

The Effects of Site Conditions and Mitigation Practices on Success of Establishing the Valley Elderberry Longhorn Beetle and Its Host Plant, Blue Elderberry

Marcel Holyoak · Molly Koch-Munz

Received: 22 April 2007 / Accepted: 19 December 2007
© Springer Science+Business Media, LLC 2008

Abstract This study performed the first systematic evaluation of the success of habitat mitigation at establishing the threatened Valley elderberry longhorn beetle (*Desmocerus californicus dimorphus*) and its host plant, blue elderberry (*Sambucus mexicana*). Habitat mitigation performed through enforcement of the U.S. Endangered Species Act represents a tightly controlled form of habitat restoration, facilitating the evaluation of restoration practice. Restoration plantings of blue elderberry have been substantial in our study area, the Central Valley of California. Surveys of 30 mitigation sites and 16 nearby natural sites showed that mitigation sites were a fraction of the size of natural habitat areas (mean = 24%) and contained smaller shrubs. The beetle colonized 53% of mitigation sites and its populations were denser in sites with moderate levels of dead stems on elderberry shrubs, and moderate damage to elderberry stems and bark. This likely indicates that the beetle responds to stressed shrubs, which are likely to contain elevated levels of nitrogen. Beetle density also increased with the size and age of mitigation sites. This indicates a need to make restoration sites as large as possible and to monitor these sites for longer than current guidelines suggest, thereby allowing more time for convergence of natural and mitigation sites. Few factors examined here directly influenced the growth of elderberry shrubs, but elderberry grew more rapidly in sites closer to riparian areas, indicating that such sites should be favored for mitigation sites.

Keywords Argentine ants · *Desmocerus californicus dimorphus* · Elderberry · Irrigation · *Linepithema humile* · Mitigation · Plant stress · Restoration · *Sambucus mexicana* · Valley elderberry longhorn beetle

Introduction

The Valley Elderberry Longhorn Beetle (“VELB”), *Desmocerus californicus dimorphus* Fisher, (Coleoptera: Cerambycidae) is endemic to California’s Central Valley (Linsley and Chemsak 1972; Barr 1991), and has been a target of substantial restoration and mitigation effort. The VELB was listed as federally threatened in 1980 because of habitat loss and degradation (USFWS 1980). The recovery plan (USFWS 1984) contained only general biological criteria to aid recovery. Recovery methods consist of planting the beetle’s sole host plant, blue elderberry (*Sambucus mexicana*, C. Presl: Caprifoliaceae), and avoiding harmful factors, such as pesticides, construction dust, and habitat destruction. It is not clear that these recovery strategies have promoted increases in the abundance or distribution of the beetle. For example the beetle occupies no more than 25% of apparently suitable elderberry shrubs (Collinge and others 2001; Talley and others 2007), indicating that factors other than host plant availability limit its distribution. Blue elderberry planting efforts have included over 130,000 shrubs in riparian restoration sites and over 47,000 shrubs through habitat mitigation in Habitat Conservation Plans (HCP’s) conducted both through Section 10(a)1(b) of the Endangered Species Act (ESA) for private parties and through ESA Section 7 consultations for Federal agencies (Talley and others 2006). From the perspective of restoration and its evaluation, mitigation plantings represent a tightly

M. Holyoak (✉) · M. Koch-Munz
Department of Environmental Science and Policy, University of California, One Shields Avenue, Davis, CA 95616, USA
e-mail: maholyoak@ucdavis.edu

prescribed form of restoration that allow evaluation of the effects of restoration. Despite the large amount of planting of blue elderberry there have been few attempts to evaluate its success in mitigation or restoration (existing attempts are described below).

For restoration in the form of mitigation, Kareiva and others (1999) and Harding and others (2001) evaluated 43 HCPs for 64 species. Their main findings were that there was considerable uncertainty in whether mitigation was likely to succeed; monitoring of mitigation was in place for only 51% of plans and was rarely considered adequate. Holyoak (unpublished data) evaluated mitigation reports for the threatened VELB and found that many reports were missing from USFWS files, and that transplanted elderberry shrubs were especially valuable because they brought both beetles and plants of a suitable size for beetles to mitigation sites. The low quality and lack of consistency of data in mitigation reports meant much of the information they contained could not be used to test restoration practice. Evaluation of five restoration sites along the Sacramento River (California) by Alpert and others (1999) for 10 species of woody plants, including blue elderberry, showed that first-year elderberry survival was highly variable among sites (13–100%), and elderberry grew in height faster on finer (“less sandy”) and deeper soils (Alpert and others 1999; see also Hey and Phillippi 1999 for a single-site evaluation). There is, therefore, a need to understand more of the causes of among-site variation in mitigation success, defined here as establishment of vigorously growing blue elderberry shrubs and large VELB populations.

Mitigation for the VELB consists of planting elderberry seedlings and associated woody species, and transplanting mature elderberry shrubs. Various factors potentially influence the success of such mitigation: the age, size, and nutrient composition at which elderberry become suitable habitat for VELB colonization (Barr 1991); the direct and indirect effects on VELB of other species, particularly invasive predatory Argentine ants (*Linepithema humile*)—which are spreading through riparian habitats in California and are capable of displacing native arthropods, including other native ants (e.g., Ward 1987; Holway and others 2002) and the VELB (Huxel 2000); habitat patch size, distribution, and location (Collinge and others 2001); and site factors that may affect elderberry growth and survival, including site age, irrigation, soil characteristics, and associated vegetation.

The uniformity of restoration practices within mitigation sites for the VELB is mandated by USFWS Conservation Guidelines that were completed in 1988 and have been modified three times (USFWS 1988, 1992, 1996, 1999). The changes reflect increasing concern over persistence of the VELB (e.g., Collinge and others 2001) and the

impression that mitigation sites frequently remained uncolonized by beetles. Modifications included an increase in elderberry planting ratios from two to ten new elderberry seedlings for every one elderberry stem lost (stems being defined as being of 2.5 cm or greater at ground level). In 1994 the guidelines were modified to include the planting of associated native shrubs and trees.

We here addressed a series of questions about the success of habitat mitigation at establishing healthy blue elderberry plants and VELB populations: Do mitigation sites differ from natural sites in the size and condition of elderberry and the type and amount of associated vegetation? Does VELB colonization increase with site age? Is VELB colonization or abundance influenced by distance to natural habitat from mitigation sites, distance from water bodies, or whether sites were within floodplains? Does irrigation type or whether sites are located within floodplains influence VELB abundance? Does the growth and condition of elderberry differ in response to site conditions such as site age, type of irrigation, associated vegetation, and whether sites were within floodplains or not? How frequently are invasive predatory Argentine ants found in mitigation sites and is there any indication of effects on VELB or native ants? These questions were used to help guide suggestions for improving mitigation practice for the VELB.

Methods

Habitat factors were measured at 30 mitigation sites and at 16 natural sites distributed throughout California’s Central Valley. Appendix describes locations and details for each site. Mitigation sites were selected from mitigation monitoring reports obtained from California Department of Transportation (CalTrans for sites they initiated), Department of Water Resources, USFWS, and California Academy of Sciences. Mitigation sites were selected if the report contained a map or detailed location for the conservation site, if the report listed at least 30 planted elderberry shrubs, and if the conservation site was located.

Natural sites were within 20 km of selected mitigation sites, and were approximate nearest known locations of VELB populations (Barr 1991). These sites were not selected randomly from among all possible natural areas with blue elderberry. Because this was a deliberate attempt to represent suitable conditions for the VELB, rather than a sampling of randomly selected natural areas with blue elderberry, we did not compare the frequency of VELB in mitigation and natural sites.

Mitigation sites were surveyed in July–early November 2005 and February–April 2006, while natural sites were surveyed in April–September 2006, and the metrics

measured are presented in Table 1. Although certain characteristics were measured in 2005 in mitigation sites versus 2006 in natural sites (Table 1), and in different seasons, these were sufficiently fixed not to have expected to have changed between consecutive years. Relative growth rate was calculated for elderberry shrubs in mitigation sites as $RGR = (\phi_2 - \phi_1) / \phi_1$, where ϕ_2 is the maximum stem diameter in year 2, and ϕ_1 is the maximum diameter in year 1. Soil variables were evaluated separately (Koch-Munz and Holyoak in press) and are not considered here.

We conducted the following analyses, all of which were performed in Statistica 6.1 (Statsoft Inc., Tulsa OK): (1) A MANOVA to test whether mitigation sites differed from natural sites in the size and condition of elderberry, and the type and amount of associated vegetation; (2) Contingency tests of the frequency of VELB presence/absence performed on individual shrubs for various habitat factors: irrigation type, amount of bark damage, type of stem damage (none, pruned, burned), percent dead stems (0–25%, 25–50%, 50–75%, 75–100%), elderberry condition

(0 = dead to 4 = healthy), type and percent (0%, 1–25%, 25–50%, 50–75%, 75–100%) of canopy cover over elderberry, species and percent (0–25%, 25–50%, 50–75%, 75–100%) of overgrowth of elderberry shrubs by other shrubs, species and percent (0–25%, 25–50%, 50–75%, 75–100%) of vines overgrowing elderberry, herb/grass understory type and percent (0–25%, 25–50%, 50–75%, 75–100%), and leaf damage type and percent (0–25%, 25–50%, 50–75%, 75–100%); (3) A multiple regression to test whether VELB abundance (and a logistic regression for VELB presence/absence) varied with site age, site size, distance from natural sites containing VELB, and distance from water bodies; (4) ANOVA's to test whether VELB colonization or abundance were influenced by whether sites were within floodplains, irrigation type, and associated vegetation; (5) Regressions to test if elderberry growth rate or condition in mitigation sites changed with site age, distance from water bodies or natural sites, or the size and age of mitigation sites. For elderberry relative growth rate (RGR), we found that it was negatively related to elderberry size and we therefore corrected for elderberry size by

Table 1 Data from field surveys and GIS layers measured during this project

Characteristic	Year of survey	
	Mitigation sites	Natural sites
<u>Measured for/at each elderberry</u>		
Presence/absence of VELB (new, 1-yr old, old holes)	2005, 2006	2005, 2006
Abundance of VELB (new, 1-yr old, old holes)	2005, 2006	2005, 2006
Stems per shrub of ≥ 2.5 cm per shrub	2005, 2006	2006
Basal diameter of stems of ≥ 2.5 cm diameter (cm)	2005, 2006	2006
Shrub height (m)	2005, 2006	2006
Canopy length and width (m)	2005, 2006	2006
Elderberry habitat quantity index	2005, 2006	2006
Elderberry condition index (0 = dead, 4 = most healthy)	2005, 2006	2006
% and type of leaf damage (herbivory)	2005, 2006	2006
% and type of nonelderberry canopy cover	2005	2006
% and type of nonelderberry shrub cover	2005	2006
% and type of ground cover (understorey)	2005	2006
% and type of overgrowth by vines	2005	2006
Irrigation type	2005	n/a
<u>Site characteristics</u>		
County	Fixed	Fixed
Waterway/watershed	Fixed	Fixed
Within FEMA 100-year floodplain	Fixed	Fixed
Site age (years since planting)	Fixed	n/a
Argentine ant presence and relative abundance	2006	2006
Distance to nearest VELB population	2006	n/a
Distance to nearest water way/body	Fixed	Fixed

The year of measurement is given for mitigation and natural sites, or as fixed for characteristics that do not change; n/a = not applicable. Shrubs consisted of either seedling elderberries or transplants in all cases. New holes were <1 year old. Further details of variables are given in Talley and others (2007)

using the residuals from the regression of RGR versus maximum stem diameter. These residuals were used in tests of the effects of factors listed here; (6) ANOVA's to test whether elderberry size or condition varied with type of irrigation, and associated vegetation; each ANOVA was for two factors' site identity and the chosen factor nested within this for individual shrubs—we did not attempt more complex designs because of the arbitrariness of which factors to include in each analysis and all factors could not be included in a single analysis; (7) A regression to test the effect of site age on the frequency of Argentine ants, and correlations to test whether the presence of Argentine ants in mitigation sites influenced either the frequency of native ants or VELB.

Results

Comparing Natural and Mitigation Sites

A MANOVA showed that on average compared to 16 natural sites, 30 mitigation sites were smaller, contained smaller elderberry shrubs but with more stems per shrub, and contained less native ants (Table 2; Wilks' lambda = 0.105, $p < 0.0001$). Mitigation and natural sites did not differ in mean elderberry shrub condition, soil moisture levels, or the mean number of Argentine ants per shrub (Table 2). On average, mitigation sites were only 24% of the size of natural sites (Table 2).

Factors Influencing the Presence of VELB

VELB were present in 16 of 30 (53%) mitigation sites. A comparison of shrubs that contained VELB and those that did not within mitigation sites involved 15 χ^2 tests (Table 3), of which 8 (53%) were significant at $p < 0.05$, which is far more than the 5% of tests expected to be

significant by chance alone; applying a more conservative statistical test, a sequential Bonferroni correction, led to significance (at $p < 0.05$) of only the first four factors listed in Table 3. When we nested shrubs within sites in preliminary tests we found broadly similar patterns to those without sites in Table 3, which we present because they are considerably less complex to summarize. We also tested for autocorrelation of residuals using Durbin-Watson tests but found no significant autocorrelation (at $p < 0.1$). Four comparisons were strongly significant (and significant at $p < 0.05$ in sequentially-corrected Bonferroni tests): (1) Relative to their average rate of occurrence across all shrubs, VELB were more frequently absent (and less frequently present) in sites with drip irrigation (Table 3a). Further, they were present more frequently than average in sites lacking irrigation, and absent more often than average in sites with sprinklers (Table 3a). Further analysis showed that this was likely an effect of site age, since visited sites with drip or sprinkler irrigation were younger than sites with no irrigation ($F_{3,26} = 3.55$, $p = 0.03$ in a 1-way ANOVA, means: no irrigation 10.3 ± 0.8 SE years; drip 8.7 ± 1.3 years; and sprinkler 5.1 ± 0.9 years). (2) VELB were more likely to be present and less likely to be absent in shrubs with partial bark damage (as opposed to girdled), and consistent with this VELB were present less frequently than average in shrubs with no bark damage (Table 3b). (3) In shrubs that had stems damaged by pruning or burning, VELB were absent less frequently than average, and similarly VELB were both present more often in shrubs with burned stems and absent more often in stems with no more damage than average (Table 3c). (4) VELB were present less often than average in shrubs with 0–25% dead stems, and absent less frequently than average in shrubs with 25–50% dead stems (Table 3d).

Other patterns were significant without sequential Bonferroni correction, but not significant at $p < 0.05$ when this (somewhat conservative) correction was applied. A weaker

Table 2 One-way ANOVA's comparing mitigation and natural sites

	SS	MS	SSE	MSE	$F_{1,41}$	p	r^2	Mean mitigation	Mean natural
ln(size in acres)	304.5	304.5	88.0	2.15	141.80	0.0001	78%	1.83 (0.24)	7.50 (0.47)
Shrub condition	0.74	0.74	10.3	0.25	2.94	0.0941	7%	2.69 (0.11)	2.97 (0.08)
Max. height (m)	105,322	105,322	468,598	11,429	9.22	0.0042	18%	326.2 (22.6)	431.8 (17.1)
Canopy width (cm)	162,875	162,875	466,963	11,389	14.30	0.0005	26%	274.6 (22.1)	406.0 (19.6)
Stem diameter (cm)	76.97	76.97	122.7	2.99	25.72	0.0001	39%	5.39 (1.78)	8.24 (1.62)
Stems per shrub	35.9	35.9	141.42	3.45	10.42	0.0025	20%	2.9 (0.4)	0.98 (0.47)
Leaf litter weight (g)	24,406	24,406	160,992	3,927	6.22	0.0168	13%	59.3 (9.4)	110.2 (22.1)
Soil moisture (%)	50.6	50.6	1,463.1	35.7	1.42	0.2405	3%	8.9 (1.1)	6.6 (1.7)
Other ant records per shrub	0.12	0.12	0.78	0.02	6.24	0.0166	13%	0.07 (0.02)	0.18 (0.05)
Argentine ants per shrub	0.02	0.02	1.46	0.04	0.46	0.5013	1%	0.11 (0.04)	0.15 (0.04)

Standard errors are given in parentheses

Table 3 Frequency and percent of expected values (in parentheses) of sites with various characteristics and VELB present or absent (from any-aged exit holes)

Characteristic	VELB absent	VELB present	χ^2	df	<i>p</i>
a. Irrigation: none	382 (97%)	48 (128%)	9.48	2	0.008*
Drip	217 (104%)	12 (60%)			
Sprinkler	29 (110%)	–			
b. Bark damage: none	614 (102%)	45 (81%)	33.29	2	0.0001*
Partial	34 (77%)	14 (345%)			
c. Stem damage: none	616 (102%)	45 (80%)	45.75	4	0.0001*
Pruned	20 (70%)	11 (419%)			
Burned	10 (91%)	–			
d. Dead stem % classes: 0–25%	617 (102%)	45 (80%)	42.64	3	0.0001*
25–50%	18 (80%)	–			
e. Elderberry condition: 0	42 (109%)	–	12.64	4	0.013
1	26 (89%)	–			
2	179 (102%)	13 (80%)			
3	259 (97%)	32 (103%)			
4	143 (103%)	–			
f. Canopy type: none	442 (100%)	43 (105%)	25.58	14	0.03
Oak	88 (100%)	–			
Willow	12 (109%)	–			
Cottonwood	48 (105%)	–			
Sycamore	20 (109%)	–			
Elderberry	12 (73%)	–			
g. Canopy cover % classes	–	–	1.45	4	0.85
h. Shrub type	–	–	7.84	16	0.95
i. Shrub % classes: 0	521 (99%)	53 (109%)	10.48	4	0.033
1–25%	101 (106%)	–			
25–50%	19 (94%)	–			
j. Overgrowth type	–	–	5.89	6	0.44
k. Overgrowth % classes	–	–	1.36	4	0.85
l. Understorey type	–	–	12.67	5	0.026
m. Understorey % classes	–	–	2.62	4	0.62
n. leaf damage: insect herbivory	592 (99%)	60 (109%)	5.73	2	0.06
o. Leaf damage % classes	–	–	2.4	3	0.49

“–” indicates $p > 0.05$ or $n < 10$. Only characteristics with $n \geq 10$ are given. *p*-values are uncorrected values, and * indicates significance at $p < 0.05$ when a sequential Bonferroni is applied. Oak is *Quercus lobata*, willow is *Salix* spp., sycamore is *Platanus racemosa*, cottonwood is *Populus fremontii*

but still significant pattern was that the frequency of VELB presence varied with the species of tree canopy present (Table 3f). VELB were present more often than average in shrubs with no canopy overhead and were absent more often than expected beneath willow, cottonwood, and oak species (Table 3f). VELB absence beneath nonplanted mature elderberry was less frequent than the average (Table 3f). The amount of canopy cover (measured in percent classes) was not significantly related to the frequency of VELB presence/absence (Table 3g).

We found several other patterns of VELB presence and absence in relation to habitat factors; however, these were

inconsistent across levels of factors and/or had sample sizes that were not much above our minimum of 10 used in analyses, or were no longer significant at $p < 0.05$ if a sequential Bonferroni correction was applied. The frequency of VELB presence was significantly related to the amount of shrubs, other than elderberry, overgrowing elderberry shrubs, but not in a way that was easily interpretable (Table 3i). The type of shrubs growing into elderberry had no significant effects on the frequency of VELB presence (Table 3h). Not surprisingly VELB were more likely to be absent in dead (condition = 0) shrubs than live shrubs; this was the effect that had the strongest

influence on χ^2 in Table 3e, and other effects of shrub condition had little effect on χ^2 . VELB were significantly affected by the type of herb or grass understorey, but this pattern was entirely due to understorey categories with less than 10 samples (Table 3l). There were no significant effects on the frequency of VELB presence/absence from shrubs of vine overgrowth amount or type (e.g., blackberry = *Rubus discolor* and *R. ursinus*, poison oak = *Toxicodendron diversilobum*), percent herb or grass understorey, nor the amount of type of leaf damage (Table 3j, k, l, m, n, o).

In mitigation sites VELB abundance per elderberry shrub was positively related to site size and site age (Table 4); VELB abundance per stem was also related to site age but not site size (Table 4). There was a weak negative relationship between VELB per shrub and the total number of elderberry planted per site, but this was not quite significant (Table 4). Distance to water bodies and distance to natural sites containing VELB were unrelated to VELB per shrub or per stem (Table 4; similar results were found for presence/absence).

Factors Influencing the Growth and Health of Elderberry

Seedlings grew faster than transplants when corrected for shrub size (Table 5, from an ANOVA in which shrub type was nested within sites, $F_{2,540} = 6.04$, $p = 0.003$); mean residual (size-corrected) growth rates for seedlings ($-0.44 \pm \text{SE} = 0.01$) were 79% of those for transplants (-0.56 ± 0.03).

Size-corrected elderberry growth rate was negatively related to site age (Table 5; see also Koch-Munz and Hoyoak in press). In the same multiple regression, size-corrected growth rate was also negatively related to the distance from natural sites (Table 5). There were no significant effects on size-corrected elderberry growth rates of distance to water (although at $p = 0.07$ sites closer to water had higher growth rates), site size, and number of elderberry planted (Table 5).

An ANOVA on size-corrected elderberry growth rates for individual shrubs with factors nested within sites showed that residual growth rates were higher for sprinklers (mean = -0.28 ± 0.04) than for no irrigation or drip irrigation (means -0.47 ± 0.01 and -0.46 ± 0.02 , respectively) and this was significant at $p < 0.001$ ($F_{2,519} = 10.08$). None of the other factors in Table 3 significantly influenced the size corrected (residual) elderberry growth rate.

Mitigation and the Presence of Argentine and Native Ants

Argentine ants were present in 16 of 16 natural sites and 8 of 30 (27%) mitigation sites. However, mitigation sites were surveyed in July–early November 2005 and February–April 2006, whereas natural sites were surveyed in April–September 2006. The frequency of Argentine ants in mitigation sites increased with site age (Fig. 1). However, the frequency of Argentine ants was not related to the frequency of VELB per shrub ($r = 0.03$, $n = 30$, $p = 0.89$). The frequency of native ants was also unrelated

Table 4 Regression of factors influencing the abundance of VELB per elderberry shrub in mitigation sites (total $r^2 = 0.37$), and VELB per elderberry stem (total $r^2 = 0.36$)

VELB per shrub	Beta	SE	B	SE	<i>t</i> (22)	<i>p</i> -level
Intercept			-0.213	0.689	-0.308	0.761
ln(distance to nearest water in m)	0.073	0.184	0.032	0.079	0.398	0.695
ln(distance to natural in m)	-0.230	0.191	-0.090	0.075	-1.205	0.242
Size (acres)	0.493	0.201	0.273	0.111	2.456	0.023
Number elderberry planted	-0.440	0.218	2.3×10^{-5}	1.1×10^{-5}	-2.022	0.057
Number elderberry transplanted	-0.316	0.188	-0.001	0.001	-1.680	0.109
Age (yrs)	0.468	0.195	0.092	0.038	2.395	0.027
VELB per stem	Beta	SE	B	SE	<i>t</i> (19)	<i>p</i> -level
Intercept			-4.952	5.496	-0.901	0.379
ln(distance to nearest water in m)	0.192	0.194	0.639	0.647	0.988	0.336
ln(distance to natural in m)	-0.162	0.194	-0.492	0.589	-0.835	0.414
Size (acres)	0.324	0.205	0.056	0.036	1.583	0.130
Number elderberry planted	-0.309	0.217	-0.001	0.001	-1.421	0.171
Number elderberry transplanted	-0.211	0.193	-0.008	0.007	-1.094	0.288
Age (yrs)	0.575	0.203	0.899	0.312	2.838	0.011

Table 5 Results of a multiple regression in which an index of elderberry growth rate was the dependent variable and sites were replicates

	Beta	SE	B	SE	<i>t</i> (18)	<i>p</i>
Intercept			1.50	0.44	3.42	0.003
Ln(distance to nearest water in m)	-0.33	0.17	-0.09	0.04	-1.93	0.069
Ln(distance to natural in m)	-0.39	0.17	-0.10	0.04	-2.26	0.037
Ln(site size in acres)	0.21	0.19	0.09	0.09	1.10	0.286
Number of elderberry planted	-0.18	0.20	-5.6×10^{-6}	6.4×10^{-6}	-0.89	0.380
Site age (yrs)	-0.47	0.17	-0.06	0.02	-2.75	0.013

The index was the residual from Ln(RGR) versus elderberry maximum stem diameter, and, hence, was corrected for elderberry size. Residual = $0.145 \times \text{stem diameter} + \text{RGR} + 1.26$. Total $r^2 = 0.52$

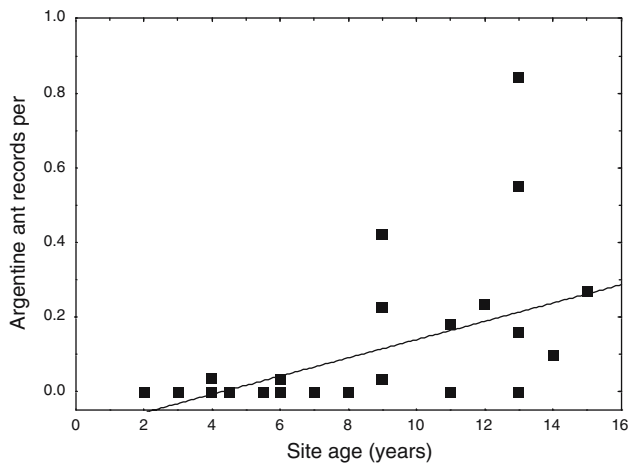


Fig. 1 The effect of site age on the frequency of Argentine ants within mitigation sites. The line shows a linear regression, where number of Argentine ants per shrub = $0.204 \times \text{site age} - 0.103$. Student's $t_{28} = 2.94$, $p = 0.007$, $r^2 = 0.23$

to the frequency of Argentine ants ($r = 0.08$, $n = 30$, $p = 0.68$).

Discussion

We performed the first broad-scale field evaluation of habitat mitigation practices and their effect on the threatened VELB. Our study showed that mitigation sites were on average only 24% of the size of natural riparian habitat remnants containing VELB (see also Morrison and others 2003). Larger mitigation sites also contained considerably more VELB than smaller sites (Table 4), and therefore were substantially more valuable. Hence, caution needs to be used to ensure that VELB mitigation does not contribute to riparian habitat fragmentation by creating small habitat areas which are not continuous with large expanses of riparian habitat. Mitigation sites also contained smaller elderberry shrubs (in height, diameter, canopy width) than natural sites. This likely reflects that elderberry shrubs were, on average, younger in mitigation than in natural

sites. (Surprisingly we also found more stems per shrub in mitigation than natural sites. However, this is likely a result of shrubs being classified as separate when their stems were separated by gaps ≥ 5 m at ground level, so that larger shrubs in natural sites are more likely to cover larger areas due to underground suckering and would be treated as a number of separate shrubs with less stems per shrub.) Mitigation sites also contained native ants less frequently than natural sites, which might reflect the time taken for native ants to colonize mitigation sites. Encouragingly, the condition of blue elderberry was similar in natural and mitigation sites.

A broad range of factors influenced the frequency of VELB within mitigation sites. It might be of management concern that VELB were more frequently absent in sites with drip irrigation or sprinklers than with no irrigation. However, this effect might be explained by sites with drip or sprinkler irrigation being younger than those with no irrigation. Younger sites would have had less time for VELB to colonize and increase in abundance, and we also found that the numbers of VELB exit holes per shrub and per stem were positively related to site age. Holyoak (unpublished data) did not find a clear effect of site age on the frequency with which mitigation sites were reported to contain VELB. However this earlier study relied on data being collected by different biologists for each mitigation site. When data were uniformly collected, both VELB emergence holes per shrub and per stem increased with site age (Table 4).

Low levels of damage to elderberry shrubs increased the frequency of presence of VELB. VELB were more likely to be present in shrubs with partial bark damage, as opposed to shrubs with greater levels of bark damage or no bark damage, and were frequently present when stems were pruned or had fire scars from previous burning. VELB were also more frequently present in shrubs with 25–50% dead stems than in shrubs with 0–25% dead stems. A possible interpretation is that VELB are attracted to stressed shrubs that may have high levels of nitrogen available within their pith. Wood-boring beetles are known to grow better and be

more abundant in trees with higher nitrogen levels (Haack and Slansky 1987), but nothing more specific is known about this for the VELB. However the relationships between plant stress and insect performance are complex, for instance, intermediate levels of stress are thought to be beneficial for cambium-feeding bark beetles (Larsson 1989). The frequency of dead stems and amounts of bark damage clearly had limits, since only partial levels of bark damage (as opposed to girdled stems) and 25–50% dead stems (as opposed to > 50%) led to increased VELB presence. Talley (2007) found that VELB spatial clusters of abundance were positively associated with spatial clusters in levels of pith nitrogen in elderberry. Therefore, while we can say that high elderberry nitrogen levels clearly benefit the VELB, the relationship to elderberry plant stress is less clear.

Another possible manifestation of this pattern, or possibly an independent effect, was that VELB were present more often than average in shrubs with no canopy, and were absent more often than expected beneath willow, cottonwood, and oak species. Elderberry stress might arise through competition between plant species, or shade cover might reduce the chance of desiccation of VELB inside of elderberry stems. Additionally VELB were frequently present beneath nonplanted mature elderberry, perhaps indicating suitability of conditions or that mature trees provided a source from which beetles colonized. This was not a simple effect of shading since the overall percent canopy cover was not significantly related to the frequency of VELB presence/absence.

It has been predicted that colonization of species following habitat restoration may be more rapid if sites are closer to existing populations (e.g., Huxel and Hastings 1999). However we found that distance to natural sites containing VELB was unrelated to VELB per shrub or VELB per stem within mitigation sites. Our analysis however had limited statistical power and we should therefore be cautious about interpreting the absence of such an effect. The distance of mitigation sites to natural sites containing VELB varied from 100 m to 54 km. While the exact distances that VELB can fly and regularly disperse are unknown, it is likely that some mitigation sites would have been readily reachable by VELB and others not (e.g., Collinge and others 2001). The absence of an effect of distance between natural and mitigation sites is therefore unlikely to be a matter of spatial scale.

Previous studies have found that blue elderberry survival was highly variable in restoration sites (Alpert and others 1999), and among mitigation sites (Holyoak and others in review). Some of this variation could be accounted for by the type of irrigation used and through annual variation in weather; most variation in survival could not be explained (Holyoak, unpublished data). In the

present study we did not analyze survival because we deliberately sampled live elderberry shrubs within mitigation sites so that we could ascertain growth rates. As reported by Koch-Munz and Holyoak (in press), within mitigation sites, elderberry health and growth were positively correlated with the amount of total soil nitrogen and less strongly with other soil nutrients and soil moisture. Within restoration sites along the Sacramento River, elderberry grew in height better on soils that were less sandy and deep (Alpert and others 1999). We found that transplants grew at 79% of the rate of seedlings when corrected for shrub size. This might be caused by shrubs being damaged during transplantation from having their roots and shoots cut back for removal and transportation. We also found that size-corrected elderberry growth rates were higher for sprinklers than for sites (and shrubs) with no irrigation or drip irrigation. Hence sprinkler irrigation seems advantageous for elderberry growth. However, Holyoak (unpublished data) found that survival of elderberry was lower for sprinkler irrigation than for no irrigation or for any other form of irrigation (survival in first year was 92% for bubbler irrigation, lower for hand and drip irrigation, 77% and 76% survival, respectively, and lowest for no specified type of irrigation, 51%, and sprinklers 48%). Hence small differences in the growth rate of elderberry are likely to be offset by differences in elderberry survival. Elderberry growth rate (size corrected) was not influenced by associated vegetation or damage to elderberry.

Contrary to fears of the potential negative effects of predatory Argentine ants in mitigation sites (Huxel 1998; Young and Evans 2000; Talley 2007) we found no such effects here. We found that the frequency of Argentine ants in mitigation sites increased with mitigation site age. Talley and others (2006) suggested that Argentine ants were introduced into mitigation sites in plant pots from nurseries, and that irrigation promoted ideal conditions for their growth and survival. If Argentine ants are introduced in plant pots, it would be difficult to explain their increase in frequency with site age. Increase in Argentine ant frequency with site age might, therefore, represent that ants are also colonizing sites independently of planting. The frequency of Argentine ants was not related to the frequency of VELB per shrub. The frequency of native ants was also unrelated to the frequency of Argentine ants (contrary to Ward 1987; Holway and others 2002). However, we should be cautious in interpreting these results because we did not use bait traps to detect ants. Using baited traps provides a more reliable record of ant presence. For example, Talley (unpublished) placed out bait stations with sugar water and tuna fish for three hours, and standardized the time of season when sites were visited. There was also a good deal of flooding of sites prior to sampling in 2006, which might of disrupted ant

populations. In the present study we should therefore be cautious about interpreting the absence of patterns between VELB and Argentine ants, between native and Argentine ants, and between Argentine ants and site conditions. For example, it is known that Argentine ants in California are associated with damp soils resulting from irrigation (Menke and Holway 2006).

Management Implications

Our findings lead to several recommendations for restoration practice. First, habitat mitigation sites for the VELB are a fraction of the size of natural sites, and are therefore contributing to habitat fragmentation. From this it follows that restoration sites should be as close as possible to existing riparian habitat areas and VELB populations, and as large as possible; this idea is also supported by meta-population theory and the equilibrium theory of island biogeography (MacArthur and Wilson 1967; Hanski and Gilpin 1991). Elderberry also grew more rapidly in sites that were closer to natural habitat areas, perhaps because of similarity of conditions or ground water availability. This would also point towards the use of mitigation banks rather than small isolated ad hoc mitigation sites. Fortunately, habitat restoration sites that include elderberry are often large (Talley and others 2007), but this is clearly not true of mitigation sites for VELB.

Second, we identified several factors that make habitat more favorable for higher densities of VELB; however, these are not clearly factors that can reliably be manipulated. Furthermore, our results are correlative, and therefore independent experimental studies are desirable. In particular, damage to elderberry stems and bark produced favorable conditions for VELB. However, too much damage did not have a positive effect and the time course over which an effect is seen is unknown. Although damage therefore cannot easily be manipulated (at least without further study), our findings do suggest that we should not

be overly concerned about damage to elderberry shrubs that is nondeliberate. A fuller experimental study of the effects of pruning is currently underway (Talley and Holyoak unpublished).

Thirdly, transplants grew proportionately less than did seedlings. However we still recommend transplanting shrubs because it has been shown that they provide large elderberry plants to give mitigation sites a head start for VELB habitat creation, and that they may bring beetles to mitigation sites, promoting colonization (Holyoak and others in review).

Our study was conducted on mitigation sites, which are considerably smaller than many restoration sites containing blue elderberry (Talley and others 2006). It is, therefore, desirable to evaluate the performance of VELB in larger restoration sites, which are also planted under a greater variety of conditions. Mitigation seems somewhat successful at establishing populations of the VELB but it is necessary to evaluate sites that are older, where VELB have had longer to colonize and where elderberry are closer in size to those in natural sites. We therefore recommend continued monitoring and evaluation of mitigation sites.

Acknowledgments We thank Rachel Zisook, Lauren Valverde, Peter Nilsson, Henning Gertz, and Karen Adler for assistance with field work. Assistance with site selection, access, and information was provided by Kelly Kawsuniak, Sharon Stacey, Terry Marshal, Margaret Lawrence, and Christina Macias at CalTrans. We thank the following for help with access to sites and/or reports: Jane Caputo, Nathan Higgins, and Hilary Dustin (Sequoia Riverlands Trust); Phil Deffenbaugh, Sidney Jones, and Larry Baker (U.S. Army Corps of Engineers); Andrew Fulks and J.P. Marie (Putah Creek Stream Keepers); Jones and Stokes Inc.; Annalena Bronson and Dwaine Cornett (Department of Water Resources); John Fitzpatrick (SunCal Companies); Sara Egan (E-Corp); Dave Camden (Greenhorn Creek Resort); Matt Gause (Wildlands, Inc); Susan P. Jones and Charlene Steeman (USFWS Sacramento Field Office). For GIS data we thank Diane Pierzinski (CalTrans) and Mary Meade (Office of Homeland Security). We thank T.S. Talley and John Callaway for their guidance and support. Funding for this project was provided by CalTrans contract 43A0067 Task Order 52.

Appendix

Table A1 Details of mitigation sites

Mitigation responsible party (project name)/mitigation agent	FWS case number	County	Coordinates (N, W)	In flood-plain?	Irrigation Type?	Nearest Waterbody	Direction/Distance to Nearest Waterbody	Size (acres)	eb planted (#)	eb trans-planted (#)	Age (yrs)
CalTrans (Cottonwood Creek)/CalTrans	1-1-98-F-95;1-1-98-F-94;1-1-96-F-150	Tehama	40.375, -122.29	Yes	none	Cottonwood Creek	80 m/S	8	630	47	6
CalTrans (Toomes Creek)/CalTrans	1-1-98-F-0150;1-1-98-F-0094;1-1-00-F-0164;1-1-00-F-0165;1-1-00-F-0024;1-1-01-F-0056;1-1-02-F-0173; 1-1-04-F-0337	Tehama	39.974, -122.07	Yes	sprinkler	Toomes Creek & Sacramento River	50 m/N & 1,200 m/W	41.5	623	31	3
CalTrans (M&T Ranch)/TCRCD	1-1-02-1-1705	Glenn	39.65, -121.91	Yes	none	Murphy Slough	913 m/N	3.6	467	15	14
ACOE (Sac River Flood Control)/The HLA Group	1-1-93-F-8	Yuba	39.04, -121.60	Yes	none	Feather River	10 m/W	75.8	7,690	0	13
CalTrans (Fleeman Parcel)/CalTrans	1-1-93-F-34	Yuba	39.11, -121.58	Yes	sprinkler & flood	Feather River	1,330 m/E	41	600	0	6
M/J Properties/Wetlands Research Associates	1-1-92-F-16	Placer	38.983, -121.03	No	drip	Reservoir	1,000 m/N	7.8	35	62	11
Suncorp (Bickford Ranch)/Ecorp Consulting, Inc.	not listed on documents	Placer	38.54, -121.87	No	drip	ephemeral - drainage	200 m/N	1	75	20	3
Highlands at Cavitt Ranch/Ecorp Consulting, Inc.	97-F-0067, 02-F-0067	Placer	38.76, -121.23	Yes	hose	Dry (Miner's) Creek	10 m/N & S	3.2	337	47	4
Sterling Point Estates/Acorn Environmental Consulting	1-1-92-F-44	Placer	38.75, -121.16	No	none	Folsom Reservoir	500 m/E	2.3	210	9	13
Granite Bay Golf Club/Jones & Stokes Associates, Inc.	1-1-92-F-80	Placer	38.72, -121.19	No	none	mitigated wetland	10 m/E - W	2.2	108	10	13
Elliott Homes (American River Canyon North)/Ecorp Consulting	1-1-99-F-0007	Sacramento/Placer	38.71, -121.19	No	none	ephemeral - drainage	30 m/S	3.3	62	5	7
Elliott Homes, Inc. (Broadstone Mall)/Ecorp Consulting, Inc.	1-1-93-F-73	Sacramento/Placer	38.69, -121.19	No	drip	Baldwin Reservoir	100 m/S	6.3	94	42	13

Table A1 continued

Mitigation responsible party (project name)/ mitigation agent	FWS case number	County	Coordinates (N, W)	In flood-plain?	Irrigation Type?	Nearest Waterbody	Direction/Distance to Nearest Waterbody	VELB Present?	Direction/Distance to Nearest Natural Site	Size (acres)	eb planted (#)	eb trans-planted (#)	Age (yrs)
Parker Development Co. (The Parkway Project)/ Wildlands, Inc.	1-1-00-F-0063	Sacramento	38.68, -121.12	Yes	drip	ephemeral - drainage	100 m/N	Historical	6,600 m/SW	1.6	170	17	3-6
Lake Natoma Shores/ Zentner & Zentner	1-1-92-F-55	Sacramento	38.67, -121.13	Yes	drip	Willow Creek	50 m/N, W, & S	Historical	4,900 m/SW	12	231	16	13
Prarie Oaks Subdivision Area #1/Ecorp	1-1-92-F-0079	Sacramento	38.657, -121.16	Yes	drip	Willow Creek	250 m/N	No	2,450 m/E	4.1	1,155	27	11
Alder Creek Automall/ Zentner & Zentner	1-1-97-F-10	Sacramento	38.64, -121.2	Yes	none	Alder Creek & American River	100 m/E & 1,100 m/N	Historical	100 m/N	0.4	240	3	11
Weyerhaeuser Venture Co. (Tributary Point)/ Jones & Stokes	not listed on documents	Sacramento	38.63, -121.28	Yes	sprinkler & drip	American River	50 m/NxNW	Yes	90 m/E	4.4	196	11	6
Unknown (Rio Americano)	not listed on documents	Sacramento	38.577, -121.35	Yes	none	American River	300 m/S	Yes	500 m/E	3.7	142	-	6
Huffman & Associates, Inc (Price Costco Site)/ Entomological Consulting Services, Ltd.	1-1-96-F-157	Sacramento	38.595, -121.45	Yes	drip	American River	520 m/S	No	560 m/SE	2	91	29	9
SRCSD & ACOE (Arden Parallel Force Main)/ UCCE & UC Davis	1-1-03-F-0023	Sacramento	38.60, -121.50	Yes	sprinkler & drip	Sacramento River & slough	500 m/S & 50 m/N	Historical	50 m/E & S	7.4	624	25	2
Jones & Stokes (Sac Urban Levee Project)/ ACOE	1-1-90-F-38R	Yolo	38.645, -121.6	Yes	drip	Sacramento River	330 m/E	Yes	1,000 m/SE	47.7	429	-	15
Teichert (Haller Habitat Peninsula)/Teichert	1-1-91-F-0008	Yolo	38.69, -121.86	Yes	none	Cache Creek	100 m/SE	Yes	26,000 m/SW	9	366	0	9
UC Davis/UC Davis	TE060073-0	Yolo	38.84, -121.21	Yes	sprinkler & drip	Putah Creek	10 m/S	Historical	1,400 m/S	158.1	579	26	4-7
CalTrans (Brannan Island)/CalTrans	1-1-91-F-40	Solano	38.12, -121.68	No	none	Sacramento River	70 m/W	No	500 m/S	12	187	841	12
Greenhorn Creek Project/ Michael W. Skenfield, Consultant	93-F-41	Calaveras	38.07, -120.56	Yes	sprinkler & hose	Greenhorn Creek & Stanislaus River	60 m/W & 5,300 m/SW	Yes	8,300 m/S	2.4	102	7	8
The Burlington Northern & Santa Fe RR Co./ Sycamore Env. Cons.	1-1-94-F-78	San Joaquin	37.75, -121.00	Y	none	Stanislaus River	60 m/S	N	700 m/W	5.7	222	99	11
CalTrans(Livingston)/ CalTrans	1-1-97-F-0129	Merced	37.398, -120.74	Y	none	Merced River	10 m/N	N	1,310 m/E&NE	4.6	444	55	8
CalTrans (Wildwood)/ CalTrans	1-1-95-F-115	Madera	36.87, -119.79	Y	drip	San Joaquin	240 m/N & W	N	-	8.6	1189	20	9

Table A1 continued

Mitigation responsible party (project name)/ mitigation agent	FWS case number	County	Coordinates (N, W)	In flood-plain?	Irrigation Type?	Nearest Waterbody	Direction/Distance to Nearest Waterbody	VELB Present?	Direction/Distance to Nearest Natural Site	Size (acres)	eb planted (#)	eb trans-planted (#)	Age (yrs)
CalTrans (State Route 216 @ St. John's River Bridge, No. 46-108)/ Sequoia Riverlands Trust	not listed on documents	Tulare	36.33, -119.17	Y	drip	Kaweah River & Deep Creek	300 m/NW & 70 m/SE	N	50 m/E, S & W	5.2	223	21	3

Abbreviations used: ACOE = Army Corps of Engineers; eb = elderberry shrub; FWS = U.S. Fish & Wildlife Service; SRCSD = Sacramento Regional County Sanitation District; TCRCD = Tehama County Resource Conservation District; UCCE = University of California Cooperative Extension; VELB = Valley elderberry longhorn beetle

Table A2 Natural sites

Natural site name	VELB Present in previous surveys	UCD Site ID	County	Coordinates (N, W)	Inside the 100-year floodplain?	Nearest waterbody	Direction/distance to nearest waterbody	VELB present in our surveys	Size ^a (acres)
Woodson bridge SRA	Yes (Barr, 1991)	N200	Tehama	39.91, -122.09	Yes	Sacramento River	200 m/E & NE	Yes	428
West of Toomes Creek	not surveyed	N406	Tehama	39.97, -122.08	Yes	Toomes Creek	10 m/N & 1,000 m/W	Yes	2.42 ^b
Feather River Wildlife Area, near Star Bend Boat Ramp	unknown (Barr, 1991)	N403	Yuba	38.99, -121.6	Yes	Feather River	10 m/W	Yes	2291
Folsom "Lake" SRA, near Dotons Point	Yes (Barr, 1991)	N301	Placer	38.76, -121.13	Yes	Folsom Reservoir	100 m/S	Yes	17,718
Folsom "Lake" SRA (Beales Point)	Yes (Barr, 1991)	N326	Placer	38.72, -121.17	No	Folsom Reservoir	100 m/S	Yes	17,718
American River Parkway MM 25-28, near Willow Creek	historic (Barr, 1991)	N432	Sacramento	38.65, -121.19	Yes	American River	300 - 800 m/W - N	Historical	4681

Table A2 continued

Natural site name	VELB Present in previous surveys	UCD Site ID	County	Coordinates (N, W)	Inside the 100-year floodplain?	Nearest waterbody	Direction/distance to nearest waterbody	VELB present in our surveys	Size ^a (acres)
American River Parkway, MM 18–20 near Lower Sunrise	Yes (UC Davis, 2005)	N416	Sacramento	38.63, –121.28	Yes	American River	50 m/NxNW	Yes	4681
American River Parkway, MM 12–13, near Jacob Lane	Yes (UC Davis, 2005)	N419	Sacramento	38.58, –121.34	Yes	American River	100 m/S	Yes	4681
American River Parkway, MM 8.5–9.5 near Howe Ave.	Yes (UC Davis, 2005)	N308	Sacramento	38.56, –121.40	Yes	American River	100 m/N	Yes	4681
American River Parkway, MM 5–6, Cal Expo West	Yes (UC Davis, 2005)	N414	Sacramento	38.59, –121.45	Yes	American River	100 m/S	Yes	4681
American River Parkway, MM 1–3, Discovery Park	Yes (UC Davis, 2005)	N407	Sacramento	38.6, –121.5	Yes	American River	150 m/S & 200 m/N	Yes	4681
Lake Solano Park	Yes (Barr, 1991)	N434	Yolo	38.49, –122.03	No	Putah Creek	10 m/N	Yes	165
Brannan Island SRA	No (Barr, 1991)	N408	Solano	38.12, –121.68	No	Delta of Sacramento River	70 m/S & E	Historical	336
ACOE McHenry Ave. SRA	Yes (Barr, 1991)	N421	San Joaquin	37.75, –121.01	Yes	Stanislaus River	10 m/S	Yes	73
Oakdale Bridge Rd, near Oakdale Recreation Area	No (Barr, 1991)	N420	Merced	37.46, –120.61	No	Merced River	10 m/S	No	71
Kaweah Oaks Preserve	unknown (Barr, 1991)	N417	Tulare	36.33, –119.17	Yes	Kaweah River & Deep Creek	300 m/NW & 70 m/S & E	Historical	324

Abbreviations are the same as in Table A1 in this appendix

^a From Barr (1991)

^b Only a portion of this publicly accessible site was surveyed; the area calculation only includes surveyed elderberry shrubs

References

- Alpert P, Griggs FT, Peterson DR (1999) Riparian Forest Restoration Along Large Rivers: Initial Results from the Sacramento River Project. *Restoration Ecology* 7:360–368
- Barr CB (1991) The distribution, habitat and status of the valley elderberry longhorn beetle *Desmocerus californicus dimorphus* Fisher (Insecta: Coleoptera: Cerambycidae). U.S. Fish and Wildlife Service, Sacramento, CA
- Collinge SK, Holyoak M, Barr CB, Marty JT (2001) Riparian habitat fragmentation and population persistence of the threatened valley elderberry longhorn beetle in central California. *Biological Conservation* 100:103–113
- Haack RA, Slansky F (1987) Chapter 15. Nutritional ecology of wood-feeding Coleoptera, Lepidoptera and Hymenoptera. Pages 449–486 in F. Slansky and J. G. Rodriguez, editors. *Nutritional ecology of insects, mites, spiders, and related invertebrates*. Wiley, New York, NY
- Hanski I, Gilpin M (1991) *Metapopulation dynamics: Empirical and theoretical investigations*. Academic Press, London
- Harding EK, Crone EE, Elder B, Hoekstra JM, Mckerrow AJ, Perrine JD, Regetz J, Rissler LJ, Stanley AG, Walters EL, N. H. C. P. W. Group (2001) The scientific foundations of Habitat Conservation Plans: a quantitative assessment. *Conservation Biology* 15:488–500
- Hey DL, Phillippi NS (1999) *A case for wetland restoration*. John Wiley and Sons, Inc., New York, NY
- Holway DA, Lach L, Suarez AV, Tsutsui ND, Case TJ (2002) The causes and consequences of ant invasions. *Annual review of ecology and systematics* 33:181–233
- Huxel GR (2000) The effect of the Argentine ant on the threatened valley elderberry longhorn beetle. *Biological Invasions* 2:81–85
- Huxel GR, Hastings A (1999) Habitat loss, fragmentation and restoration. *Restoration Ecology* 7:309–315
- Kareiva P, Andelman S, Doak D, Elder B, Groom M, Hoekstra J, Hood L, James F, Lamoreux J, Lebuhr G, McCulloch C, Regetz J, Savage L, Ruckelshaus M, Skelly D, Wilbur H, Zamudio K, N H W Group (1999) *Using science in Habitat Conservation Plans*. AIBS, Washington DC
- Koch-Munz M, Holyoak M (in press) An evaluation of the effects of soil characteristics on mitigation and restoration involving blue elderberry, *Sambucus mexicana*. *Environmental Management*
- Larsson S (1989) Stressful times for the plant stress-insect performance hypothesis. *Oikos* 56:277–283
- Linsley EG, Chemsak JA (1972) *Cerambycidae of North America*. Part VI, No. 1. Taxonomy and classification of the subfamily lepturinae. University of California Publications in Entomology 69:1–138
- MacArthur RH, Wilson EO (1967) *The theory of island biogeography*. Princeton University Press, Princeton, NJ
- Menke SB, Holway DA (2006) Abiotic factors control invasion by Argentine ants at the community scale. *Journal of Animal Ecology* 75:368–376
- Morrison ML, Smallwood KS, Hall LS (2003) Creating habitat through plant relocation: Lessons from Valley elderberry longhorn beetle mitigation. *Ecological Restoration* 21:95–100
- Talley TS (2007) Which spatial heterogeneity framework? Consequences for conclusions about patchy population distributions. *Ecology* 88:1476–1489
- Talley TS, Fleishman E, Holyoak M, Murphy DD, Ballard A (2007) Rethinking a rare-species conservation strategy in an urban landscape: The case of the valley elderberry longhorn beetle. *Biological Conservation* 135:21–32
- Talley TS, Wright D, Holyoak M (2006) Assistance with the 5-Year Review of the Valley elderberry longhorn beetle (*Desmocerus californicus dimorphus*). United States Fish and Wildlife Service, Sacramento
- United States Fish, Wildlife Service (1984) *Valley Elderberry Longhorn Beetle Recovery Plan*. U.S. Fish and Wildlife Service, Portland, OR
- United States Fish and Wildlife Service (1980) Listing the Valley elderberry longhorn beetle as a threatened species with critical habitat. *Federal Register* 45, 52803. August 8, 1980
- Ward PS (1987) Distribution of the introduced Argentine ant (*Iridomyrmex humilis*) in natural habitats of the lower Sacramento Valley [California, USA] and its effects on the indigenous ant fauna. *Hilgardia* 55:1–16
- Young TP, Evans RY (2000) Container stock versus direct seeding for woody species in restoration sites. *Combined Proceedings International Plant Propagators' Society* 50:577–582