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The Effects of Dust on the Federally Threatened Valley Elderberry Longhorn Beetle

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ABSTRACT / We combined a natural experiment with field surveys and GIS to investigate the effects of dust from recreational trails and access roads on the federally threatened Valley elderberry longhorn beetle ("VELB," *Desmocerus californicus dimorphus*) and its host plant, elderberry (*Sambucus mexicana*). Dust is listed in the species recovery plan as a threat to the VELB and unpaved surfaces are common throughout the riparian corridors where the VELB lives, yet the effects of dust on the VELB have been untested. We found that dust deposition varied among sites and was highest within 10 m of trails and roads, but was similar adjacent to dirt and paved surfaces within sites. Elderberry density did not differ with distance from dirt surfaces. Despite similar within-site dust levels, elderberry adjacent to paved surfaces were less stressed than those near dirt ones, possibly because increased runoff from paved surfaces benefited elderberry. Dust deposition across sites was weakly correlated with elderberry stress symptoms (e.g., water stress, dead stems, smaller leaves), indicating that ambient dust (or unmeasured correlates) influenced elderberry. Direct studies of the VELB showed that its distribution was not negatively affected by the proximity to dirt surfaces. Dust from low traffic dirt and paved access roads and trails, therefore, affected VELB presence neither directly nor indirectly through changed elderberry condition. These results suggest that the placement of VELB mitigation, restoration, and conservation areas can proceed independently of access roads if dust and traffic levels do not exceed those in our study site. Furthermore, dust control measures are likely to be unnecessary under such conditions. The potential effects of increased traffic and dust levels are addressed through a literature review.

Factors listed as threats to the persistence of threatened and endangered species are often no more than best guesses based on the best available information about the species at the time of listing. The lack of quantitative information about threats to these species is due in part to rarity, especially at the time of listing, which makes study difficult. Understanding the relationships between these species and their proposed threats reduces the chance of "take" (the harming, harassing or killing of the organisms), and subsequently the risk of the species' extinction. Information may also limit misdirected conservation efforts and avert unnecessary cost. If exposure to proposed threats is unavoidable, then jeopardy may be declared to safeguard the species against uncertainty. This jeopardy opinion, in turn, dictates the amount of compensation, or mitigation required. This is the case with the valley elderberry longhorn beetle (the "VELB," *Desmocerus californicus dimorphus*, Fisher, Cerambycidae), a Federally threatened endemic beetle that has been the catalyst for many riparian mitigation projects in the Central Valley of California since its listing in 1980 (Federal Register 1980).

Loss of habitat due to urban and agricultural development was cited as the main cause of decline of this subspecies (Federal Register 1980). The Recovery Plan lists development-related factors as threats to the beetle, such as further loss of habitat or host plants, pruning of elderberry shrubs, use of pesticides or herbicides, excessive noise from traffic and construction, and dust from construction and roadways (USFWS 1984). The effects of all of these factors on the beetle are poorly understood, making effective management and conservation difficult. Some of these factors necessitate mitigation, and their omission from planning and management may also jeopardize

KEY WORDS: American River Parkway, California; *Desmocerus californicus dimorphus*; Elderberry; Environmental pollution; Threatened species; VELB

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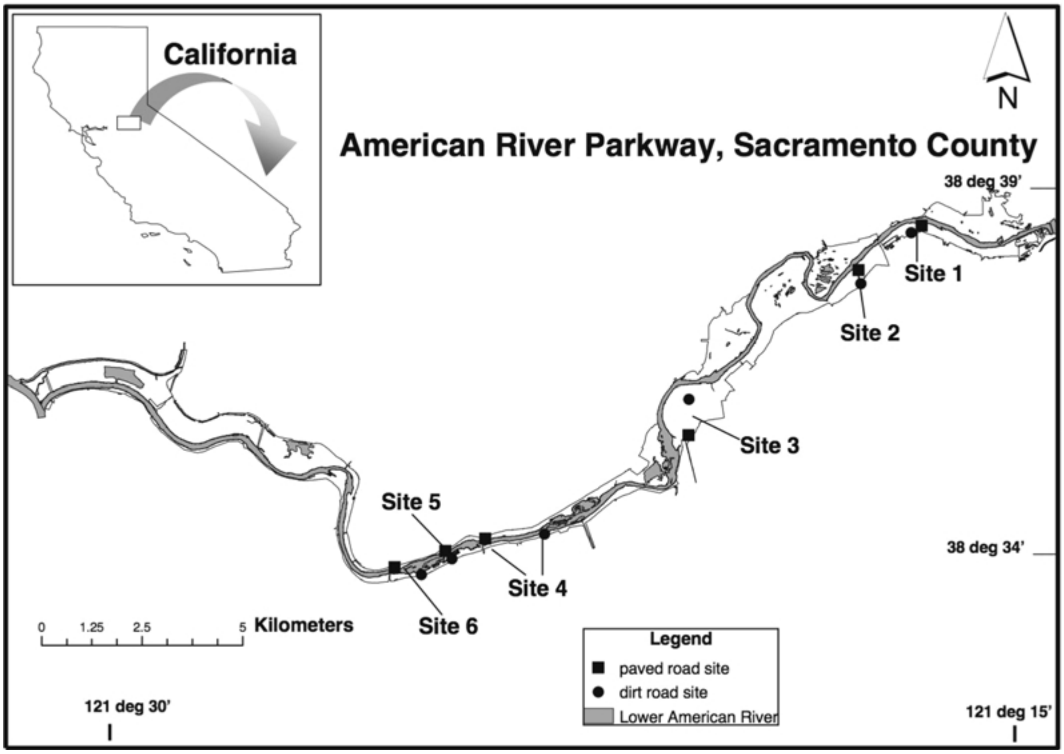

Figure 1. Location of the dust experiment and surveying of lower American River Parkway. The map shows the six paved and dirt trail sites used for the dust experiment conducted during August 2003: Sites 1–6 with paved and dirt trail areas paired within each site. Also shown is the extent of "mapped elderberry" that was surveyed between June 2002 and March 2003 for the valley elderberry longhorn beetle (VELB). Elderberry and VELB data were incorporated into GIS and used in analyses to determine relationships between both elderberry characteristics and VELB presence and the distance from both dirt and paved trails. For clarity, trails and roads are not shown on the map.

mitigation success. This study quantifies the effects on the beetle and its host plant elderberry of one threat listed in the Recovery Plan, dust from access roads and recreational trails, which are common within the riparian corridors where this beetle lives.

Dust can have both chemical and physical effects on plants and animals. The chemical effects of dust are potentially greatest when dust contains toxins, acids, bases, or metals such as dust from motor vehicles, industrial emissions, or mines (Farmer 1993; Pagotto and others 2001). Elderberry and the VELB are primarily riparian species, and often occur in areas that have alluvial-based soils on granite (non-toxic) bedrock (Smith 1996). Therefore, it is likely that the physical effects of dust are the greatest threats to VELB and its host shrub. Additionally, much of the beetle's range contains dirt roads that experience only low levels of motor vehicle traffic, and therefore dust exposure may be limited; this is the case with the study area, the American River Parkway (Sacramento, CA; Figure 1).

The effects of dust on elderberry are not well documented. The effects of cement dust on European *Sambucus nigra* included cell destruction, bark peeling, and leaf necrosis, all symptoms specific to cement exposure (Czaja 1961, 1962 as cited in Farmer 1993). However, plants coated with non-toxic dust are expected to mainly display symptoms stemming from leaf shading, blocked stomata, and increased leaf temperatures, such as inhibition of transpiration, reduced photosynthesis, increased water loss, reduced vegetative and reproductive growth, and reduced fruit set (e.g., Eveling 1969; Eller 1977; Farmer 1993 and references therein; Hirano and others 1995; Sharifi and others 1997). These stress symptoms could indirectly influence the VELB through mortality and loss of host plants or a change in host plant quality. While the former would have obvious negative impacts on the beetle, the effects of the latter are complex.

Depending on the type and amount of dust, elderberry may be slightly to severely stressed, altering habitat for the VELB. VELB may be attracted to slightly stressed hosts (Arnold 1984; Hanks 1999). Stressed plants may emit chemicals that act as host plant cues for woodborers and may have increased nutrient content in above ground tissues (Haack and Slansky 1987), both of which would be beneficial to the VELB. Plant stress may, however, be detrimental to woodborers by creating chemical attractants for their predators and parasites, or decreasing food quality through production of toxic chemicals or desiccation of plant tissue. Finally, host plant quality can influence sex pheromone production in woodboring insects, which could have beneficial or negative outcomes depending on the phermone and the species (Haack and Slansky 1987).

Direct effects of dust on the VELB have not been documented but may include smothering adults or larvae, disruption of chemical cues used for mating or host plant detection, and making leaves or flowers unpalatable. Since the adult stage of this beetle is rare both in space and time and the larvae develop unseen within elderberry stems, the use of VELB in experiments or surveys to quantify the direct and indirect effects of dust is not practical. Both direct effects of dust on beetles and indirect effects through host plant quality are expected to be reflected in changes in VELB presence or absence, although such studies are not necessarily able to identify the mechanisms behind such patterns. Nonetheless, observed relationships between proximity to roads and VELB presence are likely to be informative.

This study addressed long-standing questions about the effects on VELB and its host plant of dust from unsurfaced trails and access roads. There were two components to this study: (1) comparing the effects of proximity to dirt versus paved surfaces on elderberry condition; and (2) identifying relationships between both VELB presence or absence and elderberry characteristics, and distance from dirt and paved surfaces. A natural experiment using paved trails as a control treatment quantified the effects of dirt trails on elderberry characteristics, while the exploration of patterns over large spatial scales (km's) indicated long-term and large-scale effects that dirt trails may be having on elderberry and VELB characteristics.

Materials and Methods

Study System Description

This study was performed along the American River Parkway, Sacramento County, California, USA, which is a 37-km stretch of riparian habitat owned by Sacramento County Parks (hereafter called the "Parkway"; Figure 1). The Parkway borders both sides of the American River and contains one of two areas designated at Critical Habitat for the VELB (USFWS 1984). It consists of both wooded riparian and open areas dominated by annual grasses and herbaceous plants. Both of these habitats contain elderberry and VELB.

The VELB is a strict habitat specialist, with all life-cycle stages except migration occurring on its host plant, elderberry (*Sambucus mexicana* C. Presl: Caprifoliaceae). Adults feed on elderberry leaves and flowers, and reproduce in the canopy. The females lay eggs in crevices of elderberry stems or leaves. After hatching, the 1–3-mm-long first instar larvae bore into elderberry stems where they develop for 1–2 years, feeding on pith (Linsley and Chemsak 1972). Fifth instar larvae create exit holes in the stems and then plug the holes and remain in the stems through pupation. Adults emerge in the spring through the distinctive exit holes (~1 cm diameter oval), which are then used to census beetle populations.

A "natural" experiment was conducted along the Parkway during August 2003 to test the effects of dust from dirt trails relative to paved trails on elderberry characteristics. Along the Parkway, dirt trails are predominantly hiking and horseback riding trails, and unsurfaced access roads. Paved trails consist mostly of bicycle trails and paved levees. All trails and roads (hereafter referred to as trails) have limited motor vehicle traffic (10 or fewer vehicles per week; R. Marck, D. Lydick and W. Katen personal communication) In each of six sections of Parkway, replicate sites adjacent to a dirt road ($n = 6$) and a nearby paved trail ($n = 6$) were established (Figure 1). Within each site, five elderberry shrubs were chosen at each of distances that were near (2–10 m) and far (25–40 m) from the edge of the trails. These distances were selected because there is a rapid decline in large dust particles (>50 μm) within the first 8 m from roads and a second decline of particles >20 μm after about 30 m (Everett 1980, as cited in Farmer 1993).

Field Measurements and Collections

From each shrub, one leaf (with 3–5 leaflets) was randomly selected for *in-situ* measurement of water potential using a PMS Model 600 Portable Nitrogen Gas Pressure Bomb. Readings were taken at times of maximum stress for the elderberry, between 10 am and 2 pm, on 4–5 August 2003; both days were calm, sunny, and clear with a high temperature of 29°C. An additional 25 leaflets were collected from each shrub for dust accumulation analysis. The bombed leaf and the leaflets for dust analysis were each placed in an airtight bag, put on ice, and returned to the lab for further leaf measures.

Background dust accumulation measurements were made by placing pairs of aluminum pans (20 cm diameter × 2.5 cm depth) on the ground, surrounded but not covered by vegetation, at two or three distances from the trail, depending on the width of the vegetated zone (near, mid, far). Pans were weighted with clean rocks, left in the field for one week, collected, placed into airtight bags, and returned to the lab. Deployment and collection times were noted, and weather was consistently calm (no wind).

Relative fecundity of each elderberry was measured by counting the number of inflorescences on each secondary main stem. Additionally, one inflorescence was randomly selected from each shrub, placed in an airtight bag, and returned to the lab for fruit counts.

Overall condition of each elderberry shrub was assessed by estimating the % dead stems, the number and diameter of main stems, maximum stem diameter, and height. Overall site quality was assessed by noting the % cover and type of other vegetation present as groundcover, shrubs, and canopy; and noting the % cover of lichens (indicators of air quality; Walker and Everett 1987) on elderberry.

Laboratory Analyses

Leaf samples were refrigerated for up to 48 hours before analysis of leaf area, wet weight (bombed leaves only) and dry weight. Dry weight (dw) was obtained by drying each leaf at 60°C until weight loss was zero (for at least 24 hours). Leaf area was measured in the lab using a LI-COR LI-3000A Portable Leaf Area Meter. Besides using these response variables (leaf area, wet and dry weight), a measure of leaf thickness was calculated using these measures (leaf dw per area).

Dust accumulation on leaves and within the sediment pans was measured by thoroughly rinsing the leaflets or pan with distilled water into a container. The contents of the container were then rinsed with distilled water into a Büchner funnel and vacuum filtered through a preweighed Whatman No. 1 filter paper. The filter was dried at 60°C and reweighed on an analytical balance to assess sediment dry weight (later converted to mg dw sediment per cm^2 leaf or mg dw sediment per cm^2 per day).

Elderberry inflorescences were frozen at −20°C until ready to be analyzed for relative fecundity. Samples were thawed and the number of fruits per inflorescence counted.

Distance from Roads

Correlative analyses exploring relationships between the proximity to dirt trails and beetle and elderberry variables were performed using GIS road data provided by Sacramento County Parks, as well as beetle and elderberry locations and field data collected from 19 km of the Parkway at the lower (west) end of the river (Figure 1). These beetle and elderberry data are part of a larger project, and were collected between June 2002 and March 2003. These data were used to determine whether the results of the natural experiment were observed over larger-spatial scales. Additionally, sample sizes in the natural experiment were low because it was difficult to find a sufficient number of VELB-inhabited shrubs for all of the treatments (site × paved/dirt surface × near/far from road combinations). This GIS data set provided large sample sizes with enough natural variability in VELB abundance and distances from roads to search for relationships between the two.

GIS Analyses and Statistics

Effects of trail surface, site and distance from the trail (near, far) on elderberry characteristics, cover of associated vegetation, and both leaf and background sediment levels were tested using three-way ANOVAs. Relationships between both sediment accumulation on elderberry leaves and background sediment deposition rates, and both the elderberry characteristics and cover of associated vegetation were explored using correlations among variables in Table 1. Sequential Bonferroni-adjusted alpha values were used for these analyses to give an overall alpha of 0.05, thereby controlling for Type I error associated with multiple comparisons (Sokal and Rohlf 1995). Bonferroni alpha values were calculated separately for the 10 elderberry variables, the three associated vegetation types, and the two VELB hole variables (total number and presence/absence).

Using available GIS data, the distance from every mapped elderberry shrub to both dirt and paved trails was calculated using the Nearest Features script available for ArcView 3.2 (Jenness Enterprises, http://www.jennessent.com). Relationships between distance of elderberry to both dirt and paved trails and the presence of the beetle were tested using logistic regressions in JMP Statistical Software. Relationships between distance of shrub to dirt and paved trails and elderberry maximum diameter, height class, % dead stem class, and shrub density, were explored using correlations (diameter) and G-tests (classes). Sequential Bonferroni adjusted alpha values were used to make the experiment-wise error rate alpha = 0.05. All data were square root or $\log_{10}$ transformed to normalize data and homogenize variances, and all statistical analyses were performed in JMP Statistical Software. Power analysis was used to test the statistical

Table 1. Effects of dust from dirt and paved trails and access roads on elderberry shrubs

	Overall			*P* values (only $P \leq 0.5$ are shown)						
Dependent variables	*P*	*F*	df	Site	Surf	Dist	Site × dist	Surf × dist	Site × surf	Site × surf × dist
Elderberry characteristics										
Within-shrub										
Water potential (bars)	0.006	2.32	74	0.014	0.048	0.015	—	—	—	—
Average leaf area (cm^2)	0.001	2.43	116	—	—	0.001	0.052	—	0.052	—
Leaf water content (%)	0.002	2.66	74	0.005	0.001	—	0.018	—	—	—
Average leaf dry weight (g)	<0.001	3.44	115	<0.001	—	<0.001	—	—	—	0.021
Leaf thickness (g dw cm^{-2})	<0.001	3.71	116	<0.001	0.005	—	0.018	—	<0.001	0.032
Whole shrub										
Shrub height	<0.001	3.10	114	—	<0.001	—	0.050	—	0.003	—
Max stem diameter	<0.001	3.44	116	0.009	—	<0.001	0.028	—	0.042	—
No. inflorescence $stem^{-1}$	<0.001	3.78	114	—	<0.001	0.001	0.033	—	0.004	—
No. fruit $inflorescence^{-1}$	0.002	2.34	116	—	—	—	0.004	0.035	0.046	0.017
Dead stems $shrub^{-1}$ (%)	<0.001	5.85	116	<0.001	<0.001	—	0.037	—	<0.001	0.027
Associated vegetation										
Shrub cover (%)	<0.001	5.33	116	<0.001	0.003	0.052	<0.001	0.012	<0.001	0.013
Canopy cover (%)	<0.001	12.16	116	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Lichen cover (%)	<0.001	6.81	116	<0.001	—	<0.001	0.013	0.005	<0.001	—
Sedimentation										
Leaf sediment (g dw sed cm^{-2})	0.020	1.86	116	—	—	—	—	—	—	0.012
Background sedimentation rate (mg cm^{-2} day^{-1})	<0.001	3.40	66	0.005	—	0.001	—	0.027	—	—

Values are results of three-way ANOVA's testing the effects of three natural treatments (trail surface type, site number, and distance from the trail) on elderberry characteristics, cover of associated vegetation, and sediment accumulation. The experiment was conducting during August 2003. n = 6 replicate sites of each treatment combination. Distance from the trail = near (2–10 m) or far (25–40 m). Surf = trail surface; dist = distance from trail; avg = average; — = $P > 0.05$. All overall *P* values are significant at their sequential Bonferroni-adjusted alpha values.

power of each comparison, or the probability that non significant results were real and not due to a lack of sufficient replication (we used G-Power 2.1.2; Erdfelder and others 1996). The effect size, or the magnitude of the differences detected by the power analysis, was defined as "large," "medium," or "small" (*sensu* Cohen 1992). This is a standard convention for describing the degree to which the populations or distributions being compared differ from each other (e.g., the amount of difference between H_0 and H_1 distributions or between μ_1 and μ_2; Erdfelder and others 1996). Cohen (1992) describes a "medium" effect size as "an average size of observed effects in various fields."

Results

Natural Experiment: Dust Effects on Elderberry

The surface treatment showed that relative to paved roads, dirt roads were generally associated with elderberry that were "stressed" in that they were shorter, had lower % leaf water content, thicker leaves, higher % dead stems, and higher water stress (Table 1; Figure 2A–F). There tended to be less canopy cover and more riparian scrub (shrubs) along dirt relative to paved trails (Table 1; Figure 3A,B), supporting the result that water stress may be higher along dirt surfaces. Exotic annual grasses and thistles dominated the ground cover in all areas sampled. Proximity to roads (near vs. far) was associated with smaller leaf area and dry weight, larger maximum diameters, more inflorescences per stem, and higher water stress (Table 1, Figure 2D,F–H); these results were consistent with a higher canopy cover (more shading) at the farther distance from roads. Additionally, % cover of lichens on elderberry was highest close to roads, regardless of road surface type (Table 1, Figure 3C).

There were differences in elderberry characteristics between sites, with Site 6 generally among the most stressed and Site 5 among the least stressed (e.g., least water stress and leaf thickness, highest % leaf water; results for means are not shown, ANOVA results are shown in Table 1). Elderberry variables differed in inconsistent ways between the other sites. Additionally, differences between sites resulted in most of the significant cross-variable interactions (Table 1). *Post-hoc* power analyses showed that the power of these analyses was reasonable for detecting large effects (power = 0.62), but somewhat low for medium-sized effects

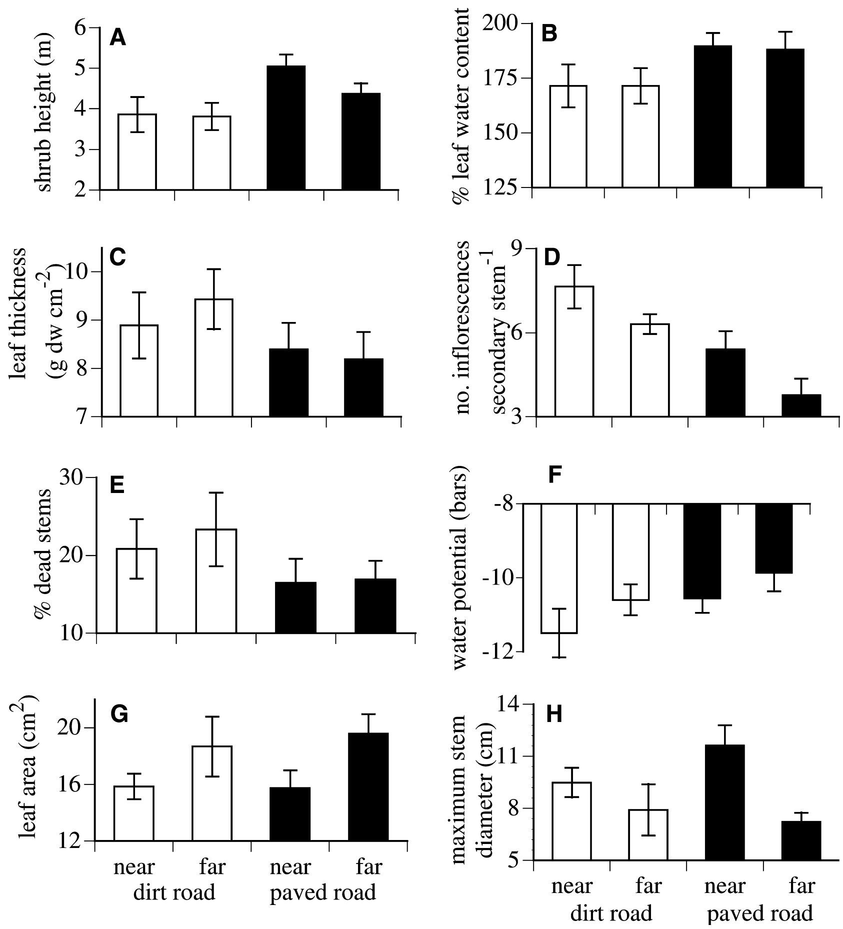

Figure 2. Elderberry characteristics at near and far distances from dirt and paved trails. Near = 2–10 m and Far = 25–40 m from the trail edge. Elderberry characteristics were means (±1 standard error) for (**A**) shrub height, (**B**) leaf water content, (**C**) leaf thickness, (**D**) number of inflorescences per secondary stems, (**E**) % dead stems per shrub, (**F**) water stress of shrub, (**G**) leaf area, and (**H**) the maximum stem diameter of the shrub. Data were collected during August 2003, n = 3–5 shrubs for each distance and trail surface type; data were pooled across sites for graphical presentation.

(power = 0.23). Hence, we conclude that large effects are likely to be consistent with the significant findings above, but we refrain from drawing conclusions about smaller effects that were not statistically significant because of limited power.

Sediment accumulation on elderberry leaves did not differ with road surface or distance, but did differ with site (Site 3 leaves had less sediment than those from Sites 4, 5, or 6; Table 1). With data from all sites pooled, the amount of sediment per cm^2 of leaf was weakly but positively correlated only with the number of fruits per inflorescence ($r^2 = 0.06$, $P = 0.007$, $F_{1,115} = 7.2$, alpha = 0.007) and not any other elderberry characteristics or vegetation cover (i.e., the variables listed in Table 1). The power for detecting medium-sized effects was high (power = 0.96), indicating that it is likely that effects of dust deposition on elderberry would have been detected were they present.

Background sedimentation rates did not differ with road surface but were higher at near relative to mid and far distances from the road (Figure 4). Background sedimentation rates also tended to be highest in sites 4 and 5, intermediate in sites 6 and 3, and lowest in sites 1 and 2 (Tables 1 and 2). When data from all sites were pooled, sedimentation rate was weakly positively correlated with the amount of sediment accumulated on elderberry leaves ($r^2 = 0.04$, $P = 0.04$, $F_{1,115} = 4.3$, alpha = 0.05), as well as with plant water stress ($r^2 = 0.08$, $P = 0.015$, $F_{1,73} = 6.7$, alpha = 0.006), number of inflorescences per stem ($r^2 = 0.05$, $P = 0.013$, $F_{1,118} = 6.3$, alpha = 0.007), and % dead stems on elderberry shrubs ($r^2 = 0.06$, $P = 0.010$, $F_{1,115} = 6.9$, alpha = 0.006), although the elderberry characteristics are not significant at the sequential Bonferroni adjusted alpha. Sedimentation rate was weakly negatively correlated with average leaf

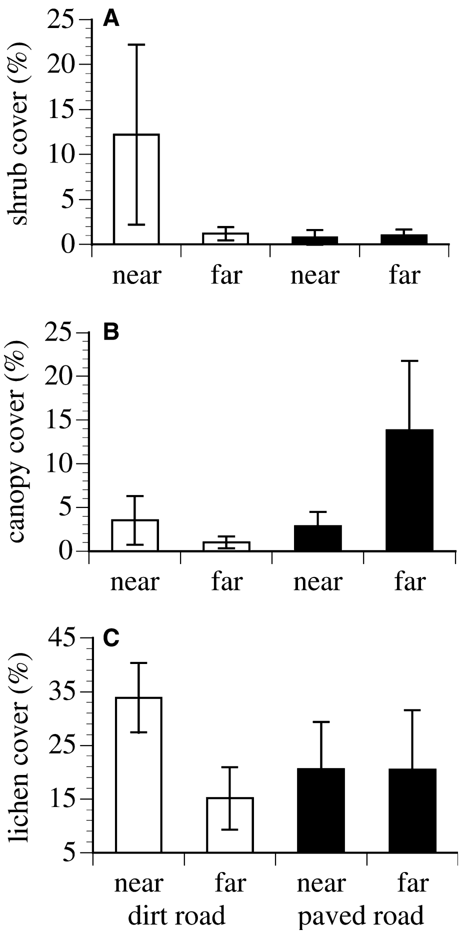

Figure 3. Effects of distance from dirt/paved trails on shrubs, canopy, and lichens. (**A**) % cover of shrubs, (**B**) % canopy cover, and (**C**) % cover of lichens associated with elderberry shrubs at near and far distances from both dirt and paved trails along the American River Parkway. Near = 2–10 m and Far = 25–40 m from the trail edge. Shrubs and canopy vegetation were those growing over or into the elderberry canopy, while the lichens were covering elderberry stems. Data are means (±1 standard error) and were collected during August 2003, n = 5 shrubs per each distance and trail surface type; data were pooled across sites for graphical presentation.

dry weight (r^2 = 0.11, P = 0.003, $F_{1,115}$ = 14.2) and, although not significant at adjusted alpha = 0.010, average leaf area (r^2 = 0.05, P = 0.021, $F_{1,115}$ = 5.5).

Correlative Analyses: Effects of Proximity to Roads on Elderberry.

Distance from dirt roads was not correlated with elderberry shrub height or shrub density (number per 1963 m^2, which is a 25-m-radius circle). While shrub height was also not correlated with distance from paved roads, elderberry density slightly increased with proximity to paved roads (Table 3); this relationship accounted for a very low proportion of the variance in elderberry density. Elderberry distance from paved roads was not correlated with other elderberry measures, but decreased distance from dirt roads was weakly associated with smaller maximum stem diameter and decreased proportion of dead stems on each shrub (Table 3). Statistical power was strong for these correlations revealing small effects (power = 0.99).

Dust Effects on VELB

Using the GIS data, there were no relationships between the presence of new or 1-year-old holes and the distance from either dirt or paved roads (power for detecting small effects was 0.99, i.e., very high). The chance of old holes being present, however, slightly increased with decreased distance to both dirt and paved roads (Table 3); the very low r^2-values indicate that these relationships have almost no predictive power and are consistent with more or less no effect. New and 1-year-old holes were most likely to occur in the presence of old holes (new: $P < 0.0001$, U = 0.20, $Chi_{1,2848}$ = 215; 1-year: $P < 0.0001$, U = 0.16, $Chi_{1,2848}$ = 316). The low correlation coefficients suggest that there are variables other than the distance from roads that may better explain variation in VELB presence.

Discussion

Despite similar dust settlement rates and leaf dust accumulation along dirt and paved trails, elderberry tended to be more stressed near the dirt than paved surfaces implying that factors other than dust influenced elderberry condition. For example, dirt surfaces generally experience less surface water runoff than paved surfaces, resulting in less water availability for roadside plants. Additionally, unsurfaced areas along the American River Parkway where this study was conducted are generally farther from irrigation and the river (i.e., less soil water) than most of the paved areas. Dust, however, may contribute to elderberry stress over larger spatial scales. Variability in ambient dust levels for the Parkway (between sites) was greater than within sites. When all sites were pooled, increased sedimentation rate was weakly associated with shrub stress symptoms, such as water stress, smaller leaves, more dead stems, and more inflorescences per stem. The weak relationships suggest weak or indirect effects of dust or that dust levels covary with other variables such as elevation or water availability gradients. This gives insight into how elderberry may potentially respond to dust stress,

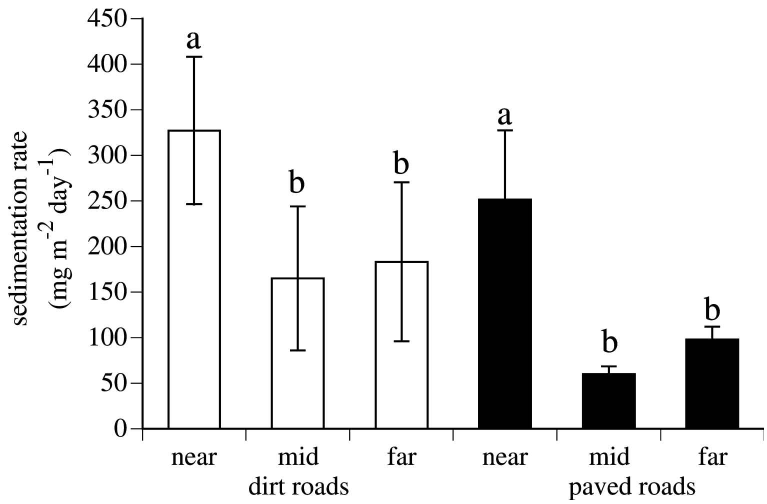

Figure 4. Sedimentation rates for near, mid, and far distances from dirt/paved trails. Near = 2–10 m, Mid = 10–25 m, and Far = 25–40 m from the trail edge. Data are means (±1 standard error) and were collected during August 2003. n = 2 particle collectors per each distance and trail surface type placed at ground level. Data were pooled across sites for graphical presentation. Different letters indicate significance at $P = 0.002$.

Table 2. Summary statistics for sediment accumulated on elderberry shrub leaves and aluminum pans

	A. Leaf sediment (mg dw sediment cm^{-2} leaf)		B. Sedimentation rate in pans (mg m^{-2} day^{-1})	
Site	Mean	SE	Mean	SE
1	0.022	0.003	95.5	44.2
2	0.021	0.003	74.6	21.8
3	0.017	0.002	168	71.8
4	0.025	0.003	367.4	100.5
5	0.031	0.004	257.3	78.2
6	0.029	0.003	185.5	68.6

The results are for accumulation of airborne dust within the American River Parkway. Datar are from August 2003. The range is 0.012–0.042 for A, 13.4–605.3 for B.

but it is not clear whether the levels of plant stress encountered are capable of having any effects on the VELB.

The amount of stress associated with elderberry found near unpaved surfaces does not appear to negatively affect elderberry population sizes since elderberry density was independent of the distance from dirt roads. The weak positive relationship between elderberry density and proximity to paved trails suggested the trails may slightly facilitate elderberry recruitment (0.2 shrubs 100 m^{-2} more next to roads vs. 600 m away), or that there are other factors correlated with paved trail locations that influence elderberry density. It appears, therefore, that while dirt surfaces did not affect elderberry quantity, they did influence elderberry in ways that may relate to host plant quality, even if dust levels are similar to ambient. The question of how elderberry condition quantitatively influences VELB presence remains uncertain and under investigation.

The presence of new and 1-year-old VELB exit holes was independent of trail location and surface type. The chance of old holes (≥2 years old) being present increased slightly (6–8%) with proximity to both dirt and paved roads. This weak relationship suggests that factors not measured in this study, but that are correlated with trail location or environment, may influence VELB presence (e.g., elevation, nutrient availability, sediment characteristics). Another explanation may be that VELB can better detect elderberry near openings in the vegetation, such as along roads, than in thicker plant cover. Additionally, VELB exit holes were noted in all sites suggesting that even the highest dust levels along the Parkway are not inhibiting VELB presence in detectable ways despite large sample sizes. This study indicates that levels of dust from dirt and paved trails and access roads

Table 3. Effects of distance from dirt and paved trails on elderberry shrubs and VELB

	Dirt			Paved		
Dependent variables	*P*	F or X^2	R^2 or U	*P*	F or X^2	R^2 or U
Elderberry characteristics						
No. shrubs in 1963 m^{2a}	—	—	—	<0.001	47.00	−0.02
Maximum stem diameter (cm)	<0.001	14.3	+0.03	—	—	—
No. stems per shrub	—	—	—	—	—	—
Height class[b]	—	—	—	—	—	—
Dead stem class[c]	<0.001	22.83		0.015	3.49	
Beetle presence/absence						
New holes	—	—	—	—	—	—
1-Year-old holes	—	—	—	—	—	—
Old holes	0.004	8.29	−0.003	0.007	7.35	−0.003

Results of simple regressions (continuous variables), logistic regressions (beetle presence/absence), or G-tests (categorical class data) showing the effects of the distance from dirt and paved trails on elderberry (*Sambucus mexicana*) characteristics, and the presence or absence of the valley elderberry longhorn beetle along the American River. Data were collected between June 2002 and March 2003, n = 2848 elderberry shrubs, except for max stem diameter where n = 524 shrubs; — = $P > 0.05$. Of the *P* values shown, only the overall *P* value for dead stems in paved sites was not significant at the sequential Bonferroni adjusted alpha.

[a]1963 m^2 = area of a 25-m radius circle.

[b]Height classes: 2–4 m, 4–6 m, 6–8 m, 8–10 m, >10 m.

[c]Dead stem classes: 0–25%, 25–50%, 50–75%, 75–99%.

are not negatively associated with VELB presence, despite variability in elderberry condition.

Management Implications

Dust Levels. This study indicates that suitable habitat for the VELB can occur adjacent to dirt and paved trails or low-traffic roads. The selection of sites for conservation, mitigation, and restoration of VELB, as well as the management of these areas, can reflect these results if sedimentation rates are similar to those found in this study (Table 2). For example, mitigation sites are sometimes initially cleared of vegetation that may compete with elderberry (Morrison and others 2003); as long as resulting dust levels remain at or below levels found here, no action need be taken. These rates are probably applicable throughout the American River Parkway or other areas where traffic on roads is restricted to 10 or fewer motor vehicles per week and consists mostly of non-motor vehicle use such as bicycles, horses, and hikers. These road dust levels appear to be relatively innocuous; they have benign or no effects on elderberry or the VELB. Additionally, lichens, known to be indicators of good air quality and observed to have high mortality next to dirt roads (Walker and Everett 1987), were highest on elderberry next to dirt roads in this study. Finally, the lowest levels of road dust documented as negatively affecting the growth, photosynthesis, and transpiration of various woody species include leaf dust levels of 0.5–1 mg cm^{-2} (Farmer 1993 and references within). Leaf dust accumulation levels found in this study were over an order of magnitude below these values and ranged from 0.012–0.042 mg cm^{-2} leaf (Table 2).

Predictions of Effects of Higher Traffic Paved Roads. - Roads with more motor vehicle traffic than in this study probably have higher deposition rates of particles originating from both vehicle exhaust emissions and from the roads. Studies of other shrub species suggest that the physical effects of dust resulting from higher traffic paved roads will not significantly affect elderberry condition. An experiment testing the effects of dust from car exhaust on the shrub *Viburnum tinus* revealed that deposits on upper leaf surfaces caused shading and reduced photoshynthesis, while deposits on the lower surfaces impeded diffusion; however, levels used in the experiments were 2.5 to 5 times greater than the highest levels found on shrubs (0.16 mg cm^{-2}) along paved motorways with 50,000 cars per day. The authors concluded that physical effects of dust from motorways on shrub photosynthesis were likely small (Thompson and others 1984).

The chemical effects of motor vehicle traffic are beyond the scope of this study and would need to be assessed. Metals such as lead, copper, cadmium, and zinc are often found associated with roadside plant leaves, roadside soil, and on the surface of highways (e.g., Naqvi and Khattak 1996; Pagotto and others 2001). It is estimated that urban road dust particle size is 3–100 μm with motor vehicle exhaust contributing to most of the finer particles (3–30 μm) (Thompson and others 1984). These small particles carry the potentially toxic metals (e.g., Gomez and others 2001) and are capable of traveling great distances from the source (Farmer 1993). Additionally, exhaust emissions produce nitrous oxides, which were found (in combination with lead) to compound the negative effects of urban dust on the growth of a species of fir (*Abies alba*) (Braun and Flückiger 1987).

Predictions of Effects of Higher Traffic Dirt Roads. In general, dirt roads produce higher dust levels than paved roads (Roberts and others 1975; Farmer 1993) but traffic is probably comparatively low. It is, therefore, likely that chemical effects of increased motor vehicle traffic on dirt surfaces would be insignificant compared to the effects of the increased particle suspension and deposition. Photosynthesis was reduced by 10% in three arid shrubs when leaves were covered with limestone quarry dust (Gale and Easton 1979). They suggested that the reduction was low considering how much dust was deposited (2142 mg m^{-2} d^{-1} at 250 m from the source) and suggested that summer light intensity was high enough to compensate for dust shading. It is not easy to relate these results to elderberry because the light sensitivity is not known.

A model for predicting particulate deposition rates from dry unpaved roads revealed, similar to the results of our study, that areas >10 m from the road generally had sediment deposition rates that were less than ambient deposition rates (Becker and Takle 1979). These results not only depended on traffic levels, but the other physical conditions of the study system, such as meteorological conditions, surface roughness, particle source and receptor heights, motor vehicle size, and particle size and type (Becker and Takle 1979).

Higher levels of dirt road dust than those observed in this study may also induce chemical effects. Again, the chemical effects of dust are beyond the scope of this study and would need to be assessed if soils were of different chemical composition (e.g., acidic or alkaline parent rocks). Road dust is commonly alkaline due to the presence of calcium, which in high levels can be toxic to plants (Farmer 1993).

Conclusions and Future Directions

Our results suggest that at the dust and traffic levels found along the American River Parkway, the placement of VELB mitigation or restoration sites and the establishment of reserves or conservation areas can occur independently of trail and access road location. Similarly, access road placement can occur near elderberry (over 10 m away), although a significant increase in the number of access roads or cleared areas could increase ambient and local dust levels, as well as have a number of other ecological effects (e.g., altered hydrology, geomorphology, invasive species spread; Trombulak and Frissell 2000). Additionally, dust abatement measures within mitigation sites and along access roads, such as rinsing shrubs and prohibiting vehicles, are probably unnecessary if dust levels remain at or below ambient levels for the Parkway. Since distances of 10 m or less from trails experience the highest dust levels, these areas should be monitored and dust abatement initiated if traffic levels increase dust levels above ambient. Furthermore, dust should be kept at or below ambient levels during beetle emergence (spring) when both dust and the physical abatement procedures could result in take of adults, eggs, or newly hatched larvae. Higher levels or different types of traffic and dust than those found along the Parkway would need to be assessed as to their effects on elderberry and VELB.

Our study indicates that it is difficult to adequately gather data about the quantitative effects of dust on elderberry and the VELB. Quantifying VELB responses to differing dust concentrations and the dust levels needed to induce an effect, will require controlled, manipulated experiments that run for a sufficient time period to study host plant physiological and population-level responses. Since the VELB is so rare, more common congeners or a surrogate species could be examined. A difficult decision for such studies, were they to be conducted, would be in deciding the time period and magnitude of dust exposure since short-term high-level exposure may produce very different effects from chronic low level exposure. A productive use of available resources might be to develop collaborative programs that monitor local and ambient dust levels, as well as VELB and elderberry populations, throughout multiuse areas that support the VELB.

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