

RESEARCH

Abundance and Distribution of Blue Elderberry (*Sambucus nigra* ssp. *caerulea*) on Lower Cache Creek: Implications for Adaptive Floodplain Management

Andrew P. Rayburn^{*1}, Michael Rogner², and Paul Frank³

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* Corresponding author: aprayburn@gmail.com

1 Independent Consulting Ecologist
Arvada, CO 80004 USA

2 Senior Biologist, River Partners
Chico, CA 95926 USA

3 Civil Engineer, FlowWest
Oakland, CA 94612 USA

ABSTRACT

Many western U.S. landscapes are managed for multiple objectives, including biological conservation, commodity production, human welfare, and recreation. Effective conservation of special-status species in managed landscapes is challenging when species protection must be balanced with broader land-management objectives. In managed river systems, actions such as channel maintenance, bank stabilization, dam operation, and habitat enhancement are often implemented to achieve objectives related to water delivery, flood control, protection of adjacent lands, public recreation, and biological conservation. However, these actions are often constrained by the presence of special-status species because of regulatory requirements that may supersede implementation of other measures. Strategies to balance special-status species conservation with broader management objectives

are directly informed by robust data sets on species abundance and distribution. On lower Cache Creek in Yolo County, California, multi-objective management seeks to balance protection of the federally-threatened valley elderberry longhorn beetle (*Desmocerus californicus dimorphus*) and its sole host shrub, blue elderberry (*Sambucus nigra* ssp. *caerulea*), with channel maintenance, bank stabilization, and habitat enhancement actions. We conducted a comprehensive field survey from 2015 to 2016 to map all elderberry shrubs across the 904-ha Cache Creek Resource Management Plan area. An estimated 10,296 shrubs that spanned small, medium, and large size classes were mapped, strongly suggesting that the local population has been increasing since in-channel mining ceased in 1996. Analyses of shrub distribution relative to floodplain inundation zones, and associated vegetation, slope, and aspect revealed that most shrubs occurred in association with other woody riparian vegetation and within the ≤ 10 -yr floodplain inundation zone. In addition, shrubs occurred more often than expected on intermediate slopes and both westerly and northwesterly aspects. The results of this study are guiding adaptive management and informing project planning and permitting on lower Cache Creek, demonstrating the importance of spatially-explicit abundance and distribution data for special-status species in managed landscapes.

KEY WORDS

Floodplain management, valley elderberry longhorn beetle, vegetation mapping, managed river systems, riparian, special-status species

INTRODUCTION

Conservation of biodiversity in landscapes managed for multiple objectives is recognized as a critical complement in establishing habitat preserves and other protected areas (Polasky et al. 2005; Sayer et al. 2013; Schindler et al. 2016). In managed landscapes, effective ecosystem management and conservation must balance physical, biological, economic, and sociological factors (Meretsky et al. 2000; Polasky et al. 2005; Smith 2011). The presence of threatened, endangered, or otherwise special-status species may result in unique challenges for multi-objective management, since species protection may potentially conflict with broader ecosystem management. In managed river systems, actions such as channel maintenance, bank stabilization, dam construction or operation, invasive species treatment, in-channel vegetation removal to maintain flow conveyance, and habitat restoration can all adversely affect special-status aquatic and riparian species (e.g., Kasul et al. 2000; Meretsky et al. 2000; Dudley and DeLoach 2004; Smith 2011). However, these actions may be necessary to achieve management objectives such as bank protection, flood control, water delivery, groundwater recharge, and public recreation. Effective conservation of special-status species in these complex managed landscapes is enhanced by a thorough understanding of species' abundance and distribution.

Blue elderberry (*Sambucus nigra* ssp. *caerulea*; "elderberry" hereafter) is a deciduous native shrub typically <8 m in height that is a common component of riparian forests, scrub habitats, and associated open savannas in California's Central Valley (Vaghti and Greco 2007; Vaghti et al. 2009). Mirroring broader trends across the western U.S., riparian habitat in the Central Valley has been reduced by approximately 95% over the past 150 years—with remaining habitat highly fragmented and often degraded (Katibah 1984; Golet et al. 2013). Riparian restoration has been widely implemented as a management practice in the Central Valley to

reconnect fragmented patches and to enhance habitat for both common and protected species (Golet et al. 2013). Elderberry is less flood-tolerant than other common riparian species, and is often found on portions of floodplains that do not experience regular and sustained inundation (Fremier and Talley 2009; Vaghti et al. 2009). Elderberry prefers moist, well-drained soils and tends to germinate in more open areas, although they also occur as midstory and understory components of mature riparian forests and oak woodlands (Holland 1986; Stevens and Nesom 2006).

The value of elderberry for wildlife and invertebrates in the Central Valley has been widely recognized, and the species is an important component of many riparian restoration projects in the Central Valley (River Partners 2004; Koch–Munz and Holyoak 2008; Golet et al. 2013). Numerous species of native mammals and birds are known to consume its fruit or foliage, and songbirds utilize larger elderberry shrubs for nesting sites (Martin et al. 1951; Vaghti et al. 2009). Elderberries also support various spider and insect species, including native bees and other pollinators that provide key ecosystem services in Central Valley agricultural landscapes (Allen–Wardell et al. 1998; Neal 1998; Vaghti et al. 2009). However, elderberry is most widely known as the host plant of the valley elderberry longhorn beetle (VELB; *Desmocerus californicus dimorphus*), a federally threatened insect that occupies elderberry at all stages of its life cycle (Fed Regist 1980; Barr 1991; Collinge et al. 2001). The VELB is endemic to riparian woodlands along rivers and streams in the lower Sacramento and upper San Joaquin Valley of California. The insect spends most of its life in a larval stage within the stems of elderberry shrubs, emerging via an exit hole from February through June. Exit holes are often the only exterior evidence of VELB presence on an elderberry shrub, although detecting exit holes in the field can be challenging (Lang et al. 1989; USFWS 2006). The beetle can be locally common, although they typically have a patchy distribution, low dispersal distances, and tend to occur at very low densities (Barr 1991; Collinge et al. 2001; Talley et al. 2007). Factors leading to the listing of VELB included widespread degradation, loss, and fragmentation of Central Valley riparian habitats, as well as use of insecticide and herbicide

(Stevens and Nesom 2006). The species was proposed for delisting in 2012, but the proposal was withdrawn in 2014 based on a re-evaluation of historical and present occurrence, and a more detailed assessment of current threats (Fed Regist 2012, 2014).

As the sole host for VELB, elderberry is a protected species in California. Proposed project sites (e.g., construction, maintenance, invasive species control, and habitat restoration) that are within the VELB range and that have elderberry shrubs with stems ≥ 2.54 cm in diameter at ground level must be surveyed by a qualified biologist before any projects are initiated that might directly or indirectly affect shrubs and associated VELB. Elderberry with stems ≥ 2.54 cm that will be left in place on project sites require the establishment of buffers, fencing, and other protective measures. Shrubs that are removed must be transplanted, or, if transplantation is infeasible, require compensatory mitigation based on the size and number of stems and other factors. Mitigation for VELB habitat loss, considered a taking under the Endangered Species Act (ESA), is regulated by the U.S. Fish and Wildlife Service (USFWS 1999; Holyoak and Koch-Munz 2008; Holyoak et al. 2010). While these measures are generally viewed as effectively protecting VELB (e.g., USFWS 2006; Holyoak et al. 2010), they can constrain projects that are intended to enhance or restore habitat, as well as those intended to accomplish broader land- and water-management objectives. For example, given the widespread distribution of elderberry along waterways throughout the Central Valley, floodplain management actions must account for the presence of elderberry, especially if surveys find that VELB are present (USFWS 1999; CDWR 2016). The substantial mitigation requirements for impacts on elderberry—justifiable from the perspective of protecting VELB—often add substantial costs and time to projects. As a result, an understanding of the abundance and distribution of elderberry on a proposed project site is critical for efficient planning before project implementation.

Among the waterways along which elderberry occurs is Cache Creek, a 140-km stream that spans Lake, Colusa, and Yolo counties in north-central California, the name of which comes from Hudson's Bay Company trappers who cached furs along tributaries of the Sacramento River (NHC 1995). The climate of

the Cache Creek basin is characterized by cool, moist winters and warm, dry summers. Most precipitation in the basin is rain, with 85% of the annual total occurring from November through March (KHE 2010). The Cache Creek watershed is divided into the upper watershed above Capay Dam, and the lower watershed below Capay Dam to the Cache Creek settling basin (WRAYC 2007). Cache Creek is one of the principal waterways in Yolo County and is characterized by a complex mosaic of aquatic and riparian ecosystems that support an array of terrestrial and aquatic species. However, the creek and associated habitat has been significantly altered over the past 150 years by anthropogenic activities, including in-channel gravel mining, dams, and diversions for agriculture and urban use.

In-channel gravel mining began along lower Cache Creek soon after settlement by eastern U.S. emigrants in the mid-1800s, and accelerated during the 20th century (NHC 1995; WRAYC 2007). In 1996, Yolo County adopted the innovative Cache Creek Area Plan (CCAP) to regulate mining, protect groundwater, restore and enhance riparian habitat, create open space and recreation areas, and preserve agricultural land use along lower Cache Creek. The CCAP comprises the Off-Channel Mining Plan (OCMP; ca. 9,597 ha) and the Cache Creek Resources Management Plan (CCRMP; ca. 905 ha), each of which have non-overlapping spatial extents. The CCAP encompasses seven creek reaches that are geomorphically and hydraulically distinct, based on factors that include bedrock, flow volume, and anthropogenic alterations (Figure 1). The CCRMP eliminated in-channel mining and established an adaptive management framework to guide the implementation of bank stabilization, channel maintenance, and habitat improvement projects within the planning area. To assess changes in channel geomorphology, hydrology and water quality, and biological resources, an inter-disciplinary team uses a combination of field and remote sensing methods to monitor the area annually. The team includes a three-member Technical Advisory Committee composed of a hydraulic engineer, a fluvial geomorphologist, and a riparian biologist, as well as Yolo County staff. Monitoring results are used to plan and implement priority projects that focus on

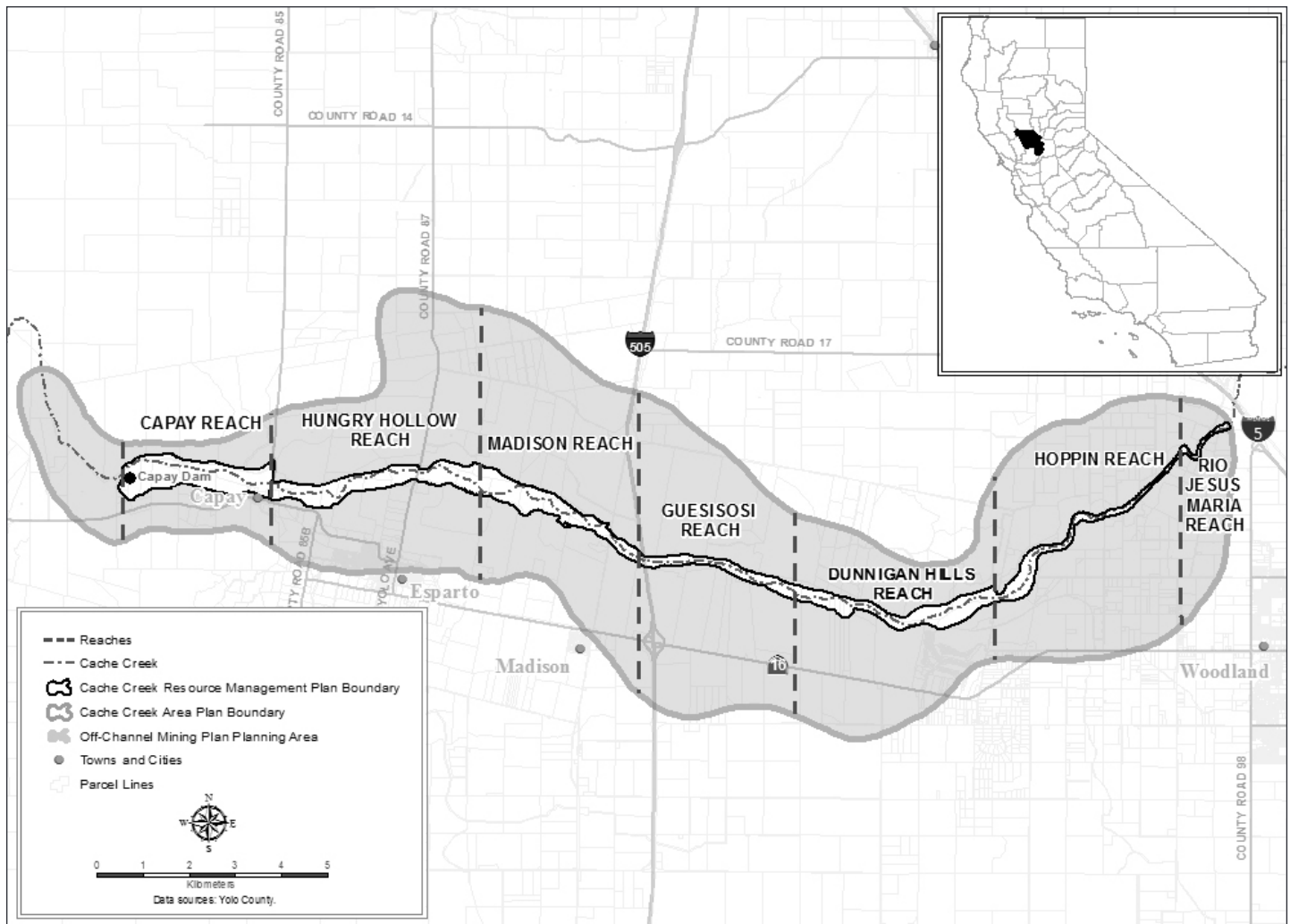


Figure 1 The boundary of the Cache Creek Area Plan (CCAP) planning area in Yolo County, California, which includes the Off-Channing Mining Plan (OCMP) area and the Cache Creek Resource Management Plan (CCRMP) area. Seven creek reaches span the CCRMP area.

habitat restoration, bank stabilization, development of recreation amenities, and public engagement.

Curtailed in-channel mining has substantially affected riparian vegetation dynamics in the planning area (WRAYC 2007; Yolo County 2016). Both natural regeneration and active restoration of riparian forest, willow scrub, and herbaceous vegetation has occurred in some areas, offset to a degree by vegetation losses to scour during high flow years and die-back that resulted from California's recent drought. Changes in vegetation have also occurred because of intensive treatment of invasive species, including arundo (*Arundo donax*), Ravenna grass (*Saccharum ravennae*), and tamarisk (*Tamarix* spp.), although other invasive species have established and spread, including

Himalayan blackberry (*Rubus armeniacus*) and perennial pepperweed (*Lepidium latifolium*). Additional factors that influence vegetation dynamics in the CCRMP area include high year-to-year variability in surface flows and groundwater, scour, channel meander, sediment deposition, off-highway vehicle (OHV) use, agriculture and other land uses, fires, and implementation of bank-stabilization measures.

Before this study, elderberry was known to be relatively common along lower Cache Creek, based on observations by land-owners, gravel operators, County staff, and academic researchers (e.g., Fremier and Talley 2009; Vaghti et al. 2009). The presence of this important riparian species has consistently been viewed as beneficial from the perspective of

native vegetation, VELB conservation, and resources for wildlife and other invertebrate species. However, the actual abundance and distribution of elderberry within the CCRMP area was unknown, as was the status of the population. Given the conservation importance of the species, the significant changes in land management associated with the adoption of the CCAP, and the need for the County to plan and implement riparian and river management projects—including habitat restoration, invasive species control, channel maintenance, and bank stabilization—data were needed on the abundance and distribution of elderberry along lower Cache Creek. Our goal for this study was to conduct a comprehensive field survey to map the locations and size classes of all elderberry shrubs within the CCRMP area (Figure 1). Specific objectives were to (1) evaluate the abundance, distribution, and status of elderberry as a component of the biological resources covered by the CCAP's framework, (2) infer the degree to which adoption of the CCAP has affected elderberry abundance, and (3) provide quantitative data to support the County's requested reissuance of programmatic permits to facilitate continued CCAP implementation.

MATERIALS AND METHODS

To map all elderberry shrubs within the CCRMP area in spring–summer 2015 and spring 2016, we conducted comprehensive field surveys on foot, using mobile mapping software (ArcGIS Collector, ESRI) with an approximate spatial precision of ± 2.0 m. We used specific phenological and morphological characteristics to help identify elderberry from other riparian vegetation. For example, elderberry shrubs are among the first species to leaf out in the early spring, and also have large clusters of white flowers that are visually distinct from other riparian trees and shrubs. We mapped elderberry shrubs as individual points and as patches when we could not easily identify discrete individuals. We visually estimated height and then assigned all individual shrubs to a size class: small (< 1.5 m), medium (1.5–4.6 m), and large (> 4.6 m). Using a rapid assessment framework that was logistically feasible in the field, we classified patches as small (ca. 3 shrubs), medium (ca. 5 shrubs), and large (ca. 7 shrubs), and noted the approximate mix of shrub size classes within

each patch. We estimated patch size conservatively because of plant density, and in some instances the actual number of plants in a patch may have been higher than we approximated. We visually subdivided patches larger than ca. 7 shrubs into the smaller patch classes described above.

We analyzed these data in ArcGIS 10.1 (ESRI) to estimate density and to examine the relationship of elderberry to associated vegetation, slope, aspect, floodplain inundation zones, and historically mined areas. We estimated kernel density using Spatial Analyst tools in ArcGIS (3.0 m cell size, 46.0 m search radii, the CCRMP boundary as the raster analysis mask). We treated points as individual shrubs, and patches as three, five, or seven individuals, depending on size. We used a five-class scheme to visualize the density raster: ≤ 2.0 shrubs ha^{-1} ; 2.1–4.2 shrubs ha^{-1} ; 4.1–20.3 shrubs ha^{-1} ; 20.3–40.5 shrubs ha^{-1} ; and 40.5–101.8 shrubs ha^{-1} .

To estimate the broader vegetation class associated with elderberry plants and patches, we joined a vegetation layer created in 2016 based on manual fine-scale classification of 2015 high-resolution aerial photography (see Yolo County 2016) with both the point and patch data. We then extracted vegetation classes (riparian forest, dense scrub, scattered scrub, herbaceous, and a “bare ground” class that represented areas with no significant vegetation) to each point and patch. Of the total CCRMP area, we classified 11.3% as riparian forest, 7.3% as dense scrub, 2.2% as scattered scrub, 21.3% as herbaceous, and 57.8% as bare ground (Table 1).

We then analyzed the topographic position of elderberry plants and patches in terms of slope, aspect, and floodplain inundation zones. Using Spatial Analyst tools in ArcGIS, we derived slope and aspect layers from a 2011 LiDAR data set with a resolution of approximately 1.0 m^2 . We extracted slope and aspect values from each raster for each elderberry plant and patch. The percentage of total CCRMP area represented by 0–10°, 10–20°, 20–30°, 30–40°, and $> 40^\circ$ slope classes was 85.5%, 9.0%, 3.2%, 1.4%, and 0.5%, respectively (Table 1). The percentage of total CCRMP area represented by the eight aspect classes was 10.5% (NW), 18.7% (N), 14.0% (NE), 9.3% (E), 11.9% (SE), 18.1% (S), 11.0% (SW), and 6.7% (W) (Table 1). Using 2011 LiDAR,

Table 1 Distribution of individual elderberry plants and patches according to estimated floodplain inundation zones, slope, aspect, and associated vegetation. Percent of total CCRMP area for each category included to illustrate point and patch distribution relative to overall extent of each category in the study area.

Landscape Variables		% Total Area	Small Shrubs	Medium Shrubs	Large Shrubs	Subtotal Shrubs	% Total Shrubs	Small Patches	Medium Patches	Large Patches	Subtotal Patches	% Total Patches
Floodplain Inundation Zone	≤ 2 yr	44.0	301	741	139	1181	25.0	55	85	63	203	19.2
	≤ 5 yr	59.3	762	1934	571	3267	69.3	178	266	242	686	64.8
	≤ 10 yr	62.8	874	2117	672	3663	77.7	209	308	278	795	75.1
	≤ 100 yr	65.8	989	2260	741	3990	84.6	221	343	319	883	83.5
	>100 yr	34.2	205	307	213	725	15.4	20	81	74	175	16.5
	>2 yr and ≤ 100 yr	21.8	688	1519	602	2809	59.6	166	258	256	680	64.3
Slope	0–10.0°	85.5	742	1847	665	3254	69.1	157	270	288	715	67.7
	10.1–20.0°	9.0	237	410	169	816	17.3	46	76	61	183	17.3
	20.1–30.0°	3.2	127	153	71	351	7.4	17	31	30	78	7.4
	30.1–40.0°	1.4	60	100	31	191	4.1	15	31	7	53	5.0
	>40.0°	0.5	28	55	17	100	2.1	5	16	6	27	2.6
Aspect	NW (292.5–337.5°)	10.5	245	394	155	794	16.9	38	78	59	175	16.6
	N (337.5–22.5°)	18.7	213	516	195	924	19.6	44	93	83	220	20.8
	NE (22.5–67.5°)	14.0	133	323	125	581	12.3	27	57	56	140	13.3
	E (67.5–112.5°)	9.3	78	183	70	331	7.0	16	34	29	79	7.5
	SE (112.5–157.5°)	11.9	147	298	100	545	11.6	31	36	46	113	10.7
	S (157.5–202.5°)	18.1	197	404	136	737	15.6	43	55	53	151	14.3
	SW (202.5–247.5°)	11.0	96	236	87	419	8.9	23	43	34	100	9.5
	W (247.5–292.5°)	6.7	85	211	85	381	8.1	18	28	32	78	7.4
Associated Vegetation	Riparian forest	11.3	504	1121	305	1930	40.9	117	188	180	485	45.8
	Dense scrub	7.3	250	698	338	1286	27.3	78	143	155	376	35.5
	Scattered scrub	2.2	21	71	15	107	2.3	2	5	1	8	0.8
	Herbaceous	21.3	261	445	234	940	19.9	37	65	41	143	13.5
	Bare ground	57.8	158	230	61	449	9.5	6	23	15	44	4.2

2015 land cover, and historical flood frequency data as inputs, we then overlaid elderberry plants and patches with polygons that represented the estimated 2-yr, 5-yr, 10-yr, and 100-yr floodplain inundation boundaries derived from a 2016 Hydrologic Engineering Center's River Analysis System (HEC-RAS) two-dimensional (2-D) model. The 2-yr inundation boundary represented the "frequently active channel," i.e., the portion of the CCRMP that is most frequently wetted, including the low-flow channel. We included the 5-yr and 10-yr inundation boundaries to examine elderberry distribution on the active floodplain. The 100-yr inundation boundary represented a reasonable "maximum extent" of potential high flows that would occur only during

the most extreme precipitation events. The percentage of total CCRMP area represented by the 2-yr, 5-yr, 10-yr, and 100-yr inundation boundaries was 44.0 (397.9 ha), 59.3 (536.3 ha), 62.8 (568.0 ha), and 65.8 (594.9 ha), respectively (Table 1). We considered the portion of the CCRMP area outside the 100-yr inundation boundary (309.5 ha or 21.8 of the total area; Table 1) as being disjunct from the active floodplain.

To test specifically for non-random elderberry distribution relative to slope, and aspect, we analyzed the number of individual plants observed versus the number expected by the percentage of the study area in each variable class (five slope classes, and eight aspect classes) using G-tests of goodness of

fit ($\alpha=0.05$) using program R (R Core Team) and functions from the DescTools analysis package (Signorell et al. 2016). We performed additional post hoc G-tests using Bonferroni corrections to determine which specific variable classes deviated significantly from expected values; after we corrected for the number of comparisons, we used these significance levels for testing: $\alpha_{\text{slope}}=0.01$, $\alpha_{\text{aspect}}=0.0071$. For example, 9.0% of the study area was classified as 10–20° slope, so, if there were no significant tendency for elderberry shrubs to be associated with 10–20° slope, the expected number of elderberry shrubs associated with riparian forest would be 9.0% of the total shrubs in the study area. A higher or lower observed number of shrubs that was significantly different from the expected number (as determined by the G-test) would provide evidence of a non-random association between elderberry and portions of the study area with 10–20° slope. We did not analyze counts of observed versus expected shrubs in the floodplain inundation zones, since observations were not independent (e.g., a shrub occurring within the 10-yr inundation zone also occurred within the 5-yr and 2-yr inundation zones by default), nor did we analyze associated vegetation, since larger elderberry shrubs and patches likely influenced the original vegetation classification to some degree. In addition, we did not analyze elderberry patches, since both the locations and number of individuals within each patch were sometimes approximated in the field.

Finally, we overlaid elderberry locations in ArcGIS with the historical extent of in-channel mining operations from 1984–1994, estimated from historical aerial photography and maps from the baseline Technical Study (NHC 1995). Because these areas were stripped of vegetation during intensive mining operations, we assumed present-day elderberry located in these areas established after in-channel mining stopped and the CCAP was adopted. This analysis provided an additional means of conservatively estimating the effect of the CCAP on the elderberry population on lower Cache Creek. We could not fully compare the elderberry data set collected in this study to baseline elderberry distribution and abundance in 1996, because logistical and technological constraints prevented a comparable data set from being collected then.

RESULTS

Elderberry Abundance

Including individual shrubs and patches, we mapped an estimated 10,296 elderberry shrubs within the CCRMP area (see Appendix A for reach-scale distribution maps). A total of 4,712 individual shrubs were mapped, including 1,194 small shrubs, 2,565 medium shrubs, and 953 large shrubs, which included some that were tree-like in form. We mapped an additional 1,056 patches (ca. 5,584 plants), including 240 small patches, 424 medium patches, and 392 large patches. To further facilitate an estimate of elderberry establishment in the CCRMP area since adoption of the CCAP in 1996 (see “Discussion” below), we approximated from field notes the number of small elderberry shrubs in each patch. In addition to the 1,194 small shrubs mapped as discrete individuals, we mapped an additional 1,456 small shrubs as components of patches, for a total of 2,650 small shrubs.

Distribution Relative to Floodplain Inundation Zones

Field observations suggested that most elderberry shrubs were found relatively near the channel on terraces, benches, and channel slopes, with only a few scattered shrubs on the channel floor. This observation was reinforced by the examination of elderberry distribution relative to the 2-yr, 5-yr, 10-yr and 100-yr floodplain inundation zones: 84.6% of plants and 83.5% of patches occurred within the 100-yr inundation zone; 25.0% of plants and 19.2% of patches occurred within the 2-yr inundation zone, a region that represented 44.0% of the study area (Table 1). Plants and patches within this region rarely occurred on the channel floor, instead occurring more often on channel slopes and occasionally on elevated bars. Within the 5-yr inundation zone, which represented 59.3% of the total CCRMP area, 69.3% of plants and 64.8% of patches occurred; 77.7% of plants and 75.1% of patches fell within the 10-yr inundation zone (62.8% of the study area; Table 1). A substantial portion of the study area (34.2%) fell outside of the 100-yr inundation zone, in which 15.4% of plants and 16.5% of patches occurred (Table 1).

Distribution Relative to Slope and Aspect

The null hypothesis that the number of individual elderberry plants in each slope class would be equal to the amount of the study area in each class was rejected ($P < 0.0001$; Table 2), suggesting a non-random distribution of elderberry shrubs relative to slope. Most elderberry shrubs (69.1%) occurred on low-slope areas (0–10°), which represented 85.5% of the total study area (Table 1). However, based on the percentage of the study area in this slope class ($P < 0.0001$; Table 2), we observed a lower number of individual shrubs than expected. For the four other slope classes, based on the percentage of the study area in each slope class ($P < 0.0001$ in all cases; see Table 2), we observed a significantly higher number of shrubs than expected. We observed more individual shrubs in the 10–20° class (816) than in the remaining three classes combined, and we observed only 291 shrubs on the steepest slopes

(>30°) (Table 1). We observed similar results for elderberry patches, with 67.7% observed on low-slope areas and only 7.6% observed on slopes >30°.

Also rejected ($P < 0.0001$; Table 2) was the null hypothesis that the number of individual elderberry plants in each aspect class would be equal to the amount of the study area in each class, suggesting a non-random distribution of elderberry shrubs relative to aspect. However, results varied widely across the eight aspect classes in terms of significant deviations of observed shrub counts versus expected based on the amount of the study area in each class (Table 2). For example, we observed more shrubs than expected on northwestern- and western-facing aspects ($P < 0.001$ for both), but fewer than expected on northeastern-, eastern-, southern-, and southwestern-facing slopes ($P < 0.001$ for all comparisons; Table 2). Forty-eight point eight percent of individual shrubs occurred on more northerly-facing areas (NW, N, NE);

Table 2 Results of G-tests of goodness of fit, with Bonferroni adjustments for multiple comparisons implemented for pairwise tests for specific classes within variables

	Variable	% Study Area	Observed	Expected ^a	G statistic	value ^b
Slope	Overall	—	—	—	928.8	<0.0001
	0–10°	85.5	3254	4024.74	809.7	<0.0001
	10–20°	9.0	816	424.08	321.26	<0.0001
	20–30°	3.2	351	150.78	201.63	<0.0001
	30–40°	1.4	191	65.97	159.44	<0.0001
	>40°	0.5	100	23.56	137.50	<0.0001
Aspect	Overall	—	—	—	2922.34	<0.0001
	NW (292.5–337.5°)	10.5	794	494.76	174.42	<0.0001
	N (337.5–22.5°)	18.7	924	881.14	2.53	0.11
	NE (22.5–67.5°)	14.0	581	659.68	11.3	0.00078
	E (67.5–112.5°)	9.3	331	438.22	31.35	<0.0001
	SE (112.5–157.5°)	11.9	545	560.73	0.51	0.48
	S (157.5–202.5°)	18.1	737	852.87	19.95	<0.0001
	SW (202.5–247.5°)	11.0	419	518.32	22.71	<0.0001
	W (247.5–292.5°)	6.7	381	315.7	13.63	0.00022

a. Expected values based on percentage of study area in each variable class.

b. After corrections for multiple comparisons, *P* values used as basis for statistical significance were: 0.01 (slope) and 0.007 (aspect).

36.1 occurred on more southerly-facing areas (SW, S, SE). We observed a similar pattern for patches: 50.7 occurred on northerly-facing areas and 34.5 occurred on southerly-facing areas (Table 1).

Distribution Relative to Associated Vegetation

Results strongly suggested a non-random distribution of elderberry shrubs relative to associated vegetation. During the field survey, we observed that elderberry shrubs were often found growing within patches of riparian forest and dense scrub in association with other native woody riparian species, including Fremont cottonwood (*Populus fremontii*), black walnut (*Juglans hindsii*), valley oak (*Quercus lobata*), California buckeye (*Aesculus californica*), and willow species such as black willow (*Salix gooddingii*). Although not tested statistically in terms of observed versus expected values, 68.2 of individual elderberry shrubs were associated with either riparian forest (40.9) or dense scrub (27.3), while 29.4 of individual shrubs were associated with either herbaceous vegetation (19.9) or bare ground (9.5) (Table 1). Only 2.3 of individual shrubs were associated with scattered scrub vegetation, which comprised only 2.2 of the study area (Table 1). We observed a similar pattern for elderberry patches: 81.4 of patches were associated with either riparian forest (45.8) or dense scrub (35.5) vegetation, while 13.5, 4.2, and 0.8 of patches were associated with herbaceous vegetation, bare ground, and scattered scrub vegetation, respectively (Table 1).

Reach-Scale and Fine-Scale Distribution

Elderberry were not distributed uniformly by reach, and were more common in reaches with a higher proportion of woody vegetation (e.g., dense scrub and riparian forest) and more shallow groundwater. We observed the highest density of elderberry shrubs in the Dunnigan Hills, Hoppin, and Rio Jesus Maria reaches; intermediate density in the Capay and Guesisosi reaches; and the lowest density in the Hungry Hollow and Madison reaches (Appendix A). Even in the latter two reaches—which are characterized by wide, braided, gravelly floodplains with deep groundwater, little woody vegetation, and a history of intensive gravel mining—we observed

dense patches of elderberry, in addition to numerous isolated individuals of all size classes.

Considering only the historically mined portion of the CCRMP area (estimated to be 332.6 ha, or 36.8 of the total area), which included large portions of the Hungry Hollow, Madison, and Guesisosi reaches as well as portions of the Dunnigan Hills and Hoppin reaches, we mapped 582 individual shrubs, including 54 small shrubs, 390 medium shrubs, and 138 large shrubs. In addition, we also mapped 123 patches comprising an estimated 691 individual shrubs (19 small patches, 47 medium patches, and 57 large patches). Thus, we mapped an estimated total of 1,273 elderberry shrubs in areas previously mined from 1984–1994, most of which occurred in clustered patches separated by open areas with little vegetation (Appendix B).

We often observed a similar fine-scale spatial distribution of shrubs throughout the CCRMP area, although elderberry shrubs did also occur as isolated individuals and patches. This type of patchy distribution has been commonly observed for elderberry along creeks and rivers in the Central Valley (e.g., Fremier and Talley 2009).

DISCUSSION

Elderberry Distribution

Past studies of elderberry distribution in relation to variables associated with riverine geomorphic processes and flooding (e.g., relative elevation on the floodplain, floodplain age, distance from the river) and physical habitat attributes (e.g., associated vegetation, canopy cover, shading, soil texture) have found some general patterns, but little consistency across Central Valley river systems. Although elderberry has been found at varying relative elevations above river channels (e.g., Lang et al. 1989; Talley 2005; Williams 2006; Fremier and Talley 2009), researchers have generally concluded that elderberry presence is most commonly associated with intermediate relative floodplain elevations, a sort of “Goldilocks Zone” in which sustained inundation occurs only occasionally but where groundwater is still accessible during warmer parts of the year (Talley 2005; Fremier and Talley 2009). We found similar results in this study, because we found

most elderberry shrubs (75.0% of individual plants, including all size classes, and 80.8% of patches) outside of the 2-yr floodplain inundation zone, e.g., the most frequently flooded portion of the CCRMP area. Of these, 44.3% of individual plants and 45.6% of patches fell within the 5-yr inundation zone; 52.7% of plants and 55.9% of patches fell within the 10-yr inundation zone. These shrubs are likely exposed to similar conditions as described above: occasional and survivable inundation, coupled with sufficient access to groundwater. Persistence of elderberry shrubs growing within the 2-yr inundation zone may result from the relative flashy nature of high flows on Cache Creek, as floodwaters most often recede rapidly, and suitable conditions for elderberry survival are re-established.

Little is known about elderberry distribution relative to slope and aspect, although fine-scale topographic variables have been analyzed as potential predictors of VELB occupancy (e.g., Talley et al. 2007). However, Fremier and Talley (2009) combined aspect, slope, and latitude into a local heat index to examine the effects of local abiotic variables on elderberry presence, abundance, and condition. They found a weak influence of local topography, which explained only a small portion of variance in elderberry occurrence and condition. This result was attributed to the widely-recognized stochasticity in elderberry distribution; data-resolution issues, which limited analysis of fine-scale topographic patterns; and, the overriding effects of more influential variables such as relative elevation and soil texture (Fremier and Talley 2009). In this study, we observed that most elderberry shrubs occurred on flatter portions of the study area, although less than expected based on the proportion of the study area characterized by low slope. This result may be, in part, because of soil moisture limitations on upper benches and terraces that have deeper groundwater, less-frequent inundation, more sun exposure, and less woody vegetation in which seed-dispersing birds perch. More elderberry occurred on intermediate slopes than expected, potentially because of the increased moisture availability from occasional inundation and shallower groundwater as a result of being lower in elevation relative to the creek. As woody vegetation was generally more common closer to the creek, and thus more common on the steeper slopes of

the channel banks, elderberry abundance may have also been higher because of seed dispersal by birds perching on branches. In terms of aspect, we found no clear pattern of elderberry occurrence, although the results suggested that elderberry may be more common on more northerly slopes, perhaps resulting from lower environmental stress (e.g., sun exposure).

Past studies have reported a wide range of vegetation in association with elderberry, including native riparian and upland trees, shrubs, and vines, as well as a wide variety of non-native and invasive species. In this study, elderberry shrubs were concentrated in areas of riparian forest (40.9% of individual plants and 45.8% of patches) and dense scrub (27.3% of individual plants and 35.5% of patches). However, we also observed a substantial number of elderberry shrubs in open, herbaceous areas (19.9% of individual plants and 13.5% of patches), and even on bare, gravelly ground with little to no vegetation observable from aerial imagery (9.5% of individual plants and 4.2% of patches). This result was likely caused by multiple interacting factors, including low rates of seed dispersal by wildlife, and the tendency for these vegetation classes to occur on upper terraces and benches with reduced soil moisture. Considering all the factors described above, floodplain inundation zones and slope classes may be better predictors of elderberry presence along Central Valley rivers than aspect and associated vegetation.

Elderberry Abundance and Population Status

Numerous factors have likely influenced the elderberry population on lower Cache Creek since the CCAP was adopted in 1996, including in-channel mining, invasive species, and seed dispersal by wildlife. Plan implementation ended in-channel mining, which likely substantially negatively affected elderberry on and near the channel floor. In this study, we mapped >1,200 elderberry shrubs of all size classes in historically mined areas of the channel, suggesting significant recovery of elderberry as a result of CCAP implementation.

Substantial investment in invasive species control has also occurred as part of the CCAP, and removal of invasive arundo, Ravenna grass, and tamarisk along the creek has most likely benefited elderberry by reducing competition for light, water, and other

resources that are known to negatively affect elderberry survival (Baird 1989; Hubbell 1997; Vaghti et al. 2009). In this study, we observed elderberry shrubs growing in some dense patches of aggressive invasive species that have yet to be treated, suggesting that elderberry on lower Cache Creek can tolerate non-native competition to some degree.

Although some elderberry seeds may fall directly to the ground under mature shrubs, seed dispersal by birds and other wildlife is likely a critical factor that influences elderberry abundance and distribution. Wildlife likely also substantially affects elderberry abundance and distribution in the study area. The CCAP was designed to, among other things, create and enhance habitat for wildlife, including native birds, which are often assumed to be the primary disperser of elderberry seeds (e.g., Vaghti et al. 2009). Over 140 species of birds have been observed in the CCAP area since the program was implemented (Yolo County 2016), and in this study we observed many bird species foraging on mature elderberry shrubs for berries and, potentially, insects.

Additional factors that influence the elderberry population include disturbance, climate, scour from high flows, mortality from age, and voluntary plantings. In terms of disturbance, while some effects on elderberry have likely occurred from fire and OHV use, elderberry readily re-sprouts after fire and can tolerate a high degree of physical damage. For example, during this study we observed many elderberry shrubs of all size classes re-sprouting in burned areas. Regarding climatic effects, especially the prolonged and significant drought that affected California in recent years, field observations confirmed the general assumption that elderberry shrubs are drought-tolerant riparian species. Although we observed drought-stressed elderberry shrubs, we did not see significant mortality, and saw some re-sprouts at the base of mostly-dead shrubs that likely died back during the drought. Scour from high flows has also likely minimally affected the elderberry population, since elderberry does not tolerate prolonged flooding, and relatively few elderberry shrubs occur on the channel floor. In addition, like other flexible-stemmed riparian vegetation, elderberry shrubs can bend under high-flow conditions without breaking or being uprooted. We observed evidence of this in the field in the form

of near-horizontal, yet otherwise healthy shrubs along some portions of the channel. Also, elderberry along lower Cache Creek can live for many years; we observed some very large individuals that were clearly aged and more tree-like in form. Finally, over the past 2 decades, a relatively small number of elderberry shrubs have been planted in parks and other properties along lower Cache Creek.

The results of this study strongly suggest that the local elderberry population on lower Cache Creek has increased substantially over the past 20 years in part from implementation of the CCAP. The lack of a comparable data set on elderberry distribution and abundance before CCAP adoption precluded a comprehensive assessment of changes in the population. However, the estimated 2,650 small shrubs mapped during the project represent new recruits added to the population in recent years. Although numerous small shrubs occurred under the canopies of mature trees and shrubs, small shrubs also occurred in the open, suggesting that recruitment is being driven by factors other than canopy cover and associated vegetation. Many medium-sized shrubs, as well as some larger shrubs, also likely established over the past 2 decades. In addition, as previously discussed, we observed many elderberry shrubs from all size classes on historically-mined areas, further supporting the hypothesis of a robust, increasing population.

CONCLUSION

Elderberry is a thriving native species on lower Cache Creek, which, in turn, has positive implications for wildlife and invertebrate species that utilize the plant for perching, foraging, nesting, and thermal refugia. Although we observed some similarities in terms of elderberry distribution relative to previous elderberry studies, the abundance of young seedlings observed in the study area suggests that the local population may be on a more rapid trajectory of growth here than along other Central Valley rivers and streams. The extent to which VELB are present in the study area is unknown, but the results of this study suggest that the CCRMP area could be an important site for the continued recovery of the species.

Continued implementation of invasive species control and habitat-restoration projects under the CCAP

framework should create favorable conditions for further elderberry expansion, and benefit native wildlife species that forage on elderberry and subsequently disperse seeds. Restoration projects should also consider including elderberry in the species palette to benefit wildlife and VELB, as well as to accelerate continued recovery of native vegetation across the CCAP area. Elderberry is an appropriate species for riparian areas along the creek, as well as for oak woodlands and grasslands on upper banks further from the channel.

Channel maintenance and bank stabilization projects are also critical components of the CCAP framework. To continue CCAP implementation, re-issuance of programmatic federal permits for these management actions is being sought. If elderberry is regarded as a protected species that could potentially be affected by such projects, the results of this study support the requests for permit reissuance. Given the abundance (> 10,000 shrubs) and widespread distribution of elderberry shrubs within the CCRMP area, as well as the thousands of small shrubs that suggest an increasing population, potential effects from these projects on a relatively small number of elderberry shrubs would negligibly affect the overall population along lower Cache Creek. Site-specific surveys will be required to verify current elderberry distribution and to determine VELB occupancy of elderberry shrubs on any particular project site; however, if VELB are detected and if elderberry shrubs must be transplanted off the project site as part of mitigation requirements, the results of this study can also be used to determine suitable, local sites for replanting transplanted individuals.

Comprehensive data sets on the distribution of special-status plants, such as the data set created for elderberry during this project, provide critical spatially-explicit data that facilitates conservation of protected species while also informing multi-objective adaptive management. Using results of this study as a baseline, future field surveys should be conducted to assess further changes in elderberry abundance and distribution as part of assessing progress toward the continued CCAP goal of restoring and enhancing riparian habitat. We recommend both site-level surveys to determine the finer-scale effects of specific CCAP projects on elderberry shrubs, as well as comprehensive re-surveys of the study area on

ca. 10-year intervals to assess changes in the local elderberry population.

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REFERENCES

- Allen-Wardell G, et al. 1998. The potential consequences of pollinator declines on the conservation of biodiversity and stability of food crop yields. *Conserv Biol* 12:8–17. Available from: <https://www.jstor.org/stable/2387457>
- Baird K. 1989. High quality restoration of riparian ecosystems. *Ecol Restor* 7(2):60–64. <https://doi.org/10.3368/er.7.2.60>
- Barr CB. 1991. The distribution, habitat, and status of the valley elderberry longhorn beetle *Desmocerus californicus dimorphus* Fisher (Insecta: Coleoptera: Cerambycidae). Sacramento (CA): U.S. Fish and Wildlife Service. Available from: http://www.sacramentoriver.org/forum/scripts/library/file.php?file_id=77
- 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. *Biol Conserv* 100:103–113. [https://doi.org/10.1016/S0006-3207\(00\)00211-1](https://doi.org/10.1016/S0006-3207(00)00211-1)
- CDWR: California Department of Water Resources. 2016. Central Valley flood protection plan draft conservation strategy. Appendix G: identification of target species and focused conservation plans. Sacramento (CA): CDWR. Available from: http://www.water.ca.gov/conservationstrategy/cs_appendices.cfm
- Dudley TL, DeLoach CJ. 2004. Saltcedar (*Tamarix* spp.), endangered species, and biological weed control—can they mix? *Weed Tech* 18:1542–1551. [https://doi.org/10.1614/0890-037X\(2004\)018\[1542:STSESA\]2.0.CO;2](https://doi.org/10.1614/0890-037X(2004)018[1542:STSESA]2.0.CO;2)

- Federal Register. 1980. Listing the valley elderberry longhorn beetle as a threatened species with critical habitat. Fed Regist 45:52803. Available from: https://ecos.fws.gov/docs/federal_register/fr449.pdf
- Federal Register. 2012. Removal of the valley elderberry longhorn beetle from the federal list of endangered and threatened wildlife. Fed Regist 77:60238. Available from: <https://www.gpo.gov/fdsys/pkg/FR-2012-10-02/pdf/2012-23843.pdf>
- Federal Register. 2014. Withdrawal of the proposed rule to remove the valley elderberry longhorn beetle from the federal list of endangered and threatened wildlife. Fed Regist 79:55879–55917. Available from: <https://www.gpo.gov/fdsys/pkg/FR-2014-09-17/pdf/2014-21585.pdf>
- Fremier AK, Talley TS. 2009. Scaling riparian conservation efforts with river hydrology: lessons from blue elderberry distribution along four Central California rivers. Wetlands 29(1): 150–162. <https://doi.org/10.1672/07-243.1>
- Golet GH, et al. 2013. Successes, failures and suggested future directions for ecosystem restoration of the Middle Sacramento River, California. San Franc Estuary Watershed Sci 11(3). <https://escholarship.org/uc/item/Odb0t6j1>
- Holland RF. 1986. Preliminary descriptions of the terrestrial natural communities of California. Sacramento (CA): California Department of Fish and Game, Natural Heritage Division. Available from: <https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=75893>
- Holyoak M, Koch–Munz M. 2008. The effects of site conditions and mitigation practices on success of establishing the valley elderberry longhorn beetle and its host plant, blue elderberry. Env Manage 42:444–457. <https://doi.org/10.1007/s00267-008-9113-7>
- Holyoak M, Talley TS, Hogle SE. 2010. The effectiveness of U.S. mitigation and monitoring practices for the threatened valley elderberry longhorn beetle. J Insect Conserv 14:43–52. <https://doi.org/10.1007/s10841-009-9223-4>
- Hubbell JG. 1997. Competitive effects of intercropping alfalfa with valley oak and blue elderberry seedlings [thesis]. [Chico (CA)]: California State University.
- KHE: Kamman Hydrology and Engineering. 2010. Watershed-based assessment of hydrologic and geomorphic conditions in Cache Creek through Capay Valley. Woodland (CA): Prepared for the Yolo County Resource Conservation District. Available from: http://yolorcd.org/documents/cache_creek_geomorphology_assessment.pdf
- Kasul RL, Martin CO, Allen HH. 2000. Characterization of sensitive species and habitats affected by operation of USACE water resource development projects. Vicksburg (MS): U.S. Army Engineer Research and Development Center, EMRRP Technical Notes Collection ERDC TN-EMRRP-SI-10. Available from: <http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA378047>
- Katibah EF. 1984. A brief history of riparian forests in the Central Valley of California. In: Warner RE, Hendrix KM, editors. 1984. California riparian systems: ecology conservation and productive management. Berkeley (CA): University of California Press.
- Koch–Munz M, Holyoak M. 2008. An evaluation of the effects of soil characteristics on mitigation and restoration involving blue elderberry, *Sambucus mexicana*. Env Manage 42:49–65. <https://doi.org/10.1007/s00267-008-9074-x>
- Lang FJ, Jokerst JD, Sutter GE. 1989. Habitat and populations of the valley elderberry longhorn beetle along the Sacramento River. Sacramento (CA): U.S. Forest Service General Technical Report PSW-110. Available from: <https://www.treesearch.fs.fed.us/pubs/27975>
- Martin AC, Zim HS, Nelson AL. 1951. American wildlife and plants: a guide to wildlife food habits. New York (NY): Dover Publications, Inc.
- Meretsky VJ, Wegner DL, Stevens LE. 2000. Balancing endangered species and ecosystems: a case study of adaptive management in Grand Canyon. Env Manage 25(6):579–586. <https://doi.org/10.1007/s002670010045>
- Neal PR. 1998. Pollinator restoration. Trends Ecol Evol 13:132–133. [https://doi.org/10.1016/S0169-5347\(97\)01322-0](https://doi.org/10.1016/S0169-5347(97)01322-0)

- NHC: Northwest Hydraulic Consultants. 1995. Technical studies and recommendations for the Lower Cache Creek resource management plan. Woodland (CA). Available from: <http://www.yolocounty.org/general-government/general-government-departments/county-administrator/county-administrator-divisions/natural-resources/cache-creek-area-plan-document-library/1995-technical-studies>
- Polasky S, Nelson E, Longsdorf E, Fackler P, Starfield A. 2005. Conservation species in a working landscape: land use with biological and economic objectives. *Ecol Appl* 15(4):1387–1401. <https://doi.org/10.1890/03-5423>
- River Partners. 2004. Survey of planted elderberry on Sacramento River National Wildlife Refuge riparian restoration sites for use by valley elderberry longhorn beetles. Prepared for the U.S. Fish and Wildlife Service. Chico (CA): River Partners. Available from: http://www.riverpartners.org/documents/VELBS_SURVEY_Report_022304.pdf
- Sayer J. et al. 2013. Ten principles for a landscape approach to reconciling agriculture, conservation, and other competing land uses. *P Natl Acad Sci* 110:8349–8356. <https://doi.org/10.1073/pnas.1210595110>
- Schindler S. et al. 2016. Multifunctional floodplain management and biodiversity effects: a knowledge synthesis for six European countries. *Biodivers Conserv* 25:1349–1382. <https://doi.org/10.1007/s10531-016-1129-3>
- Signorell A, et al. 2016. DescTools: tools for descriptive statistics. R package version 0.99.17. Available from: <https://cran.r-project.org/web/packages/DescTools/index.html>
- Smith CB. 2011. Adaptive management on the central Platte River: science, engineering, and decision analysis to assist in the recovery of four species. *J Env Manage* 92:1414–1419. <https://doi.org/10.1016/j.jenvman.2010.10.013>
- Stevens M, Nesom G. 2006. Blue elderberry *Sambucus nigra* L. ssp. *caerulea* (Raf.) R. Bolli. Davis (CA): U.S. Department of Agriculture Natural Resources Conservation Service. Available from: <https://plants.usda.gov/core/profile?symbol=sanic5>
- Talley TS. 2005. Spatial ecology and conservation of the valley elderberry longhorn beetle [dissertation]. [Davis (CA)]: University of California Davis.
- Talley TS, Fleishman E, Holyoak M, Murphy D, Ballard A. 2007. Rethinking a rare-species conservation strategy in an urbanizing landscape: the case of the valley elderberry longhorn beetle. *Biol Conserv* 135:21–32. <https://doi.org/10.1016/j.biocon.2006.09.022>
- USFWS: U.S. Fish and Wildlife Service. 1999. Conservation guidelines for the valley elderberry longhorn beetle. Sacramento (CA): Sacramento Fish and Wildlife Office. Available from: https://www.fws.gov/sacramento/es_species/Accounts/Invertebrates/es_valley_elderberry_longhorn_beetle.htm
- USFWS: U.S. Fish and Wildlife Service. 2006. Valley elderberry longhorn beetle (*Desmocerus californicus dimorphus*) 5-year review: summary and evaluation. Sacramento (CA): Sacramento Fish and Wildlife Office. Available from: https://www.fws.gov/cno/es/VELB_20_5-year_20review.FINAL.pdf
- Vaghti MG, Greco SE. 2007. Riparian vegetation of the Great Valley. In: Barbour M, Keeler-Wolf T, Schoenherr A, editors. *Terrestrial vegetation of California*, 3rd edition. Berkeley (CA): University of California Press.
- Vaghti MG, Holyoak M, Williams A, Talley TS, Fremier AK, Greco SE. 2009. Understanding the ecology of blue elderberry to inform landscape restoration in semiarid river corridors. *Env Manage* 43:28–37. <https://doi.org/10.1007/s00267-008-9233-0>
- WRAYC: Water Resources Association of Yolo County. 2007. Integrated Regional Water Management Plan for Yolo County. Woodland (CA). Available from: http://www.yolowra.org/irwmp_final/FINAL_IRWMP_20_Document_5-10-07.pdf
- Williams AM. 2006. Modeling the spatial distributions of riparian plant species on the Sacramento River, California, with conservation applications [thesis]. [Davis (CA)]: University of California Davis.
- Yolo County. 2016. Cache Creek annual status report. Woodland (CA): Yolo County Planning, Resources, and Public Works Department, Parks and Natural Resources Division. Available from: <http://www.yolocounty.org/home/showdocument?id=39649>