatments and below *L. tridentata* compared to openings? (3) How
METHODS

Study Area and Pipeline Treatments

This study was conducted in LMNRA, Clark County, Nevada, 30 km east of Las Vegas at an elevation of 400 m (UTM 696000 m E, 3993000 m N; zone 11; NAD83). The study area consisted of a 0.21-ha section in each of four areas: a 1998 ROW receiving no restoration treatments (hereafter untreated 1998 ROW), an adjacent section of the same ROW that received restoration treatments (hereafter treated 1998 ROW), an adjacent Larrea tridentata community off the ROW that served as a control, and a ROW cleared in 1968 adjacent to the 1998 ROW (Fig. 1). This study is limited by a lack of replication; however, the study area occupies the same landform (an alluvial fan) and one soil association (Carrizo-Carrizo-Riverbend, primarily consisting of Typic Torriorthents; Lato 2006). This supports an assumption that potential differences among the four areas result from their successional age or the restoration treatments, rather than from pre-existing environmental differences. Both the treated and the untreated 1998 ROW were cleared by blading with heavy equipment, with the upper 20 cm of soil stockpiled and reapplied after construction. The 20-cm depth may have varied slightly depending on rockiness or other factors. Procedures for clearing the 1968 ROW are not known to the authors, but are thought to have included mechanical blading without soil replacement.
Restoration treatments the National Park Service applied in January-February 1999 to the 1998 ROW included hand raking the soil surface after soil replacement to re-spread rocks, applying artificial desert varnish (product name = permeon) evenly to the soil surface for color restoration, and planting *Larrea tridentata* (96 plants), *Ambrosia dumosa* (12 plants), *Opuntia basilaris* Engelm. & J. Bigelow (9 plants), and *Acacia greggii* A. Gray (2 plants). Newton (2001) provides details of the planting. Survival by 2001 was 0% for *A. greggii* and *A. dumosa*, 92% for *L. tridentata*, and 100% for *O. basilaris* (Newton 2001).

Annual precipitation from 1999-2005 after clearing of the 1998 ROW averaged 105% of the long-term (32 yr) mean (14 cm/yr), measured at Willow Beach, AZ, 26 km south of the study site (Western Regional Climate Center, Reno, NV).

**Field Sampling**

Between 31 August and 25 October 2006, we delineated a 30 × 70 m section in the centers of each of the four areas. Within these sections, we randomly established a 10 × 70 m transect divided into seven 10 × 10 m (0.01 ha) plots. Using simple random sampling, we selected three plots in each section for sampling. In six 1 × 1 m subplots per plot, we visually estimated areal percent cover of each plant species rooted in subplots using a 1-m$^2$ frame divided into 25, 0.04 m$^2$ compartments. We also surveyed whole plots on a presence/absence basis for species not occurring in subplots. We included dead annuals in subplot and plot sampling, but not dead perennials. Shrubs, including seedlings, were counted on each plot. Nomenclature and native/exotic species classifications follow Baldwin et al. (2002). To compare soils among the control and the treated and untreated 1998 ROW, we collected a 0-10 cm soil sample in an opening (≥ 1 m away from any shrub) at the northwest and southeast corners of each plot and
composited these samples on a plot basis. We also selected a dominant *Larrea tridentata* on each plot on the control and on the treated 1998 ROW (the untreated ROW contained no *L. tridentata*) and collected four soil samples (composited on a plot basis) halfway between the main stem and the canopy edge.

**Laboratory and Data Analysis**

The air dry < 2 mm fraction of soil samples was analyzed for pH (saturated paste), total P and K (Olsen NaHCO₃ method), total C and N (Leco C/N analyzer), and texture (hydrometer method). We compared mean (*n* = 3 for each area) species richness, total shrub density, and open-area soils among the control and the treated and untreated 1998 ROW using one-way analyses of variance and Tukey’s test in SAS JMP (SAS Institute 2004). For the control and the treated 1998 ROW, paired *t* tests were used to compare soil properties between openings and below *Larrea tridentata*. Statistical results should not be extrapolated to other sites since treatments were not replicated, but mean comparisons are presented as interpretational aids. Mean vegetation characteristics for the 1968 ROW were compared descriptively to the 1998 ROW and the control.

**RESULTS**

**1998 Right-of-Way**

Exotic species richness/m² was lowest in the control, and was similar between treated and untreated areas (Fig. 2). Total species richness/100m² was similar among treatments, ranging from 8-9.3 species. The exotic annual grasses *Schismus* spp. exhibited the highest relative cover on the ROW compared to the control, but total absolute cover for all species on the ROW was only 5-6% (Fig. 1).
3). Relative cover of the native annual *Plantago ovata* Forsskal increased from the untreated ROW to the control. Perennial forbs and grasses were sparse or absent from all treatments. Shrub density was eight times higher in the control than in the untreated ROW, which contained no *Larrea tridentata* (Fig. 4). *Ambrosia dumosa* and *Encelia farinosa* Torrey & A. Gray were the only shrubs inhabiting the untreated ROW, and these species did not occupy plots on the treated ROW or on the control. *Larrea tridentata* exhibited a density of 300/ha on the treated ROW, which was 36% of the density on the control.

In openings, soil properties were similar among the three areas except for K, which was significantly greater on the untreated ROW than on the control (Table 1). Sand concentration was 10% higher and silt 9% lower on the untreated ROW compared to the control, but all soils were still sandy loams. P and K both tended to be greater below *Larrea tridentata* than in openings for the treated ROW and the control, but the only difference that was statistically significant was for P for the control.

### 1968 Right-of-Way

Exotic species richness was minimal, and total richness/100 m² was comparable to the 1998 ROW (Table 2). Similar to the 1998 ROW, *Plantago ovata* was a major contributor to relative cover, although *Stephanomeria pauciflora* exhibited the highest relative cover. Total shrub density averaged 3134/ha, 4-31 times more than the 1998 ROW or the control. *Stephanomeria pauciflora* and *Hymenoclea salsola* contributed 76% of the total shrub density.
Although lack of replication and one-time sampling limits statistical inferences, our findings represent a case study of succession after land clearing in the eastern Mojave Desert and how a particular set of restoration treatments may influence succession. Several dominant species on the 1968 ROW, such as *Stephanomeria pauciflora*, *Ambrosia dumosa*, and *Eriogonum inflatum* Torrey & Frémont, also were important nine years after land clearing in the California Mojave Desert (Vasek 1979/80). Two species differences, however, were that *Encelia farinosa* was an important early colonizer in our study rather than *Encelia frutescens*, and *Chamaesyce polycarpa* (Benth.) Millsp. was important in Vasek’s (1979/80) study but not in ours. Additionally, shrub densities are 50% lower on the 1968 ROW and 98% lower on the untreated 1998 ROW in our study compared to Vasek’s (1979/80) study.

Also in the eastern Mojave Desert, Bolling and Walker (2002) concluded that soils beneath *Larrea tridentata*, even 88 years after road abandonment, lacked tight circular gradients in nutrient concentrations relative to control shrubs. P and K showed the strongest trends to concentrate below control *L. tridentata* in our study (Table 1). It is also possible that a weak trend may exist for these nutrients to be more concentrated below planted *L. tridentata* relative to openings on the treated 1998 ROW.

While effects of individual restoration treatments cannot be discerned in this study, the set of treatments including surface raking, applying artificial desert varnish, and planting of shrubs, appeared to make shrub composition on the
treated 1998 ROW converge with that of the control (Fig. 4). Although our study was not designed to track survival of planted individuals, we found that *Larrea tridentata* established on the treated 1998 ROW at a density 36% that of the control. Previous studies of *L. tridentata* outplanting have produced widely differing results, ranging from complete mortality (Graves et al. 1978) or < 2% survival (Brum et al. 1983), to > 90% survival (Wallace et al. 1980; Clary and Slayback 1984; Newton 2001). In our view, the restoration treatments also made the 1998 ROW less visually distinct from surrounding *L. tridentata* communities, an important consideration on National Park Service lands (Fig. 1).

This study highlights several topics requiring additional research for a better understanding of Mojave Desert successional patterns and how ecological restoration might be used to influence successional trajectories. The effects of soil salvage and replacement after disturbance may depend on several factors, such as soil type, depth of salvage, and length of time soil is stored (Bainbridge et al. 1998). Effects also hinge on whether or not nutrients and seed banks are diluted upon reapplication by mixing upper and lower soil layers (Nelson and Chew 1977). Soil salvage has been little studied in the Mojave Desert, and cannot be evaluated in this study since this would have required areas on the 1998 ROW that were bladed but did not have soil replaced. While we believe that applying artificial desert varnish helped make the treated 1998 ROW less visually distinct from control areas, potential ecological effects of this application are not clear. The darkening varnish could affect soil temperatures or have other ecological effects (Elvidge and Iverson 1983). While many studies in the Mojave Desert, including this one, have compared post-disturbance revegetation to composition...
of adjacent control communities, these “control” communities likely have been exposed to other human disturbances. These communities may not be good reference models for ecological restoration, unless a specific restoration goal is to blend a disturbed area into the surrounding matrix (Lovich and Bainbridge 1999). For example, neither the control nor the two ROWs contained perennial grasses or forbs, with the exception of *Eriogonum inflatum*. It remains unclear whether these plant groups were more common at this site historically, or whether establishing them would produce ecological benefits.

Our analysis of the 1968 ROW revealed that species previously classified as early successional (Vasek 1983) remain dominant even 38 years after clearing (Table 2). This concurs with other research in the Mojave Desert reporting that plant composition on denuded areas can require over 40 years to approximate that of adjacent areas (e.g., Carpenter et al. 1983; Prose et al. 1987). Early successional shrub communities are not necessarily “bad,” depending on ecological management objectives. For example, plant species richness on the 1968 ROW was similar to the control, and exotic species richness was actually lower (Table 2, Fig. 2). Communities similar to those on the 1968 ROW also characterize natural washes in this region (Wells 1961). Since early successional shrubs have established at only low densities eight years following creation of the 1998 ROW, future research could evaluate whether establishing these species more rapidly speeds natural recruitment of longer lived species like *Larrea tridentata*.

**ACKNOWLEDGEMENTS**
We thank Stacey Provencal, Mike Boyles, and Mark Sappington with the National Park Service for facilitating our research permit for this study; the Southern Nevada Water Authority for enabling sampling on their right-of-way; Utah State Analytical Laboratories for analyzing soil samples; and Jill Craig and Jef Jaeger for reviewing the manuscript. Funding was provided by the National Park Service through a cooperative agreement with the University of Nevada Las Vegas.

LITERATURE CITED


Table 1. Comparison of 0-10 cm soil properties among treatments and between openings and below Larrea tridentata within treatments on an eight-year-old (1998) water pipeline right-of-way, Lake Mead National Recreation Area, southern Nevada.

<table>
<thead>
<tr>
<th>Property</th>
<th>Untreated ROW&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Treated ROW</th>
<th>Control</th>
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<tr>
<td>pH</td>
<td>8.1±0.1&lt;sup&gt;2&lt;/sup&gt;</td>
<td>8.1±0.2</td>
<td>8.1±0.1</td>
</tr>
<tr>
<td>P (mg/kg)</td>
<td>4.0±1.2</td>
<td>3.5±0.7</td>
<td>3.7±0.8</td>
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<td>K (mg/kg)</td>
<td>555±13a</td>
<td>491±62ab</td>
<td>575±204</td>
</tr>
<tr>
<td>C (mg/kg)</td>
<td>942±35</td>
<td>716±118</td>
<td>954±107</td>
</tr>
<tr>
<td>N (mg/kg)</td>
<td>27±5</td>
<td>37±14</td>
<td>43±8</td>
</tr>
<tr>
<td>Sand (% wt.)</td>
<td>70±2a</td>
<td>65±3b</td>
<td>67±4</td>
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<td>Silt (% wt.)</td>
<td>24±1b</td>
<td>29±3a</td>
<td>27±3</td>
</tr>
<tr>
<td>Clay (% wt.)</td>
<td>6±2</td>
<td>6±0</td>
<td>6±1</td>
</tr>
</tbody>
</table>

<sup>1</sup> ROW = right-of-way. Restoration treatments included raking the soil surface, applying artificial desert varnish, and planting four species of native shrubs.

<sup>2</sup> Values are mean ± SD (n = 3 within each treatment and canopy combination).

Letters within a row compare means among treatments for openings only. Values in bold denote significant differences at \( p < 0.05 \) between openings and below Larrea tridentata within treatments.

<sup>3</sup> Not measured because L. tridentata did not occur in this treatment.
Table 2. Plant community attributes on a 38-year-old (1968) water pipeline right-of-way, Lake Mead National Recreation Area, southern Nevada.

<table>
<thead>
<tr>
<th>Community attribute</th>
<th>Mean±SD</th>
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<tbody>
<tr>
<td>Species richness</td>
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<tr>
<td>No. natives/m²</td>
<td>2.2±0.2</td>
</tr>
<tr>
<td>No. exotics/m²</td>
<td>0±0</td>
</tr>
<tr>
<td>No. natives/100 m²</td>
<td>7.7±1.5</td>
</tr>
<tr>
<td>No. exotics/100 m²</td>
<td>1±0</td>
</tr>
<tr>
<td>Relative % cover</td>
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</tr>
<tr>
<td><em>Stephanomeria pauciflora</em></td>
<td>41±16</td>
</tr>
<tr>
<td><em>Chamaesyce</em> spp.</td>
<td>30±14</td>
</tr>
<tr>
<td><em>Plantago ovata</em></td>
<td>18±10</td>
</tr>
<tr>
<td>Other species</td>
<td>10±8</td>
</tr>
<tr>
<td>Shrubs/ha</td>
<td></td>
</tr>
<tr>
<td><em>Ambrosia dumosa</em></td>
<td>367±379</td>
</tr>
<tr>
<td><em>Bebbia juncea</em></td>
<td>167±208</td>
</tr>
<tr>
<td><em>Encelia farinosa</em></td>
<td>233±321</td>
</tr>
<tr>
<td><em>Hymenolea salsola</em></td>
<td>767±551</td>
</tr>
<tr>
<td><em>Stephanomeria pauciflora</em></td>
<td>1600±361</td>
</tr>
</tbody>
</table>
Figure 1. Views of (a) bladed eight-year-old (1998) water pipeline right-of-way that received no restoration except for soil replacement; (b) the same right-of-way that received the restoration treatments of raking the soil surface, applying artificial desert varnish, and planting four species of native shrubs in addition to soil replacement; (c) control area adjacent to the right-of-way; and (d) 38-year-old (1968) water pipeline right-of-way, Lake Mead National Recreation Area, southern Nevada. Photos by S.R. Abella, 31 August 2006 for (a-c) and 25 October 2006 for (d).

Figure 2. Mean plant species richness at (a) 1 m$^2$ and (b) 100 m$^2$ scales among treatments on an eight-year-old (1998) water pipeline right-of-way, Lake Mead National Recreation Area, southern Nevada. Restoration on the treated right-of-way (ROW) consisted of raking the soil surface, applying artificial desert varnish, and planting four species of native shrubs. Error bars are 1 SD for total mean richness. In comparisons within native or exotic categories, only exotic species/m$^2$ differed significantly ($p < 0.05$) among treatments.

Figure 3. Relative cover of dominant plant species and genera among treatments on an eight-year-old (1998) water pipeline right-of-way, Lake Mead National Recreation Area, southern Nevada. Restoration on the treated right-of-way (ROW) consisted of raking the soil surface, applying artificial desert varnish, and planting four species of native shrubs. CRYSPP = Cryptantha spp., ERIDEF = Eriogonum deflexum, LARTRI = Larrea tridentata, PLAova = Plantago ovata, and SCHSPP = Schismus spp. Numbers at the top of each bar represent total mean absolute cover.
Figure 4. Shrub densities among treatments on an eight-year-old (1998) water pipeline right-of-way, Lake Mead National Recreation Area, southern Nevada. Restoration on the treated right-of-way (ROW) consisted of raking the soil surface, applying artificial desert varnish, and planting four species of native shrubs. Error bars are 1 SD for total mean density. Means without shared letters differ at $p < 0.05$ for total density.
Fig. 1 (a)  

Fig. 1 (b)  

Fig. 1 (c)  

Fig. 1 (d)
Fig. 2. (a) richness/m²

No. species

Exotic
Native

(b) richness/100 m²

No. species

Exotic
Native

Treatment

Untreated ROW
Treated ROW
Control
Fig. 3.
Fig. 4.