Central Valley *Arundo*: Distribution, Impacts, and Management

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CAL IPC
CALIFORNIA INVASIVE PLANT COUNCIL

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Cover photos:

Top:	*Arundo* distribution mapping from Cal-IPC dataset.
Middle:	*Arundo* controlled as part of management by the California Dept of Water Resources. Photo: Paul Hames, DWR. 2009.
Bottom:	Steelhead trout. The California Central Valley DPS is one of the sensitive species that is impacted by *Arundo* in the region. Photo from NOAA Fisheries website.

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EXECUTIVE SUMMARY

Arundo donax (giant reed) is a large and extremely damaging invasive plant found along waterways across California. The Central Valley is among the most impacted regions, along with coastal rivers from the San Francisco Bay Area south to the border with Mexico. *Arundo* damages both ecosystems and human infrastructure. It impacts water resources, flooding, habitat for wildlife including sensitive species, and wildfire. To date over $200 million has been spent on *Arundo* removal projects in California, including major projects on the Santa Ana, San Luis Rey, Santa Margarita, San Diego, Ventura, Santa Clara, San Juan and Salinas rivers. Cal-IPC estimates that well-executed *Arundo* control projects on high-priority watershed across the Central Valley would provide a benefit-to-cost ration of 1.7 to 1 based on an economic valuation of benefits to water supply, flood and fire safety, and wildlife habitat.

This report summarizes results from an extensive *Arundo* mapping effort in California's Central Valley, which includes the surrounding foothills. Using the mapping dataset as a basis, we estimate *Arundo*'s impacts in each of 25 watershed units across the region and assess the relative benefits of removal in each unit. We then integrate the impact for each watershed unit with an assessment of local capacity to build and implement a long-term *Arundo* removal program. (Local capacity is critical—it is a big lift to secure permits and landowner access authorization, implement control work, and build a system for consistent long-term follow-up up for a minimum of 10 years.) From these integrated factors we suggest priorities and make management recommendations.

The overall study area spans 38.4 million acres; we searched 17.4 million core acres to find all *Arundo*. We mapped *Arundo* upstream along major tributaries until we identified the uppermost populations (*Arundo* was concentrated at lower elevations, with 97% found below 500 feet elevation in California). Because *Arundo* is a large distinctive plant, we were able to map it from high-resolution aerial imagery. We followed up with field visits to a subset of sites to verify accuracy in the field. While in the field we measured *Arundo* physical properties to see how it compared to *Arundo* in California's coastal watersheds and in other studies across the world. We found that the average height of *Arundo* in the Central Valley was 12% shorter than *Arundo* in coastal southern California watersheds, and biomass was 15% lower. (Results reflect timing of sampling: Central Valley *Arundo* was sampled in 2018 after a prolonged drought while coastal *Arundo* was sampled in 2010 after a period of normal rainfall.)

We mapped a total of 2,256 acres of *Arundo* in the Central Valley. Of this total, 74% was found in the Sacramento River Valley and 26% in the San Joaquin River Valley. This represents a lower level of invasion than in coastal watersheds where 7,864 acres was mapped. However, the most heavily invaded areas in the Central Valley, such as Stony Creek watershed with over 500 acres of *Arundo*, demonstrate the potential for *Arundo* to become more extensive in the future.

We established the 25 watershed units based on a hydrologic GIS layer. For each watershed unit, we scored the level of four impacts—impact to water, impact to geomorphology, impact to wildfire, and impact to sensitive plant and wildlife species—as described below.

Water: *Arundo* water use in the Central Valley was calculated to be 19.4 acre-feet/year per acre of *Arundo* based on current stand structure sampled across the Central Valley. This represents potential water use of *Arundo* stands if water is available, which it is in many Central Valley systems, especially those conveying water from dams to the valley floor. This is significantly more than native vegetation whose use is estimated as 4 acre-feet/year per acre. This is nearly five times greater water use then that of native vegetation, so removal of *Arundo* can provide a significant increase in water availability (15.4 acre-feet/year per acre of *Arundo* controlled) and hydrologic function in impacted areas of the Central Valley. As part of the project, we developed a spreadsheet-based model that calculates annual *Arundo* water use for a particular region based on user inputs for *Arundo* stand and site characteristics: live cane density, height, percent cover of cane area and seasonal daylight. This tool allows program managers to generate site-specific water use estimates.

Geomorphology: The geomorphology of waterways is impacted when dense stands of *Arundo* obstruct and modify streamflow, raising the floodplain and changing braided channels to single channels. High flow events can result in more frequent bank failure and flooding. Bank failure can result in dense clumps of *Arundo* being carried downstream where it can damage infrastructure such as bridges and roads. Flows confined to a single narrow channel may also result in less groundwater recharge.

Fire: In addition to providing a high fuel load, *Arundo* stands have a tall, well-ventilated fuel structure containing dry fuels throughout the year, which is especially conducive to carrying wildfire. *Arundo* stands increase the number of fire events by harboring significantly greater number of transient camps than native vegetation. Transient camps in *Arundo* are a primary ignition source for fires in riparian areas as documented in the coastal *Arundo* study. Central Valley field work documented encampments and open fires in *Arundo* stands. In southern California, *Arundo* stands have been documented as being the starting point for fires as well as conveying wildfires through riparian areas. As fire frequency and size increases in the Central Valley, these patterns are likely to be repeated.

Sensitive species: Plants and wildlife can be harmed when *Arundo* changes abiotic and biotic properties of ecosystems. This includes habitat structure, stream flow patterns, water availability, fire and available food sources. We examined 24 sensitive species from five taxonomic groups—plants, insects, fish, herps, birds and mammals—to determine the degree to which *Arundo* is likely to impact the species and the degree to which the species co-occurs with *Arundo* in a given watershed. Elderberry beetle is the most impacted, followed by bank swallow, Central Valley DPS of steelhead, Chinook salmon CV spring-run ESU, and tricolored blackbird.

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We score each of these four types of impact (water, geomorphology, fire, sensitive species) for each of the 25 watershed units based on the amount of *Arundo* present and other factors, then aggregate the scores to capture the relative impact of *Arundo* on each watershed unit. This aids in setting priorities for *Arundo* removal efforts across the Central Valley region.

We conclude the report by making management recommendations for removing *Arundo* in Central Valley watersheds using a 'top down' approach to assure long term program viability. Planning and implementing a successful watershed-scale *Arundo* removal project is a major undertaking. It means acquiring permits, obtaining right-of-entry agreements from landowners, securing funding, coordinating partners, and implementing comprehensive treatments over a period of ten years. For each watershed unit we rate the capacity and readiness of the presumptive project lead organizations and suggest approaches for effective *Arundo* removal. These organizations are often RCDs but County Agricultural Departments and NGOs such as River Partners also have a role and history of work on *Arundo* control regionally. The top three watershed units are Cache-Putah Creeks (where an *Arundo* removal effort by Yolo RCD is currently underway with funding from the California Wildlife Conservation Board), Stony Creek in the Sacramento Valley, and Chowchilla-Fresno Rivers in the San Joaquin Valley.

Some groups have sufficient capacity to take on such an effort. In the Cache Creek and Putah Creek watersheds for instance, the Yolo County Resource Conservation District (RCD) has secured state funding to begin an eradication effort. At the top of the Sacramento River watershed, the Western Shasta RCD has a CEQA document in place and is poised to apply for implementation funding. But in many areas, significant local capacity will have to be built if *Arundo* is to be controlled effectively. We will work to foster this growth and to pass on lessons learned from each watershed. With successful full-watershed *Arundo* removal programs being implemented in California's most infested coastal watersheds, and new programs like the one on Cache and Putah creeks to serve as a model for the Central Valley, we are hopeful that more full-watershed programs will form to protect the region's resources from the impacts of *Arundo*.

1 *ARUNDO* BIOLOGY, PHYSIOLOGY, AND PHYSICAL STRUCTURE

1.1 General Biology and History of Introduction

Arundo donax (giant reed) is the largest grass species that is not a bamboo. It is a clonal plant that grows in dense stands in moist, warm conditions, found in many subtropical and warm-temperate areas of the world. It is thought to be native to eastern Asia (Polunin and Huxley 1987), but the precise extent of its native distribution is unknown. *Arundo* has been introduced and used around the world for many purposes: as an ornamental, for erosion control, for production of reeds for musical instruments, as a source of fiber for paper, and most recently as a biofuel crop. It has become invasive in many regions, primarily in riparian habitat. Where *Arundo* invades it often forms dense stands resulting in a wide range of impacts to ecosystems and infrastructure. The Invasive Species Group of the World Conservation Union includes giant reed in its list of the top 100 Worst Invaders of the World (Lowe et al. 2000).

Arundo was first introduced to California by Spanish colonists in the 1700s (Newhouser et al. 1999), and in the early 1800s for erosion control in drainage canals (Bell 1998). It is now a major threat to riparian areas across California as well as other southwestern states. Three areas in the United States have particularly significant *Arundo* infestations (characterized as >20% of riverine habitat over areas longer than a river mile): coastal California (six river systems from Monterey to San Diego), the Rio Grande (Texas), and the Central Valley (portions of two watersheds exhibit this level of invasion, Cache and Stony Creeks, both in the Sacramento Valley).

Arundo is a facultative wetland species: it achieves its greatest growth rate near water but also has the capacity to grow in many different habitat conditions and soil types. It is a tall, erect, perennial grass that grows to a height of up to 9 meter in favorable conditions (Perdue 1958; Cal-IPC 2011). Being a clonal organism, most of its reproduction and dispersal occurs via fragments from underground lateral stems (rhizomes).

Arundo is popular as a biofuels crop and for wastewater treatment—and infamous in the wildland and waterway management community—due to its very high transpiration rates, high photosynthesis rates, and exceptionally high rates of biomass accumulation under favorable conditions. It can also tolerate drought and saline conditions (Lewandowski et al. 2003, Perdue 1958, Peck 1998, Sanchez et al. 2015), though both stressors reduce photosynthesis and, ultimately, growth rates (Sanchez et al. 2015) by triggering stomatal closure. Evidence for salinity tolerance can be found in California, where it is found growing along the edges of beaches and estuaries (Else 1996).

Arundo generally becomes dormant during the colder months, as can be seen by the leaves turning brown or yellow and the stems fading from their green color. Stems and leaves turn green again in spring as temperatures rise, the period of daylight lengthens, and secondary branches begin to form. *Arundo* is restricted by cold temperatures. In areas with hard freezes during winter months, *Arundo* generally dies back to the ground and then re-sprouts in the spring. Deep freezes can kill the plant, presumably by destroying the rhizome network.

1.2 Physiology and Chemistry

Arundo has C_3 photosynthesis that is typical for cool-season grasses. However, it also exhibits the unsaturated photosynthetic potential of C_4 photosynthesizing plants, making it capable of very high photosynthetic rates (19.8 – 36.7 μmol m^{-2} sec^{-1}; Papazoglou et al. 2005, Rossa et al. 1998). Its growth rate of nearly 10 cm/day is among the highest recorded (Dudley 2000).

Arundo's stems and leaves contain an unusual variety of noxious chemicals for a grass, including triterpenes, sterols (Chandhuri and Ghosal 1970), cardiac glycosides, curare-mimicking indoles (Ghosal et al. 1972), and hydrozamic acid (Zuñiga et al. 1983), and as silica (Jackson and Nunez 1964). These compounds likely reduce herbivory by most native insects and grazers where *Arundo* has been introduced (Miles et al. 1993, Zuñiga et al. 1983), thereby further enabling it to grow and spread quickly.

Arundo responds strongly to excess nitrogen from anthropogenic and fire sources (Ambrose and Rundel 2007). Most studies on growth and transpiration indicate that water availability is the primary factor affecting its metabolic rate and productivity (Abichandani 2007, Perdue 1958, Watts 2009). Where there is lower water availability, such as on river terraces, *Arundo* will generally have lower productivity and grow to a shorter stature.

1.3 Genetic Variation

Genetic variation in *Arundo* in North America is highly limited. Recent studies suggest that invasive *Arundo* here derives from a single or very low number of genetically uniform clones (Khudamrongsawat et al. 2004, Ahmad et al. 2008, P-S Liow et al. 2008). There has been no verification of successful reproduction by seed to date in North America (Else 1996, Khudamrongsawat et al. 2004, Witje et al. 2005). Populations appear to have originated from the Mediterranean; these in turn are believed to have been introduced from East Asia. Both Mediterranean and North American populations are not know to reproduce sexually in the wild and, therefore, do not disperse by seed. The substantial spread of *Arundo* has been the result of purposeful and accidental human introductions into discrete watersheds, followed by stand expansion, and subsequent downstream spread via rhizomes and, to a lesser degree, above-ground stem fragments that can also produce new plants.

Low genetic variation makes *Arundo* a good candidate for biological control since low genetic diversity and clonal reproduction limit the opportunity for selection for resistance against control agents (Tracy and DeLoach 1999). Two biocontrol agents have been approved in California, *Rhizaspidiotus donacis* (*Arundo* armored scale) and *Tetramesa romana* (*Arundo* shoot gall wasp). To date, neither has had a substantial impact in controlling *Arundo* (see Chapter 2).

1.4 Cane and Stand Structure

1.4.1 Canes

Cane stems (culms) are hollow with walls 2-7 mm thick. Culms are divided vertically by a sclerotized partition at each node. First-year canes are unbranched. Second-year canes grow single or multiple secondary branches laterally from nodes (Decruyenaere and Holt 2005). Secondary branches are a much smaller diameter than the main canes (typically <10 mm versus >20 mm) but ultimately bear most of the leaves. These secondary branches can occasionally give rise to third-degree stems and even fourth-degree stems (Decruyenaere and Holt 2005).

Once a cane generates secondary branches, these become the main areas of new growth. Older canes with extensive secondary branching often cannot support the weight of the branches and leaves and may flop over if nearby canes do not support it. As canes mature, the leaves on the main cane becomes less important to photosynthetic production as new leaves are produced on secondary branches. Decruyenaere and Holt (2005) note that central leader canes effectively stop growing once secondary branches are generated. These growth patterns are important to document because they improve estimates of total photosynthetic leaf area and water use.

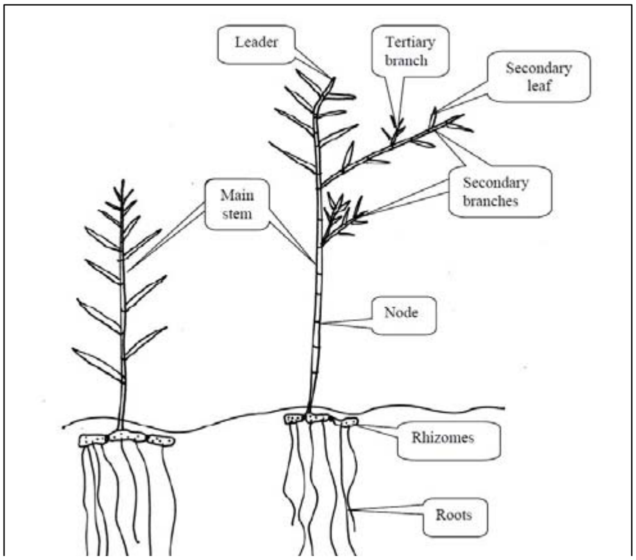


Figure 1-1. Illustration of Arundo structure for first-year and older stems. Older canes typically have many secondary branches while first year canes do not. Drawing by J. Giessow from Cal-IPC (2011).

The underground structure of *Arundo* is composed of fleshy rhizomes that function as storage organs and, when fragmented, reproductive propagules. Adventitious roots sprout from these organs and serve to anchor plants and obtain resources from deeper into the soil profile (Figures 1-2, 1-7, 1-8, 1-9, 1-10, 1-11). Rhizomes are shallowly buried, spreading out horizontally from the plant and forming a dense underground mat. They are typically found 5-15 cm below the soil surface (occasionally as far down as 50 cm). Roots that stem from them are also shallow but can extend to more than 100 cm deep (Sharma et al. 1998, Cal-IPC 2011).

Figure 1-2. Dense rhizome and root network of an Arundo clump that was scoured during a flow event, removing the upper soil matrix and canes (Cal-IPC 2011).

Figure 1-3. Rhizome network arising from a single growth point (far right). There are 33 canes (painted red) emerging from this single network within a 1 meter x 1 meter area (Cal-IPC 2011).

1.4.2 Stand Structure

We sampled *Arundo* canes from 19 stands across 13 Central Valley watersheds within the project study area in early summer 2018 (Figure 1-5). Sample sites were well distributed across the Valley, with nine occurring in the San Joaquin River watershed and ten in the Sacramento River watershed. An additional seven stands were sampled outside the project area in the nearby Salinas River Valley in early summer 2018, where site conditions were very similar to those in the Central Valley. Within each site, a single 1 m^2 plot was chosen and canes within that plot were harvested. Plots were selected arbitrarily at each site to represent the interior (not leading edge) of a stand. Data were compared with similar metrics collected previously from coastal southern California populations. It is important to note that Central Valley and Salinas Watershed sampling reflected the legacy of a multi-year drought (2011-2016) whereas coastal southern California populations were sampled in summer 2010 during a multi-year period of average rainfall.

At each site we collected data within the 1 m^2 plot: number of old canes, number of new canes, number of dead canes, new cane height, old cane (leader) height, number of nodes producing secondary branches per cane, number of secondary branches, length of each secondary branch, length of the topmost fully formed leader leaf. Data were used both to describe Central Valley *Arundo* physiognomy as well as to calculate total photosynthetic leaf area, biomass, and ultimately, water use per area (for more on water use, see Chapter 4).

Figure 1-4. First year *Arundo* canes at full height (6+ meters; the tractor is 3 meters high). Note the simple un-branched vertical structure, very high cane density, and deep green color of the new canes that re-sprouted from rhizomes after the previous year's cut. Older canes in the background are less vertical and are a more yellowish color. (Cal-IPC 2011).

First, we established the cane density for a site as the total number of canes—old, new, and dead—within the 1 m^2 sample plot. Then we estimated leaf area, which relates to transpiration rates, for (1) secondary branches, (2) leaders on older canes, and (3) new canes, using ratios derived from previous studies to estimate leaf area based on the length of these various branches and canes. For leaf area from secondary branches, we totaled the secondary branch length for the plot and calculated leaf area = 5.016 × branch length, based on analyzing a selection of 18 secondary branches (see Figure 1-5). Leaf area of the leader (top-most part of the old cane) was estimated using leaf area = 26.05 × leader length. New cane leaf area was estimated by multiplying the number of new canes by an average leaf area of 4,745 cm^2 per new cane. Data and calculations are presented in Table 1-1 below. Total leaf area (LAI) varied from 8 to 36 m^2 for the plots, averaging 19 m^2.

Figure 1-5. Central Valley field sample sites. Salinas River sites not shown.

Arundo stands across different regions occurring in the Central Valley exhibited slight differences in their physical structure. Because stands have no genetic variation, we can conclude that differences are the result of environmental conditions. Growth patterns in distinct environments can provide some indication of the rate and type of proliferation we can expect elsewhere.

For instance, *Arundo* in the San Joaquin Valley appeared to have a slightly lower rate of branching than did *Arundo* in the Sacramento Valley (Figure 1-7). The nearby Salinas Valley (not part of this study) had an even lower rate of branching of less than one branch per node. Cane height varied in a similar manner, reflecting the association between height (or more specifically, number of nodes) and number of branches: the greater the height, the greater the number of stem nodes with branches and the greater the number of branches.

Cane density was similar in Sacramento and San Joaquin river valleys but both were marginally lower than the Salinas River and marginally higher density than coastal sites (Figure 1-10). Both San Joaquin and Salinas stands were growing more actively (as evidenced by the number of new canes) than were stands in the Sacramento River Valley. When only live canes wre considered, cane density was lower in these watersheds than in coastal sites.

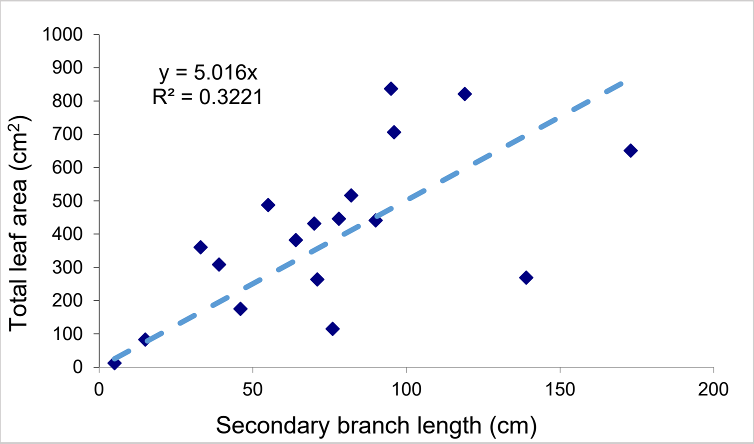


Figure 1-6. Relationship between secondary branch length and total leaf area, based on a selection of 18 secondary branches sampled.

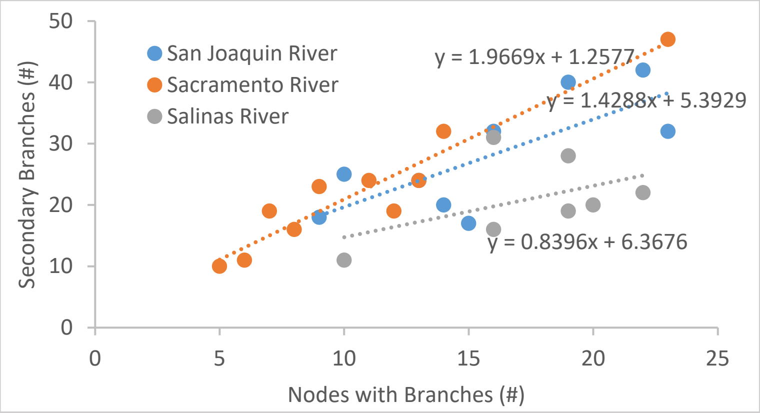


Figure 1-7. Branching behavior within Arundo stands across two Central Valley regions and the comparable Salina River watershed.

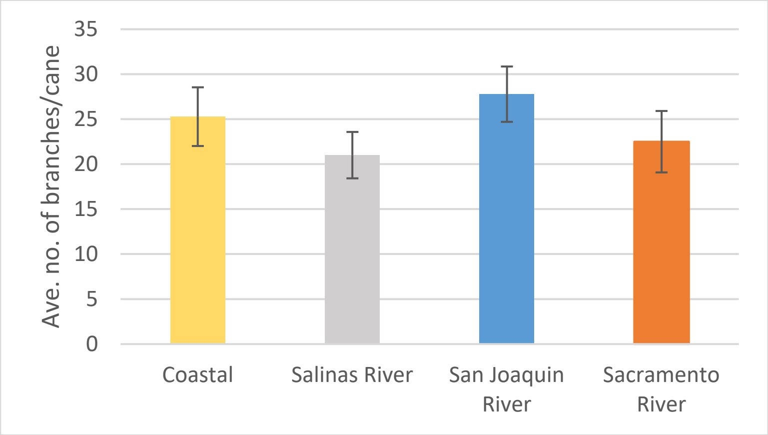


Figure 1-8. Arundo cane branching across regions. Error bars = standard error of mean.

Table 1-1. Summary of *Arundo* cane data from nineteen Central Valley and seven nearby Salinas Valley sites.

			Data per plot						Data and calculations per cane								Leaf area/plot		
			Number of canes				Height$_{avg}$		L_{Leaf} Leader	LA Leader	# canes w branches	# branches	L_{avg} branches	LA_{avg} branches	LA_{total} branches	LA_{avg} Old canes	Old canes	New canes	Total
Region	Plot	Location	Old	New	Dead	Tot.	Old	New	(cm^2)	(cm^2)			cm	(cm^2)	(cm^2)	(cm^2)	(m^2)	(m^2)	(m^2)
SJ	1	Kings R.	33	9	4	46	5	3	.	0	23	32	34	170	5453	5453	18	4	22
SJ	2	San Joaquin R.	17	3	19	39	4	3	.	0	16	32	39	196	6256	6256	11	1	12
SJ	3	Little Dry Cr.	28	7	17	52	5	3	32	834	14	20	44	222	4430	5264	15	3	18
SJ	4	Berenda Cr.	20	3	8	31	6	3	42	1094	22	42	33	166	6989	8083	16	1	18
SJ	5	Ash Slough	29	7	18	54	4	3	47	1224	15	17	48	241	4104	5328	15	3	19
SJ	6	Bear Cr.	36	8	4	48	6	3	83	2162	13	24	57	286	6852	9014	32	4	36
SJ	7	Tuolumne R.	24	7	8	39	7	1	77	2006	19	40	24	121	4836	6842	16	3	20
SJ	8	Stanislaus R.	44	2	11	57	7	3	140	3647	9	18	28	140	2524	6170	27	1	28
SJ	9	Calveras R.	34	3	1	38	7	3	0	0	10	25	39	196	4890	4890	17	1	18
Sac	10	Bear R.	45	5	17	67	4	4	0	0	5	10	36	183	1826	1826	8	2	11
Sac	11	Colusa Trough	43	3	17	63	6	1	67	1745	7	19	31	156	2964	4709	20	1	22
Sac	12	Sac R., Glenn	36	2	7	45	7	5	0	0	11	24	44	219	5256	5256	19	1	20
Sac	13	Stony Cr.	34	2	10	46	5	4	71	1849	14	32	28	142	4541	6390	22	1	23
Sac	14	Hall Cr.	22	9	18	49	5	5	80	2084	8	16	41	208	3326	5410	12	4	16
Sac	15	Thomes Cr.	16	1	10	27	6	5	62	1615	13	24	24	118	2825	4440	7	0	8
Sac	16	Elder Cr.	24	0	23	47	6	.	.	0	23	47	31	154	7247	7247	17	0	17
Sac	17	Red Bank Cr.	18	3	18	39	6	5	80	2084	9	23	36	182	4188	6272	11	1	13
Sac	18	Sac R., Molinos	47	4	7	58	7	6	80	2084	12	19	31	156	2970	5054	24	2	26
Sac	19	Moody Cr.	37	3	11	51	6	5	110	2865	6	11	34	169	1861	4727	17	1	19
Sal	1	King City	14	6	26	46	6	2	22	573	19	28	39	194	5443	6016	8	3	11
Sal	2	Salinas Land	34	13	24	71	4	2	.	0	22	22	44	220	4844	4844	16	6	23
Sal	3	Greenfield	13	4	30	47	5	2	110	2865	10	11	65	324	3562	6427	8	2	10
Sal	4	America	12	9	31	52	4	2	34	886	19	19	48	238	4524	5410	6	4	11
Sal	5	Gonzales	17	4	23	44	3	2	.	0	16	31	44	219	6777	6777	12	2	13
Sal	6	Chualar	10	4	49	63	5	2	65	1693	16	16	58	291	4650	6343	6	2	8
Sal	7	Spreckles	47	5	4	56	5	3	51	1328	20	20	64	318	6366	7694	36	2	39

L = length; LA = leaf area.
LA of leader per old cane = 26.049 × average leaf length on the leader
LA of leader = LA of leader per old cane × number of old canes
Average LA of branches = 5.016 × average branch length
Total LA of branches per old cane = average number of branches per old cane × average leaf area of branches
Average LA for old canes = average leaf area per cane for leaders + average leaf area per cane for branches
Total old cane LA = number of old canes × average leaf area for old canes
Total new cane LA – 4745 cm^2 per new cane × number of new canes

Cane density was similar in Sacramento and San Joaquin river valleys but both were marginally lower than the Salinas River and marginally higher density than coastal sites (Figure 1-10). Both San Joaquin and Salinas stands were growing more actively (as evidenced by the number of new canes) than were stands in the Sacramento River Valley. When only live canes were considered, cane density was lower in these watersheds than in Coastal sites.

Virtually no dead canes were found in the Coastal region where monitoring occurred during a higher rainfall period. Clearly, one consequence of boom-and-bust rainfall years as experienced 2012-2018 (2011-16 drought, 2017-18 wet) is the accumulation of substantial live and dead above-ground biomass.

Photosynthetic leaf area per m², as estimated from height, branch number, branch length, and cane density, appeared variable and marginally higher in the San Joaquin region than the Sacramento region of the Central Valley. Leaf area estimates for all regions provides some indication of the large amount of biomass that *Arundo* produces, even just by leaf area. Averages of over 20 m² of leaf area per m² footprint equate to 20 layers of leaves for every m². Clearly, stands in the Central Valley and Salinas River Valley have a greater proportion of dead standing vegetation than those in coastal southern California. This reflects severe drought stress from 2011-2016. This stress, it should be noted, did not kill the *Arundo* stands; they re-

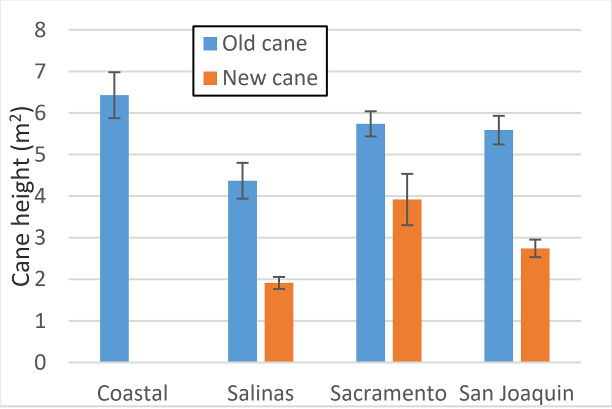


Figure 1-9. Arundo cane height across regions. Cane height in the coastal study combines old and new canes. Error bars = standard error of mean.

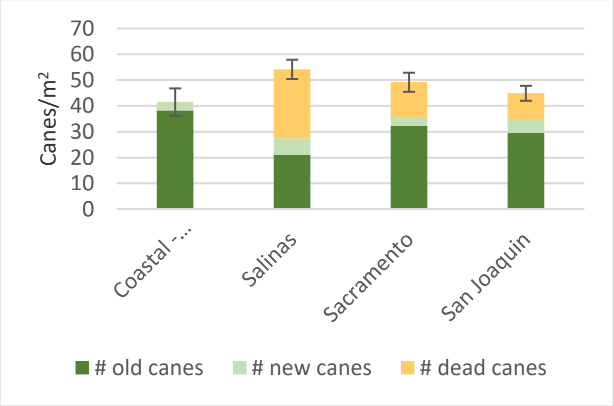


Figure 1-10. Arundo cane density across regions. Error bars = standard error of mean.

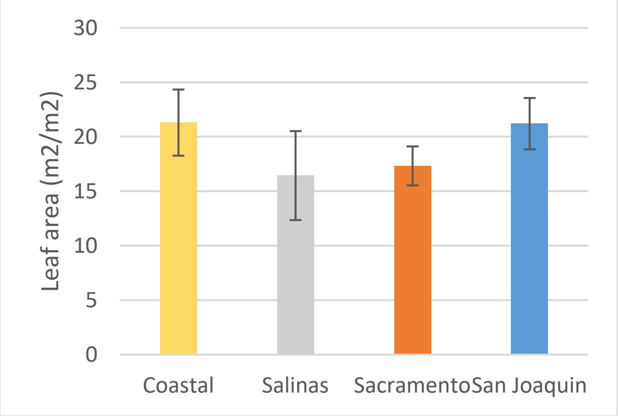


Figure 1-11. Photosynthetic leaf area across regions. Error bars represent standard error of mean.

sprouted when rainfall averages increased. In the Salinas River, however, portions of the system had tree mortality >90%. *Arundo* has greater drought tolerance.

Arundo stand structure was comprehensively reviewed in Cal-IPC's 2011 report on coastal southern California *Arundo* impact and distribution. Stand structure is critical to understand when estimating water use, fuel load, and stand growth rates. We combined with field data collected in the Central Valley and the nearby Salinas Valley in order to estimate stand density, leaf area (presented above), biomass, and transpiration rates (see Chapter 4).

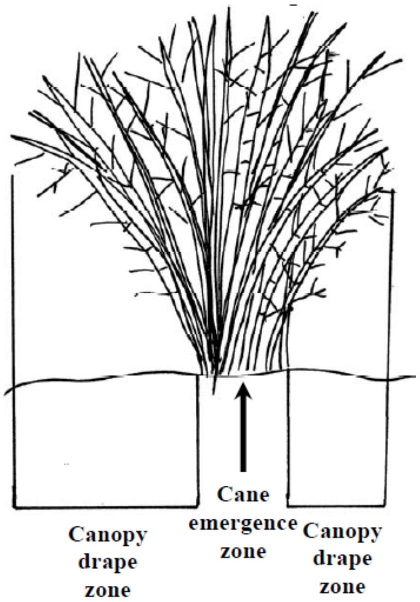


Figure 1-12. Visualization of the effect that drape zone can have on estimations of cane density.

It is important to adjust aerial canopy measurements to account for actual cane emergence cover. This is a potential source of error that was addressed in the coastal 2011 report and is also addressed for the Central Valley Study. Cane density is typically measured as the number of canes occupying a given area at ground level (see "cane emergence zone" below). However, *Arundo* is typically mapped by demarking its canopy cover from above, which includes a large "canopy drape zone". Although a large proportion of the canopy area of small stands can be occupied by canopy drape, this proportion is much smaller for larger stands. In general, our mapped polygons were moderate size patches, rather than small, isolated stands as depicted below. When calculating stand biomass, transpiration rates, and water use, stand density estimates were adjusted downward to a conservative 50% of the mapped area to account for the drape zone. For comparison, coastal southern California estimates were adjusted down to 70% of mapped size, given that stand size was typically larger leading to less of an impact of drape zone.

1.5 Biomass

The biomass that *Arundo* produces is central to the impacts it has on ecosystem services and local biodiversity. Biomass estimates provide information on productivity, resource consumption (nutrients, light, and water), physical presence, and persistence in the system. They can also help to predict impacts to streamflow, sediment movement, wildlife, light penetration, and local wind patterns.

Arundo produces very high amounts of biomass per area as has been documented in many studies of standing biomass of wild infestations as well as annual productivity of cultivated stands (Table 1-2). Few if any other plants generate as much biomass per unit area, which is why biofuel and wastewater treatment programs are so interested in *Arundo*. This study found *Arundo* stand biomass of 107.8 t/ha which is corroborated by other studies, from both wildlands and field and cultivation. The large amount of biomass measured is related to this plant's productivity, the high density of individual canes, and tall growth form of the plant.

Table 1-2. Arundo aboveground biomass estimates from various studies (wild and cultivated).

Location	Above ground dry mass (US tons/acre)	Above ground dry mass (US tons/ha)	Source
Measurements of wild stands:			
U.S. - 19 sites CA Central Valley	44	108	Cal-IPC (2020)
U.S. - 14 sites CA coastal	62	153.1	Cal-IPC (2011)
U.S. - 13 sites across US	69	171	Spencer (2006)
India	15 - 68	36 - 167	Sharma et al. (1998)
Annual yield from wild stands:			
CA (Santa Clara River)	22	54	Ambrose and Rundel (2007)
India – wild stands	32	79	Raitt (1913)
Annual yield from crops/constructed wetlands:			
Australia	45	111	Williams et al. (2008)
Europe	45	111	Shatalov and Pereira (2000)
Italy	42	104	Milani et al. (2019)
Italy	13	32	Angelini et al. (2005)
Italy	18	44	Marinotti (1941)
Greece	53 - 102	131 – 252	Mavrogiapolus et al. (2002)
Greece (Year 1)	7	17	Hidalgo and Fernandez (2000)
Greece (Year 2)	9	22	Hidalgo and Fernandez (2000)
Greece (Year 3	13	32	Hidalgo and Fernandez (2000)
Greece (Year 4)	17	42	Hidalgo and Fernandez (2000)
Spain	13 - 28	32 - 69	Hidalgo and Fernandez (2000)

Table 1-3. Above- and below-ground biomass values for *Arundo*, using an estimate of 22.5% of total biomass for below-ground biomass from Sharma (1998).

Study	Cane drape adjustment	Above-ground biomass (US tons/acre)	Below-ground biomass (US tons/acre)	Total biomass
CA Central Valley (this study)	50%	44	13	56
CA coastal (Cal-IPC 2011)	70%	69	20	89
Spencer (2006)	None needed, measured directly	76	22	98

Table 1-4. Typical biomass values for different vegetation types. From Turhollow (1999).

Vegetation type	Above-ground biomass (US tons/acre)
Willow forest (as crop)	4-8 (annual) 15 (four-year growth)
Switchgrass	5

In addition to the high amount of biomass per unit of land area, *Arundo* has a large amount of energy per unit of dry weight (17.0-19.8 MJ/kg; see Chapter 6 on wildfire impacts). These values compare favorably with other biofuel crops and are higher than most native tree, scrub, and herbaceous assemblages in the riparian zone. (This is the reason that biofuel producers consider *Arundo* one of their top potential crops.) Below-ground biomass estimates are less well studied but appear to be in the range of 22.5% of the plant's total biomass (Sharma et al. 1998). Applying this proportion of above- and below-ground biomass generates overall estimates of 20.0 kg/m^2 or 89 tons/acre (Table 1-3). These biomass levels are at the upper end of any vegetation class (Table 1-4) and are well above typical riparian vegetation values.

1.6 Growth Rate

When conditions are favorable, *Arundo* canes can grow 0.3-0.7 meters per week over a period of several months (Perdue 1958). Young stems rapidly achieve the diameter of mature canes, with subsequent growth involving thickening of the walls (Perdue 1958). Annual yield studies demonstrate the productivity of *Arundo* stands (Table 1-2). Old canes typically have little new growth on the main leader (Decruyenaere and Holt 2005), but have extensive growth on secondary branches, as well as growing new secondary branches. In colder regions of the world *Arundo* dies back and then re-sprouts. Frost can damage the plant if it occurs after initiation of new growth (Sharma et al. 1998, Perdue 1958). In most places in California, canes do not die back and dormancy takes the form of a partial or total browning of canes and leaves during winter, which then re-green in the spring.

In mature stands, most new shoots develop from large apical buds at rhizome termini, resulting in relatively evenly spaced, vertically oriented stem shoots that are typically 2 cm in diameter or bigger (Decruyenaere and Holt 2005). Rhizome growth extends laterally along an axis, and branching is generally dichotomous (Figure 1-4). Rhizomes appear to 'self-discriminate', growing into areas with no rhizomes present (Decruyenaere and Holt 2005). Stands expand laterally 7-26 cm/year (Decruyenaere and Holt 2005), as well as generating higher cane density. Aerial imagery comparisons in San Diego

County over a 10-year period suggest that expansion of individual stands is surprisingly slow (0.5 m in diameter per year), but also highly variable (Giessow, unpublished data). A few studies have examined expansion and lateral spread of rhizomes and canes, but these data are presented as increasing cane density within quadrats. Future studies should more explicitly describe length (m) or area (m^2) of spread.

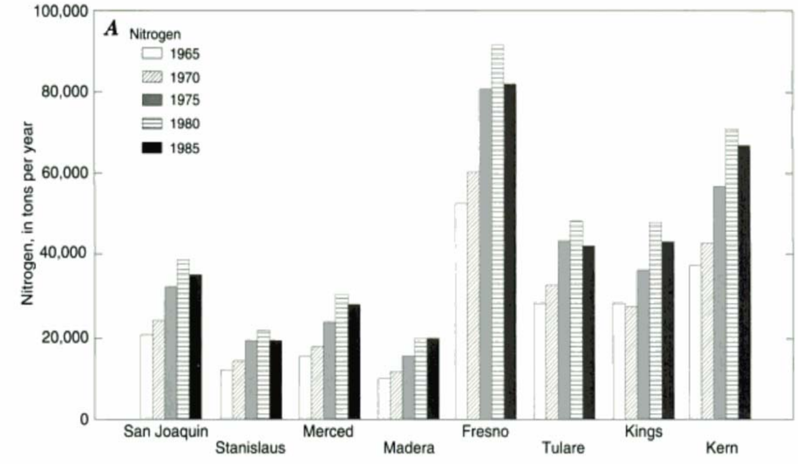


Figure 1-13. Nitrogen fertilizer application in the San Joaquin-Tulare Basin, 1965-1985. Fresno, Kern, Kings and Tulare County were ranked highest in the nation. Reproduced from Kratzer and Shelton (1998).

Three general factors seem to affect growth rates of both canes and rhizomes: (1) availability of water, (2) availability of nutrients and (3) temperature regimes (which are is affected by shade). Water availability seems to be the primary factor restricting the growth of *Arundo* stands in coastal California. This is based on field observations across the study area and our review of transpiration and nutrient studies. Generally, watersheds in coastal California have favorable temperature ranges and are not nutrient limited. Those in the Central Valley are more variable and occasionally reach freezing. In both regions, areas with water available throughout the year develop into dense, tall *Arundo* stands. High terraces that are far from the water table frequently have *Arundo* stands with lower cane density, shorter stature, and large amounts of dead material in the canopy (an indicator of stress). Many Central Valley *Arundo* stands reflect some level of water stress, as evidenced by their lower stature and higher proportion of dead, standing biomass. But this likely is a symptom of recovery post 2011-16 drought (data was collected early 2018). Similar to coastal regions, channel and river systems in the Central Valley are not nutrient limited, and may actually carry a higher nutrient load than many coastal southern California river systems because of runoff from surrounding agriculture (although urban runoff also generates a high nutrient load, and many systems are listed as impaired by the state). Artificially high nutrient levels increase growth rates of all riparian vegetation, but *Arundo* with its higher productivity potential (compared to native vegetation) can capitalize on this, turning it into a competitive advantage (Ambrose and Rundel 2007).

In the last century, nutrient inputs to river systems across the country, including in southern California and Central Valley watersheds, have increased steadily (see Suffet and Sheehan 2000, Cal-IPC 2011). In the Central Valley, increases in surface water nitrogen come from both nitrate and ammonia, and from non-point sources (agricultural run-off, including fertilizer and manure) and point sources (waste water treatment, food production, manufacturing, and mining); they rank among the highest in the nation (Kratzer and Shelton, 1998; Figure 1-12). As with many plants, *Arundo* grows more quickly with increased nutrient load (specifically, nitrogen). Several studies suggest the implications of increased nitrogen for *Arundo* in a wildland setting. For instance, when nitrogen was added in the context of competition with other plants, Quinn et al. (2007) found that growth rates of *Arundo* increased to what was observed without competition. Therefore, *Arundo* can be presumed to be even more impactful in areas with existing native vegetation in the present of additional nitrogen input from run-off than without it.

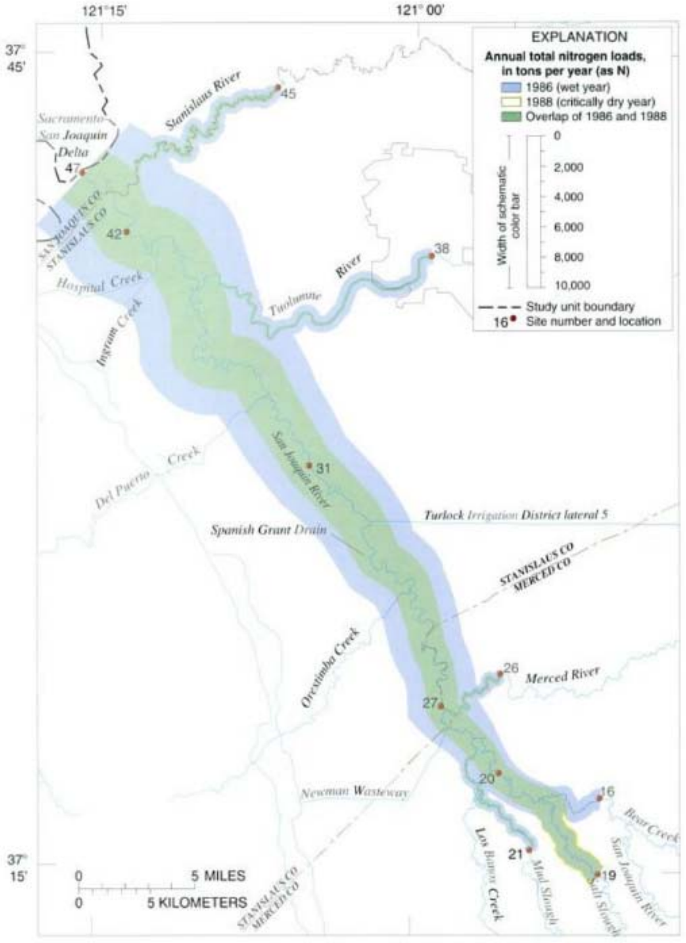


Figure 1-14. Schematic of estimated total nitrogen load in a wet and a dry year along the San Joaquin River. Reproduced from Kratzer and Shelton (1998).

1.7 Reproduction and Spread

In the absence of disturbance, *Arundo* stands grow relatively slowly, with rhizomes growing laterally and then producing new canes (see Decruyenaere and Holt 2005). In addition, canes that have contact with the soil surface can also root and form new buds, and eventually new individuals, if conditions are favorable (Boland 2006).

New individual plants within a watershed—and the colonies they grow into—are created entirely through vegetative propagation. This occurs when plant fragments, usually rhizomes, become dislodged from one clump and re-root at new locations to form separate plants. Dispersal generally occurs during flood events, when floodwaters break off pieces of *Arundo* plants and transport them downstream (Else 1996, Decruyenaere and Holt 2005). Establishment of new *Arundo* stands within a watershed is, therefore, generally limited by the extent of river flow and floodplain inundation. However, *Arundo* fragments can also be moved to new locations within a watershed via human disturbance (machinery or plant material that is moved either consciously or unconsciously). See Cal-IPC (2011) for a more detailed description of vegetative propagation.

The combination of within-watershed dispersal events and stand growth rates generates a pattern of expansion that increases episodically to the system's maximum carrying capacity for *Arundo*. Because *Arundo* is so competitive once established, it as a rule grows towards a trajectory of 100% cover where conditions are favorable. *Arundo* spread occurs from upstream to downstream and has a slow but steady growth pattern once established, making it an ideal candidate to address with strategic eradication measures from the top of the watershed down. In addition, stream reaches and water bodies with greater likelihood of high episodic stream flow or other disturbance are more likely to be continuing sources of propagules further downstream.

The spread of *Arundo* between watersheds is primarily due to humans moving *Arundo* plants. This can be through actively planting *Arundo*, or through dumping materials that included *Arundo* propagules (rhizomes). *Arundo* fragments can wash up into estuaries, but generally cannot get very far up into the riparian system as river flows push material out of the system. Therefore watershed-based control should theoretically be achievable.

2 *ARUNDO* ECOLOGY

Invasive species that modify ecosystem processes and ecological communities are considered ecosystem engineers. They have dramatic and far-reaching impacts on the environment as well as our economy and infrastructure. *Arundo* is a quintessential ecosystem engineer: if left unchecked, it changes stream flow patterns, alters nutrient cycling rates, restructures the geomorphology of waterways, increases wildfire fuel loads, and permanently modifies habitat structure and food resources. Given its broad-reaching impacts, *Arundo* has been implicated by the California Department of Water Resources (DWR) as one of the four highest priority target invasive species to control as part of its Central Valley Flood Protection Conservation Strategy (DWR 2016). Impacts on geomorphology, water use, sensitive species, and fire are dealt with separately in later chapters. Here we provide an overview of the types of ecosystem and habitat alterations that *Arundo* can cause, most of which have been dealt with in greater depth in a previous report (Cal-IPC, 2011).

2.1 Flora

Arundo tends to form dense, monotypic stands that replace native riparian vegetation and fills in un-vegetated portions of the habitat. The exclusion of native vegetation affects vegetation composition, vegetation structure, and food resources. These changes have impacts on the native flora and fauna. A study of the Russian River, a northern California coastal waterway, showed that *Arundo* invasion was associated with significantly lower richness of native perennial plant species along stream banks (Cushman & Gaffney 2010). Plots invaded by *Arundo* supported significantly lower native and exotic plant species richness and lower numbers overall of both established plants and seedlings than uninvaded plots. Native species also recolonized quickly after *Arundo* was removed.

In coastal southern California watersheds, *Arundo* often displaces nearly all vegetation, leaving only mature gallery trees. These invaded areas are highly vulnerable to wildfire which is fueled by *Arundo*, which serve as a ladder fuel. *Arundo* also produces fine fuels which facilitate ignition as well as harboring transient camps, which are a documented ignition source for *Arundo* fires in riparian areas (Cal-IPC, 2011). Lower stature vegetation, such as native shrubs, perennial herbs and annual herbs, are particularly easily displaced and are usually completely excluded in dense *Arundo* stands. Quinn and Holt (2004) observed that *Arundo* growth was largely unaffected by competing adjacent vegetation and that it grew well across a wide variety of environmental conditions. Other regions of the world, such as Brazil, are also suffering the dramatic ecological impacts of this species (Simões 2014).

In addition to displacing native vegetation, *Arundo* also alters habitat by filling in areas that would naturally be open and un-vegetated. These microsites are the preferred habitat for several sensitive plant species, such as Suisun marsh aster and wooly rose-mallow. *Arundo* impacts on sensitive plant species that occur in the Central Valley are described in Chapter 7. Open portions of riparian habitat can also be critical for fauna that move through these areas.

Figure 2-1. A dense contiguous stand of *Arundo* in New Mexico's lower Rio Grande Valley that is reducing stream breadth, channeling the river, and displacing native riverbank vegetation. Photo: Center for Invasive Species Research, University of California, Riverside.

Of particular importance are modifications of abiotic processes, as these factors shape the entire riparian ecosystem. Dense stands of *Arundo* in coastal southern California tend to support a higher fire frequency and intensity, as well as altered flooding patterns (Cal-IPC, 2011 and references therein). Suppression of lower-biomass and more heterogeneous riparian vegetation by *Arundo* exacerbates the impact of flood and fire events, alters the natural successional patterns of riparian vegetation, and generally leads to more dominance of *Arundo*. This is an important positive feedback loop that leads to habitat type conversion (Ambrose & Rundel 2007). Modification of geomorphic riverine processes (as described in Chapter 5) strongly modifies plant succession patterns (Cal-IPC 2011).

2.2 Food Webs

Arthropods are increasingly seen as indicators of ecosystem health and, because they either directly or secondarily serve as food resources for much of our wildlife and because they represent all trophic niches except that of primary producer. They also serve as a helpful surrogate for overall diversity because they are easier to survey than vertebrate communities. They provide a rich source of data on food webs and trophic structure, in addition to diversity. Studies conducted of arthropod abundance and diversity in *Arundo*-invaded habitat have unambiguously concluded that *Arundo* supports lower diversity, density and productivity of arthropods within *Arundo* stands compared to native riparian vegetation.

Native riparian vegetation in Sonoma County in spring contained twice the abundance, biomass, and species richness of aerial insects compared to *Arundo* (Herrera & Dudley 2003). Those insects that were recorded were rarely observed feeding, suggesting that *Arundo* was not being used as a food source. Ground-dwelling insects showed the same responses to *Arundo*, but to a lesser degree than aerial insects. Osbrink et al. (2017, 2018) more recently found similar patterns of higher native ant and beetle abundance and diversity in uninvaded versus invaded riparian habitat along the Rio Grande River.

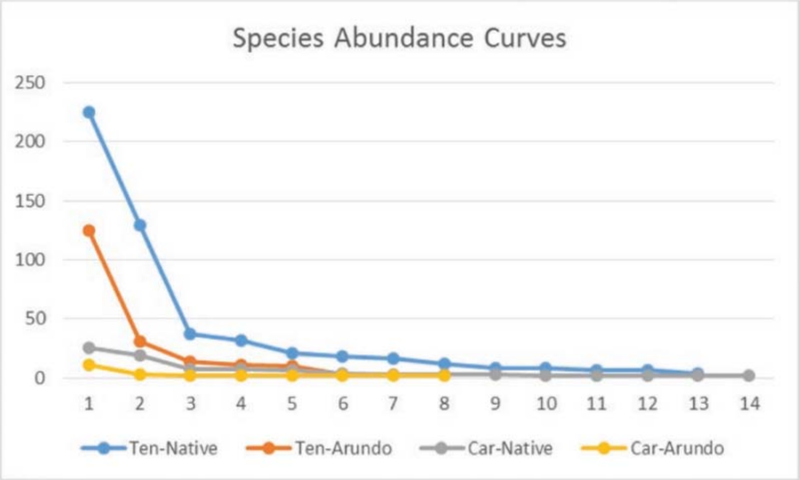


Figure 2-2. Species abundance curves for Tenebrionids and Carabids in *Arundo* stands versus native riparian habitat (x axis = number of species; y axis = number of individuals collected; reprinted from Osbrink et al. 2018).

Arundo leaf tissue appears to be of low quality and/or unpalatable for many native arthropods. Aquatic caddisfly larval survival was significantly lower for individuals fed *Arundo* compared to alder, willow, or even tamarisk litter (Going & Dudley 2008). High concentrations of secondary compounds (tannins, alkaloids) and silica and low nitrogen levels are likely the reason they are poor food resources (Khuzhaev & Aripova 1994, Wynd et al. 1948).

Within the soil and leaf litter of *Arundo* stands, assemblages of invertebrate species tend to be dominated by scavengers and detritivores that generally do not utilize the plant tissue directly. The assemblages tend to be dominated by non-native invertebrate species. Forty-three percent of the invertebrate species associated with *Arundo* rhizomes in a southern Californian study were non-native. In Sonoma County in the Central Valley, non-native detritivorous isopods were the most abundant arthropod sampled in *Arundo* stands (Herrera & Dudley 2003, Lovich et al. 2009).

The preference that native arthropods show for native riparian vegetation over *Arundo* is likely due to the greater complexity in habitat structure that native vegetation provides, the great presence of floral resources (largely absent in *Arundo*), the more heterogeneous list of host species for specialist herbivores, and higher quality food resources found in native vegetation. Therefore, despite its large biomass per square meter, *Arundo* appears to provide little to the food web. It therefore presumably has a significant impact on wildlife. The large reduction in aerial insects, in particular, could have serious negative impacts for insectivorous birds such as the endangered least Bell's vireo (*Vireo bellii pusillus*) and bank swallow (*Riparia riparia*). Lower growth rates in aquatic insects such as caddisflies could impact native Chinook salmon and steelhead.

2.3 Wildlife

As described above, dense *Arundo* stands can negatively impact wildlife by reducing food resources, altering structure for nesting and denning, and creation of physical barriers to movement. While there are few studies to our knowledge that document these impacts directly for wildlife, impacts seem probable based on the limited research that does exist, coupled with personal field observations and wildlife specialists' assessments as reported in management plans and regulatory documents.

Studies on the use of *Arundo*-invaded habitat by wildlife can be compromised by adjacent native riparian habitat that may affect study results. Large contiguous stands of *Arundo* do exist, but they are difficult to monitor because the density of canes restricts access to interior portions of the stand. Species frequently have territories/ranges that include invaded and un-invaded habitat, so their occurrence in *Arundo* stands may be incidental. Even with these caveats, patterns are still apparent.

Many reports and surveys have identified *Arundo* as a factor that reduces habitat suitability for reptiles and amphibians, although there are no specific research studies. Since reptiles and amphibians are highly dependent on specific hydrological and geomorphological processes, they may be severely impacted by *Arundo*'s long-term impacts on hydrology, geomorphology, and water use. *Arundo* stands likely also affect reptiles and amphibians by creating physical barriers to their movement and eliminating areas for basking. Specific potential impacts will be explored for two federally listed herps and five fish species in Chapter 7.

Arundo impacts on bird species have been documented and are presumed to be the result of changes to physical structure and reduction in available food resources. Kisner (2004) reported a reduction in abundance and species richness of birds in *Arundo* stands compared to native stands in southern California. Orr (2010) found lower avian species diversity and fewer total individuals in *Arundo* stands relative to native stands in the Santa Clara Valley in the San Francisco Bay Area. The branching structure of *Arundo* appears to be unsuitable for most nesting for most birds. Only 0.8% percent of least Bell's vireo nests were in *Arundo*, compared to 76% in willow and mulefat in the Prado Basin in southern California (Pike et al. 2007). Aditionally, observed nesting in *Arundo* does not indicate successful nesting. Least Bell's vireos occasionally nest in hemlock, only to have nesting failure later in the season as the plant dies (Kus, personal communication). Nesting habitat for western snowy plover on beaches is reduced and predation risk is increased by large depositions of *Arundo* along coastal beaches that have washed down from riverways (USFWS 2007). Impacts on six federally listed bird species will be reviewed in Chapter 7.

Arundo effects on mammal species have been poorly studied to date but are likely to be significant. *Arundo* stands may provide shelter for larger mammals, but food resources and food accessibility are likely lower in comparison to habitat dominated by native plants (see above). Dense *Arundo* cover and growth reduces mobility of mammals, which can reduce the use of riparian habitat as corridors for movements. A recent camera- and live-trapping study by Hardesty-Moore et al. (2020), found that mesopredators avoided *Arundo* stands, but that rodents seem to be more abundant within them, suggesting their role in limiting movement and providing refuge from predation. This study provides the first clear evidence of *Arundo's* suspected impact on habitat use. Radio collars studies would also be well-suited to further investigate habitat use in invaded versus non-invaded landscapes. Radio telemetry has been used successfully in upland habitats to better understand fine-scale habitat use and have shown patterns that may also apply to areas with high levels of *Arundo* invasion. For example, Lyren et al. (2008) found that bobcat did not utilize non-native grassland patches dominated by dense, tall annual grasses and mustard that restrict their movements across landscapes to more traversable shrubland, woodland, and riparian habitat. These results may be very relevant to wildlife protection programs, especially in protected land, where the actual habitat suitable for wildlife species may be significantly less than that which appears available on a map. Five federally endangered mammals, including species that move between upland and riparian habitat, such as the San Joaquin kit fox and the riparian brush rabbit, will be examined in Chapter 7.

In addition to the above listed biotic impacts presented for species, abiotic impacts can be particularly devastating. Fire in particular can result in direct mortality of species and degrade riparian habitat for years post-fire. Modification of flooding and geomorphic processes can drastically alter habitat structure, impacting critical resources for breeding and plant establishment succession. Impacts to sensitive species are further explored in Chapter 7.

2.4 Biological Control

Two biological control agents targeting *Arundo* have been introduced and are now established in California. However, they are not well enough established across California to have made a significant difference and it is unclear whether they will have a more significant impact in the future (It is important to remember that biocontrol agents never eliminate their host species.) Releases have been conducted by the U.S. Department of Agriculture's Agricultural Research Service (USDA-ARS) regional office in Albany, California through the Invasive Species and Pollinator Health Research Unit.

The shoot-tip *Arundo* galling wasp *Tetramesa romana* (Hymenoptera: Eurytomidae) is native to the Mediterranean region and makes galls in lateral shoot tips. Larvae feed on the tissue and pupate inside the gall. Adults that emerge from pupae chew their way out of the gall, leaving small, round exit holes. The wasp significantly reduced both live shoot density and biomass of *Arundo* seven years after its initial release in the Lower Rio Grande Basin of Texas and Mexico (Goolsby et al. 2016; Moran et al. 2017). Its impacts were also associated with a two- to four-fold increase in native plants at study sites

(Moran et al. 2017). The *Arundo* wasp has been experimentally released on private land along Stony Creek near Orland in Glenn County (Sacramento River watershed) since 2010 and on private land along Berenda Slough and Cottonwood Creek in Madera County (southern San Joaquin River watershed) since 2017. Reproductive populations of *Arundo* wasps were observed at both sites in the summer of 2019, two years after the last releases. It is too early to evaluate the wasp's potential impact on *Arundo* in California. Adventive (accidentally released) populations of the *Arundo* wasp have also been found in the Ventura and Santa Clarita River drainages near Ventura, California (Lambert et al. 2010). These systems remain heavily invaded by *Arundo*, so the wasps appear to be having only a minor impact.

The *Arundo* armored scale (*Rhizaspidiotus donacis*) is the second biocontrol agent that has been released by USDA-ARS. It feeds and reproduces solely on *Arundo* (Goolsby & Moran 2019). Adult females are immobile, with no legs or antennae, and use their stylet-like mouthparts to remove fluids from the vascular tissues of *Arundo* rhizomes and the bases of the shoots. Adults produce tiny crawlers, which disperse a few feet at most to settle and feed. Crawlers become sessile as they mature; they lose legs and antennae and secrete a white waxy covering. The *Arundo* armored scale is established in southern Texas where it is reducing live shoot biomass by up to 50% in release plots with both wasp and scale compared to the wasp alone (Goolsby & Moran 2019). Dispersal of the armored scale is far slower than for the wasp, and its long-term impact is likely to be localized to release plots until flooding events or other disturbance distributes it further. The *Arundo* armored scale was first released in 2014-2015 at several sites along Stony Creek in Glenn County and on Andrus Island in the western Delta. Armored scales were again released at five sites in the Central Valley in 2017, two near Orland, Glenn County, and three along Berenda Slough and Cottonwood Creek, Madera County. One year later, in 2018, establishment of reproductive females was confirmed at all five sites. Additional releases are being made in the Central Valley. In 2018, an adventive population was found in the Santa Clarita River drainage in Ventura County (A. Lambert and T. Dudley, UC Santa Barbara, unpubl. data).

A third agent, the *Arundo* leaf miner *(Lasioptera donacis)* (Diptera: Cecidomyiidae), which mines the leaf sheaths of *Arundo,* is also host-specific (Goolsby et al. 2017) and approved for release in the U.S. It and is It has not yet been released due to difficulties in rearing adults outside of the lab setting.

3 *ARUNDO* DISTRIBUTION IN THE CENTRAL VALLEY

One of the primary objectives of this study was to map the distribution of *Arundo* and quantify its abundance in the Central Valley. Although numerous smaller mapping and control projects have been conducted throughout the region, no comprehensive map of this species existed prior to our work. Mapping is especially important for strategically treating *Arundo*, because this species reproduces entirely by rhizome fragments that are transported downstream along river courses. This reproductive and dispersal strategy is a weak point, in terms of control, in the otherwise formidable suite of character traits. It makes *Arundo* a feasible eradication target for upstream river reaches, subwatersheds, and even entire watersheds.

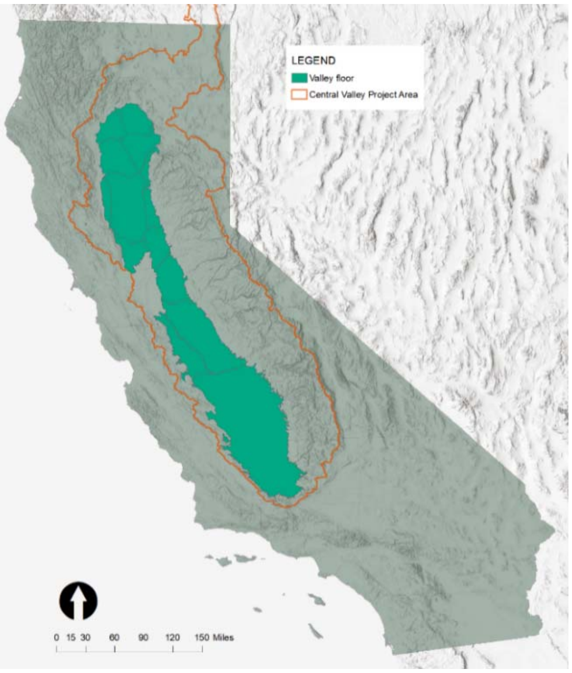


Figure 3-1. Project area showing valley floor within Central Valley Project Area.

We mapped *Arundo* across the Central Valley basin, from the Sierra Nevada foothills to the estuaries of the Sacramento and San Joaquin River valleys. The project area (Figure 3-1) was further subdivided into 25 distinct hydrologic units, referred to here as "watershed units" across which we quantified its abundance and, in later chapters, its potential impacts.

3.1 Methodology

3.1.1 Survey Area

Arundo was mapped across Central Valley waterways from the headwaters of the Sacramento River in the north to the headwaters of the San Joaquin River in the south. Because *Arundo* is a large plant with a growth form that is distinct from other riparian vegetation, it can be relatively easily mapped using aerial imagery. A team of GIS mappers (J. Casanova, B. Castro, J. Giessow, D. Morawitz, M. Roberts, A. Young) mapped *Arundo* by visually reviewing relevant aerial imagery of each water feature in the 38.4 million-acre survey area.

We developed a workflow and methodology prior to initiating mapping and conducted trainings that all team members participated in to ensure consistency in data collection across different mappers. Each team member was assigned to a series of Digital Ortho Quarter Quads (DOQQs—each is one-fourth of a 7.5-minute USGS quad). We began by mapping the valley floor (13.8 million acres) and expanded the search area to include river and stream reaches in foothill and headwater areas. This was done to ensure a thorough search for the uppermost *Arundo* occurrences in all the watersheds flowing into the Central Valley (Figure 3-1).

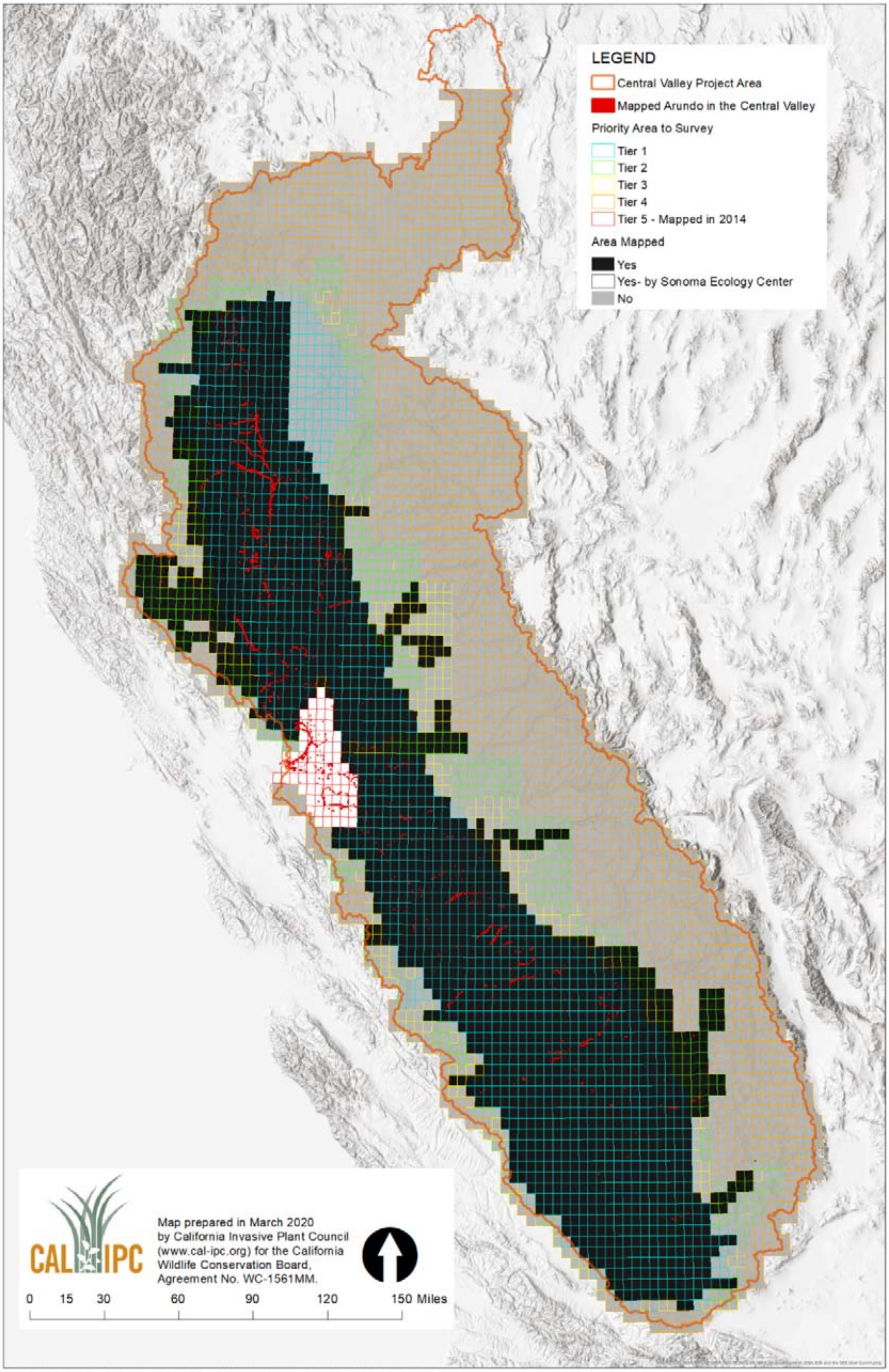
In order to streamline work and maximize efficiency, we initially recorded the time needed for mapping the first DOQQs. We then used this timing information to estimate the time to complete work for all DOQQs, adjusting for the amount of *Arundo* expected to occur in each. Subsequently, DOQQs were reassigned as either Tier 1, Tier 2, and Tier 3 priority. Tier 1 DOQQs comprised the valley floor and areas where we expected *Arundo* to be. Tier 2 included all areas within the Central Valley where *Arundo* had been previously reported as well as areas downstream from there. Tier 3 were those areas directly upstream of historic reports and upstream of the waterways in which we had mapped and found *Arundo*. Tier 4 were all DOQQs within the project boundary where we suspected *Arundo* would be absent. Tier 5 were the 72 DOQQs in the Delta that the Sonoma Ecology Center had previously mapped in 2014 and which would be incorporated into our dataset. A total of 2,542 DOQQs (24 million acres) were categorized into Tiers 1, 2 and 3 (1,706 in Tier 1, 522 in Tier 2, and 314 in Tier 3) out of a total 4,342 total DOQQs in the study area.

We mapped 92% of Tier 1 areas, 38% of Tier 2 areas and 26% of Tier 3 (Figure 3-2). Most Tier 1 quads that were not mapped were located in the northeastern section of the original project area and were, on further examination, considered highly unlikely to support *Arundo*. To ensure that any previously undetected *Arundo* patches were captured in our mapping efforts in the Tier 2 and 3 areas, we continued to search upstream along each water feature into Tier 3 areas until we found two DOQQs absent of *Arundo* beyond the last *Arundo* found in that waterway.

Due to limited high-resolution aerial photo coverage in less populated areas as well as steep slopes in some areas along both the coastal range and the foothills of the Sierra Nevada, some *Arundo*, and particularly isolated planted populations, may not have been detected. Over the course of our quality control review, we also determined that some *Arundo* had not been accurately detected or was mapped incorrectly. To correct for this error, we re-mapped 257 DOQQs. In total we mapped 1,844 DOQQs (17.4 million acres) in the project area and the remainder was assessed and evaluated as highly unlikely to contain *Arundo*.

3.1.2 Mapping

The mapping methodology utilized for this project uses techniques developed in our previous large-scale, watershed-based weed mapping effort that took place on California's southern coast (Cal-IPC, 2011). Each stand of *Arundo* was digitized using one of the following two digital mapping



Map prepared in March 2020 by California Invasive Plant Council (www.cal-ipc.org) for the California Wildlife Conservation Board, Agreement No. WC-1561MM.

\\Projects\Arundo\FinalCVArundo_Maps_Tables\20200310_Arundo_InsetMap_PrioritybyTiers_Esize_Portrait.mxd

Figure 3-2. Final area mapped within project area with initial priorities identified.

approaches: (a) heads-up digitizing using high resolution aerial imagery within a GIS, or (b) heads-up digitizing followed by field checking and either field edits or later in-office refinement. An *Arundo* geodatabase was generated within ESRI's desktop GIS application (ArcGIS 10.4) using a geodatabase (GDB) as the chosen file format. Domains (e.g. a data dictionary) were set up before the mapping commenced to ensure data integrity by standardizing the choice of values within each field and enabling the different mapping partners to easily share date. *Arundo* was then digitized within GIS implementing a dual-monitor workstation setup. A primary tablet monitor (Figure 3-3) hosted the GIS application where stands were delineated as defined areas (e.g. polygons). High-resolution (1 ft or better) aerial photos were the primary base layer used for delineating plant population boundaries in the GIS.

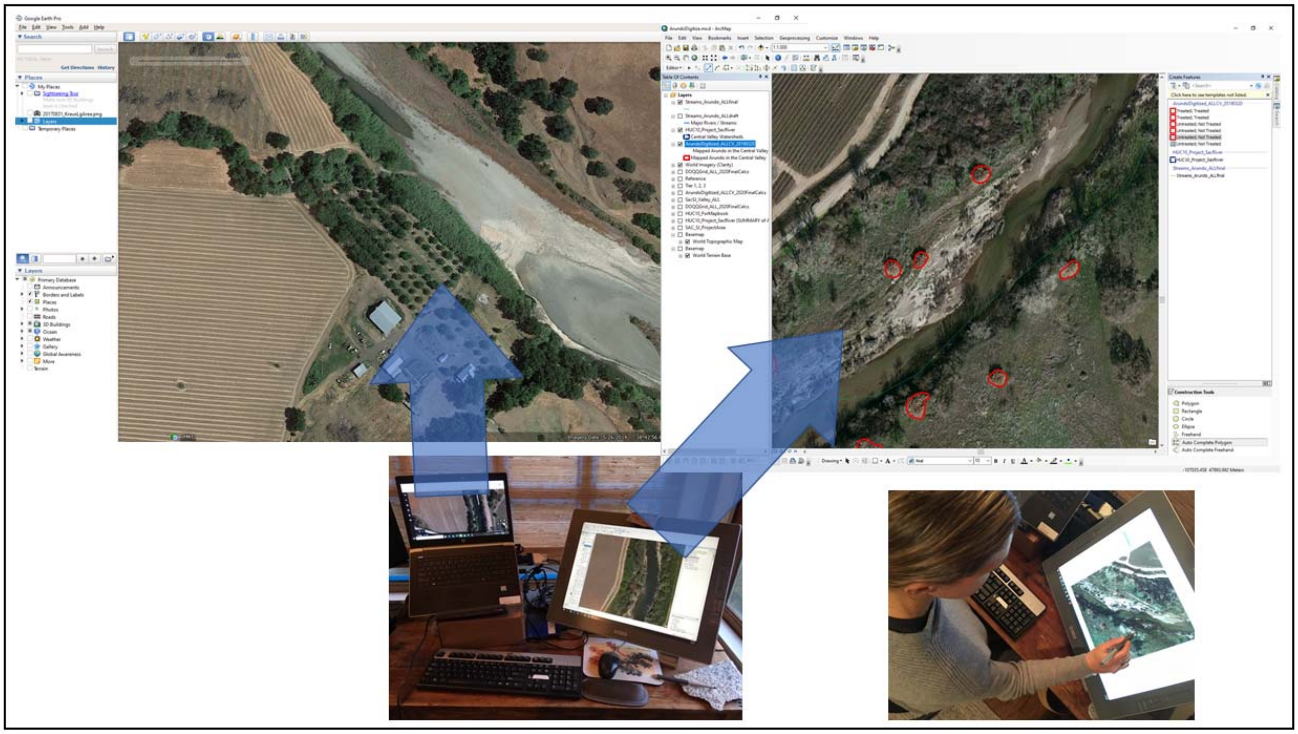


Figure 3-3. In-office surveys using a dual-monitor workstation.

When a stand of *Arundo* was encountered in an aerial image, the mapper traced the extent of the canopy using a freehand tool to draw polygons around areas with a cover class greater than 90% cover, and as close to 100% cover as possible, to capture discrete identifiable units. Digitizing typically occurred at a scale between 1:1,000 to 1:2,000. The scale used depended on the resolution of imagery available for the area being mapped as well as personal preference. Depending on how dense the *Arundo* was, we used a minimum mapping distance of 7-20 feet to map discrete patches.

To be consistent between mapping teams we each completed two test DOQQs and compared results and adjusted mapping methodology so that different mappers would generate repeatable results across the study area (Figure 3-4).

After a population was digitized, key attributes were noted (Table 3-1). A secondary reference monitor displaying different imagery was used as an additional aid to help distinguish smaller clumps as well as those populations partially covered by thicker tree canopy cover. Additional imagery sources included: Google Earth, Nearmap®, Microsoft Bing Maps, Bing Bird's Eye oblique imagery, DOQQs from the Department of Water Resources (DWR), and Google Maps Street View. These additional sources for imagery allowed us to view the same sites from different angles, different times of year, and higher resolution, with KML versions of our index grids and other GIS features in Google Earth and multiple sources of imagery viewed side-by-side while digitizing.

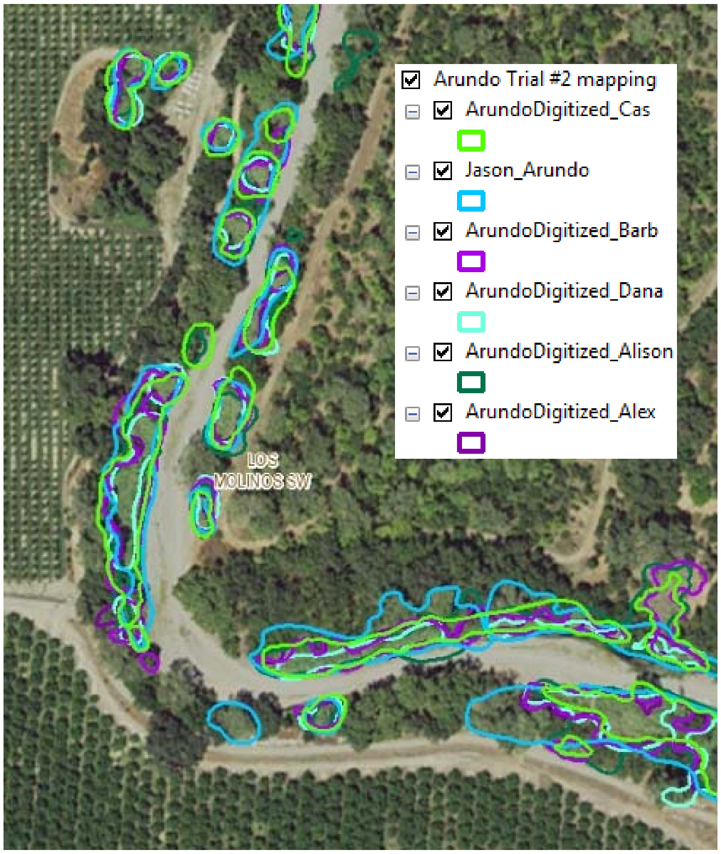


Figure 3-4. One of the trial DOQQs used to practice and review mapping technique and standardize methods.

Most areas were visually inspected using imagery with 1- to 2-foot pixels. Higher elevation areas were restricted to lower quality imagery (3-foot pixels). Higher quality 0.5-foot imagery was used in and around urban areas. The Google Maps Street View was used in a few areas to view any riparian areas that were visible from streets. As a result of using these various data sources, the data mapped represent a composite picture of *Arundo* distribution over a ten-year period (2008-2018). Some *Arundo* stands had been or were currently being treated; we recorded treatment status for these stands with the aid of Google Earth's multi-year imagery slider to look for evidence of control work through time.

Table 3-1. Data attributes collected for *Arundo* mapping (data dictionary).

Attribute	Notes
Plant Species	Common and scientific names are noted.
Percent Cover	70-100%(=85%); 50-69(=60%); 15-49%(=32%); 2-14%(=8%). Mapping was done by aerial imagery, and polygons were mapped with the goal to get as close to 100% cover as possible.
Treatment Status	Status was marked as: treated, untreated, funded for treatment, or status unknown. For each population, we used the imagery slider in Google Earth to determine if the population had been controlled. If we knew a population/area was funded for treatment, we included that.
Comments	Supplementary information
Date Mapped	Records that were only collected in-office used the most recent imagery date in Google Earth even if the *Arundo* was detected at an earlier date. The max extent of *Arundo* detected was mapped, but the most recent was recorded. If it was verified in the field date, this date was used.
Data Source	Imagery source used for data collection.
Mapping Methodology	Method was noted as: in-office survey, field survey, or combination.
Observer	Person responsible for the last edit of a particular record.
Date Edited	Autogenerated within geodatabase.
Field check	Mapper’s request for field confirmation. Often combined with Comments if marked ‘Yes’.

3.1.3 Data Compilation and Analysis

Each member of the mapping team provided their geodatabase when their assignments were complete. Because we had established domains, we could easily compile the features into one geodatabase. We had a few instances where several mappers had mapped the same DOQQ, and in these cases, we reviewed the mapping and chose a prime mapper for that area or combined the mapping by automation. We also did a spot check of everyone’s mapping to confirm that our methods and results were similar. Last, we compiled one tracking DOQQ layer which shows where each team member mapped and, in the instance of redundancies, who was the prime mapper and who was the second or third mapper.

We generated a GIS layer of waterways with *Arundo* for use in describing the distribution of *Arundo* and in designing management programs based on watershed units. Generating this layer was not trivial, since USGS National Hydrography Plus Dataset (NHDPlus HR) stream layers are complex and difficult to decipher in relatively flat valley areas with braided streams and manmade water channels. The accuracy of this waterways layer also appeared to vary across the project area. We “dissolved” multiple line features to create single lines for major waterways in order to better calculate river miles. We identified the uppermost *Arundo* population on each major waterway, then measured the distance in river miles from that population downstream to the point where the waterway merged into the next waterway downstream. We also associated *Arundo* populations with the most invaded waterways using spatial queries between 350′ and 1500′ in addition to visual identification depending how wide the waterway was and how segmented or low quality the GIS stream data was. In some watershed units, virtually all the *Arundo* can be associated with a waterway, while in others the portion is much lower.

As this project ended, we located a synthesized CDFW California Streams GIS layer (CDFW 2018) which served our purpose for calculating "total stream miles" per watershed unit. We still used our GIS layer of waterways to calculate invaded river miles per watershed unit because of the extensive work already invested to assess waterways with *Arundo*. Last, to find miles of manmade waterways we used the NHD Plus layer, the only dataset we found that tracks manmade features. See Figure 3-6 for different waterway types.

We subdivided the project area into watershed units based on a combination of Hydrologic Unit Code (HUC) 6, 8 or 10 levels and, in some instances dividing them at the Sacramento River so the watershed unit did not cross it. The main stem of the Sacramento River was buffered by 1200′ and divided into three reaches that served as watershed units in order to better differentiate the *Arundo* found on the main stem of the Sacramento versus *Arundo* found upstream in the watershed. The goal of this analysis was to provide a project-wide watershed unit layer across which to present the *Arundo* data and describe potential project areas by watershed unit.

3.1.4 Field Verification

After compiling the survey data, we designed and tested a field verification system. The data was 'checked out' of the GIS database and transferred to ArcGIS online for input into ESRI's ArcCollector. ArcCollector uses an ESRI imagery server as a base layer for the field mapping and ground-truthing (Figure 3-5). ESRI's ArcCollector allowed for seamless integration between the field computers and the geodatabase in the cloud.

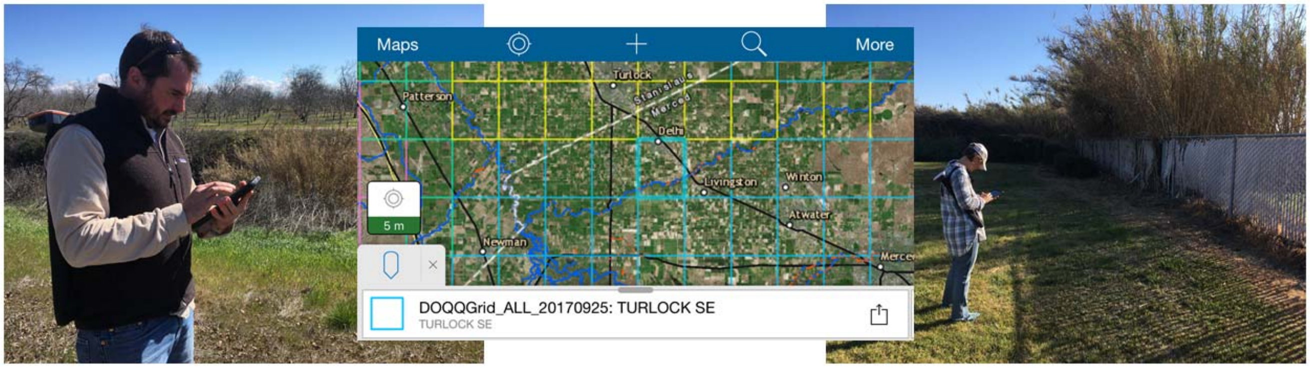
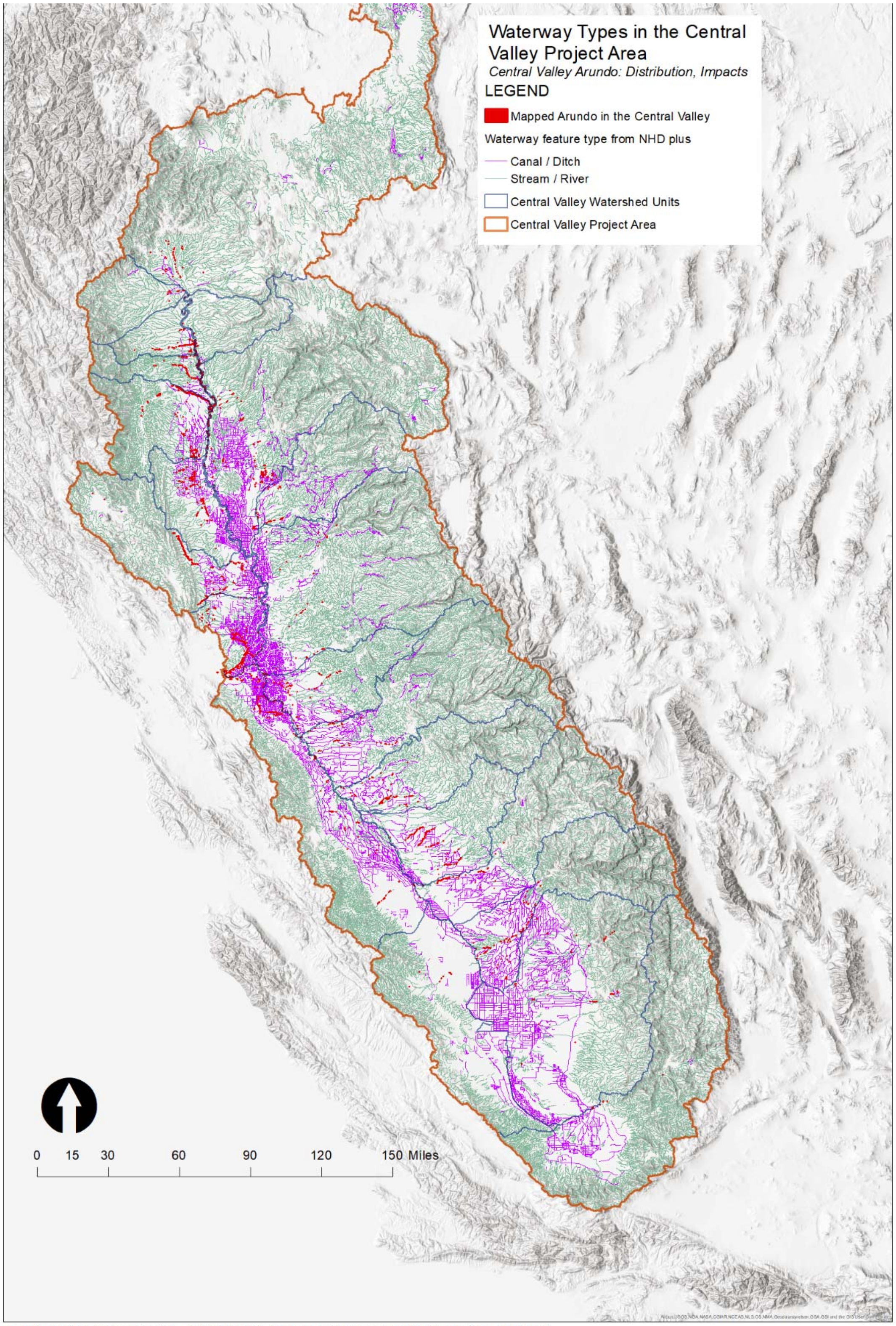


Figure 3-5. Field surveys used ArcCollector to navigate to *Arundo* populations in the field, check the accuracy of mapping, and update GIS data.



\\Projects\Arundo\FinalCVArundo_Maps_Tables\20200329_Arundo_InsetMap_WaterwayFeatureTypes_Esize_Portrait.mxd

Figure 3-6. Waterway types in the study area.

Over four days, a field reconnaissance team of two surveyors verified the accuracy of office mapping for an arbitrarily chosen subset of surveyed *Arundo* populations, prioritizing sites that had been flagged as unclear in the office, sites that were accessible, and sites where line-of-sight could be established (Figure 3-5). Records were checked for spatial accuracy, percent cover estimation, and current treatment status. Each polygon that was checked was designated as either "verified", "verified–enlarged", "new" or "deleted". An additional field for notes was used to describe other changes, such as a revision to a stand's treatment status.

New stands and edits to existing stands were collected by either sketching directly on the tablet with a digital pen or by editing the existing polygon's vertices. The GPS functionality was used as a reference to orient the mapper's position on the background imagery. Once saved, the polygon edit was saved back to the geodatabase in the cloud on ArcGIS Online.

In all, we tagged 1.6% of mapped *Arundo* polygons (701 of 32,374 total) for field verification. Of these, we were able to check 23% (161 polygons) in the field. We were limited by lack of access, logistical challenges and funding availability. The California Department of Water Resources conducted all field verifications in the Feather River-Chico-Butte Creeks watershed unit, in Lindo Channel and Little Chico Creek, areas where ground-truthing would otherwise have been difficult to conduct.

After field verification was complete, the geodatabase was downloaded from ArcGIS Online and integrated back into the office-mapped geodatabase. Polygons marked to be enlarged or deleted and any new polygons found were edited in the office. Additional data attributes (watershed name, mapping status, acreage) were added through an automated process and existing attributes were re-checked for consistency (Table 3-2).

Table 3-2. Additional fields added to the final *Arundo* dataset after field verification.

Attribute	**Notes**
Field check notes	Weather
Field check date	Date on which field verification occurred
Field Observer	Field verifier
Population ID	Unique ID for each *Arundo* polygon
Gross Area (Acreage)	Total area in acres
Net Area (Acreage)	Total net area (factoring in percent cover) in acres
Data Source	2 options: 'Cal-IPC and project partners' or 'Sonoma Ecology Center'
Watershed Name	Name of major waterways within watershed unit
Treated Gross Acres	Total treated area in acres
Treated Net Acres	Total treated net area in acres

3.1.5 Data Quality Assurance and Mapping Caveats

The combination of methods described above captured the highest possible accuracy that we felt was possible, but there were instances where accurate digital mapping or field surveys were not feasible. With field checking, it became apparent that smaller clumps were often misidentified or omitted when we did not have high-resolution imagery or imagery from a preferable season. On the whole we found that polygons were under-mapped in size, suggesting that, our estimates of *Arundo* cover are conservative. Based on field checks from previous surveys that used a similar approach, overall acreage totals typically were underestimated by 15-20% (Giessow pers. comm. 2019).

Areas well away from *Arundo* stands that we mapped and away from delineated waterways (i.e., many of the Tier 3 DOQQs) were not scrutinized with the same level of intensity as Tier 1 and 2 DOQQs were. Although they are unlikely to contain *Arundo*, mapping data suggest that they may be capable of supporting it. Any project embarking on *Arundo* control can use our data as a baseline but should conduct a thorough site-specific survey prior to starting work.

All *Arundo* stands mapped were defined by their full footprint as interpreted from an aerial perspective. For *Arundo* in particular, this means capturing both the cane emergence zone and cane drape zone (see Chapter 1). Although drape zones can lead to an overestimate of cane density if they are not accounted for, they present a very accurate picture of the canopy impact of this species. Drape zones also typically do not support other plant species since they tend to block out most light.

Treatment status may not represent current conditions on the ground due to ongoing treatment programs that are currently unknown or not being tracked by the project team. We onducted field checks at two sites, Lindo Channel and Little Chico Creek, where imagery showed evidence of substantial treatment. Stretches of Berenda and Ash sloughs also showed evidence of significant past treatment and were field checked. Because the geodatabase of *Arundo in* the Central Valley is intended to be a living database, treatment information can be updated periodically as new data becomes available. Treatment status was occasionally used as a modifier for *Arundo* acreage calculations. Acreage from *Arundo* stands with treatment was excluded for "minimum" or "current" watershed acreage estimates. Because the true current status of most stands with evidence of treatment could not be confirmed, we relied primarily on raw (otherwise referred to as "maximum. or "peak") acreage estimates to estimate *Arundo* cover and impacts.

Positional accuracy may vary across the project area due to the variable resolution of the base imagery available for different areas when the in-house mapping took place. This is particularly true on both the east and west edges of the Central Valley where imagery is distorted to accommodate elevational relief. Data collected during the project is limited to the accuracy of the base photography used to delineate a population's extent, but the mapping is sufficient to relocate all populations.

3.2 Results: Acreage by Watershed and Region

The data presented here are a composite picture of the abundance and distribution of *Arundo* in the Central Valley, as seen over the course of 10 years of aerial imagery. Our mapping effort has produced the best available large-scale map of *Arundo* outside of coastal southern California, and the only one available for this region.

3.2.1 General Overview

We mapped a total of 2,256 acres of *Arundo* in 32,372 occurrences across 25 watershed units in the 38.4 million-acre Central Valley project area (Figure 3-7 and 3-8; Table 3-2). Of this, 264 acres appear to have been the target of some level of treatment (successful or unsuccessful). A total of 1,844 DOQQs were directly surveyed using aerial imagery to collect distribution data; the remainder of the project area was assessed at a coarse scale and considered unlikely to support *Arundo* (Figure 3-9). *Arundo* was distributed throughout the region, with 96% of records occurring at an elevation less than 500 feet and 99% occurring at elevations less than 1000 feet.

Across all watershed units, an average of 16% of the length of natural and partially modified stream courses was considered invaded by *Arundo*, as measured by the length of a waterway from its upper-most infestation down to the next major tributary (see Table 3-3). Larger lowland waterways were more invaded, but many smaller infestations were also found in smaller tributaries, which could provide source material for future downstream infestations. Most *Arundo* patches found were small: 86% of the occurrences mapped were less than 0.1 acre in size and only 13 were over five acres. These results suggest both challenges and opportunities that are discussed in later chapters.

The distribution pattern of *Arundo* in the Central Valley was more complex than that for other less modified river systems such as coastal southern California and the Rio Grande Valley of New Mexico and Texas. As a result of river channelization and extensive irrigation, *Arundo* was not as tightly associated with waterways as we had expected: out of a total of 32,372 occurrences (mapped stands), only 74% could be associated with major named waterways. Others were found on channelized water distribution channels, on margins of the Delta, or were more "landlocked" populations that are less able to move downstream.

3.2.2 Local and Regional Patterns

The main stem of the Sacramento River and the lower sections of its tributaries were the areas with the highest level of *Arundo* infestation, with over 90% of all reaches but its headwaters invaded (Table 3-3). Three major lower elevation tributaries, Stony Creek, Cache Creek and Putah Creek, were also highly invaded. Both the total amount of *Arundo* mapped and the proportion of waterways invaded were higher in watershed units that included lower reaches of streams and rivers. The Chowchilla-Fresno River watershed unit, which contains tributaries to the San Joaquin River, also had high *Arundo* acreage, of which 76% was either being treated at the time of the survey or had previously been controlled. (Evidence of *Arundo* treatment in other watershed units was substantially less and, in a few cases, non-existent.) The Stony Creek, Cache-Putah Creeks, Thomes Creek and Elder Creek watershed units all have natural, un-channeled waterways that experience high pulses of water flow periodically (Figure 3-10). Where these river sections were infested, they supported extensive, dispersed stands of *Arundo* and provide ample opportunity for dispersal during flood events. Likewise, the two upper reaches of the Sacramento River mainstem ("Sac River Upper: Cottonwood to Thomes" and "Sac River Middle: Stony to Cache Creek" watersheds) are braided and support substantial stands of *Arundo*.

Sections of Central Valley waterways that are more channelized have steeper banks and provide less spatial area for *Arundo* to establish—there is no floodplain or terrace—but *Arundo* will colonize and persist on these steep channelized banks.

With exception of the highly infested subsection of the Chowchilla-Fresno watershed unit, the watershed units in the San Joaquin River watershed are more difficult to characterize. Some waterways have retained their natural character, but others are partially or completely channelized. Some modified waterways are moderately to highly invaded and others are relatively free of *Arundo*. Partially channelized sections of creeks with enough water conveyance allow *Arundo* to establish beyond the creek channel and up bank faces (see Bear Creek and Berenda Slough in Figure 3-11). More channelized systems have a narrower band of *Arundo* restricted to bank faces.

Table 3-3. *Arundo* surveyed in the Central Valley project area by watershed unit.

				Occurrences by Elevation (ft)						
Watershed Units *(North to South)*	**Arundo Acres**	**% Trt**	**Total Occur.**	**Delta**	**0-500'**	**501-1K'**	**1K-1.5K'**	**1.5-2K'**	**2K-2.5K'**	**2.5K-3K'**
Sac River Headwaters: Castle-Stillwater Creeks	24	30%	614		325	285	4			
Cottonwood Creek	5	0%	238		204	30	4			
Elder Creek	85	11%	1314		1239	73	2			
Sac River Upper: Cottonwood to Thomes Creeks	154	0%	2940		2940					
Antelope-Mill Creek	14	0%	163		163					
Thomes Creek	75	6%	1515		1489	26				
Stony Creek	562	1%	6609		6417	183	9			
Feather River-Chico-Butte Creeks	70	11%	1041		1041					
Sac River Middle: Stony to Cache Creeks	153	1%	2074		2074					
Colusa Trough-Stone Corral-Freshwater Creeks	115	18%	1838		1838					
Bear-Yuba River	44	0%	551		551					
Cache-Putah Creeks	254	6%	4421		4410		10	1		
Sac River Lower: Cache to Putah Creeks	1	0%	26		26					
American-Mokelumne Rivers-Deer Creek	29	4%	406	7	337	49	13			
Ulatis Creek	80	3%	1821	170	1615					
Los Banos-Panoche-Salado Creeks-San Joaquin River	65	15%	1178	65	1113					
Calaveras River	28	1%	402	1	401					
Stanislaus-Tuolumne Rivers	36	0%	400		400					
Bear Creek-Merced River	39	1%	559		554			5		
Chowchilla-Fresno Rivers	230	74%	1785		1785					
San Joaquin River	57	0%	773		770	2	1			
Tulare Lake-Los Gatos Creek	8	0%	378	36	355	22	1			
Kings River	91	5%	708		704	4				
Kaweah-Tule River	34	7%	540		359	162	16	3		
Kern River	4	25%	78		59	2			14	3
Grand Total	**2,257**		**32,372**	**279**	**31,169**	**838**	**60**	**9**	**14**	**3**

Table 3-4. Level of *Arundo* invasion across water courses in the Central Valley.

Watershed Units ***(North to South)***	**Total Stream Miles**	**Invaded Miles**[1]	**Proportion Invaded**
Sac River Headwaters: Castle-Stillwater Creeks	4397	41	1%
Cottonwood Creek	6626	43	1%
Elder Creek[2]	439	33	8%[2]
Sac River Upper: Cottonwood to Thomes Creeks	95	86	91%
Antelope-Mill Creek	645	4	1%
Thomes Creek	421	44	10%
Stony Creek	958	67	7%
Feather River-Chico-Butte Creeks	3778	74	2%
Sac River Middle: Stony to Cache Creeks	86	80	93%
Colusa Trough-Stone Corral-Freshwater Creeks[2]	664	34	5%[2]
Bear-Yuba River	1497	29	2%
Cache-Putah Creeks	1305	57	4%
Sac River Lower: Cache to Putah Creeks	79	76	96%
American-Mokelumne Rivers-Deer Creek[2]	3739	56	1%[2]
Ulatis Creek[2]	344	6	2%[2]
Los Banos-Panoche-Salado Creeks-San Joaquin River[2]	1512	70	5%[2]
Calaveras River	884	94	11%
Stanislaus-Tuolumne Rivers	2354	164	7%
Bear Creek-Merced River	1300	134	10%
Chowchilla-Fresno Rivers	754	147	19%
San Joaquin River	1728	40	2%
Tulare Lake-Los Gatos Creek	815	18	2%
Kings River	1610	71	4%
Kaweah-Tule River	2534	57	2%
Kern River	2039	68	3%
Grand Total	**34,604**	**1,734**	5%

[1] Invaded river miles are aggregated across a subset of major rivers/streams and water features, measured from the uppermost *Arundo* population on a waterway to the point where the waterway joins another waterway.

[2] The portion of invaded miles for these watershed units are likely an underestimate because much of the *Arundo* in these areas is not found on major waterways and therefor not counted in the watershed units' "invaded miles" figures.

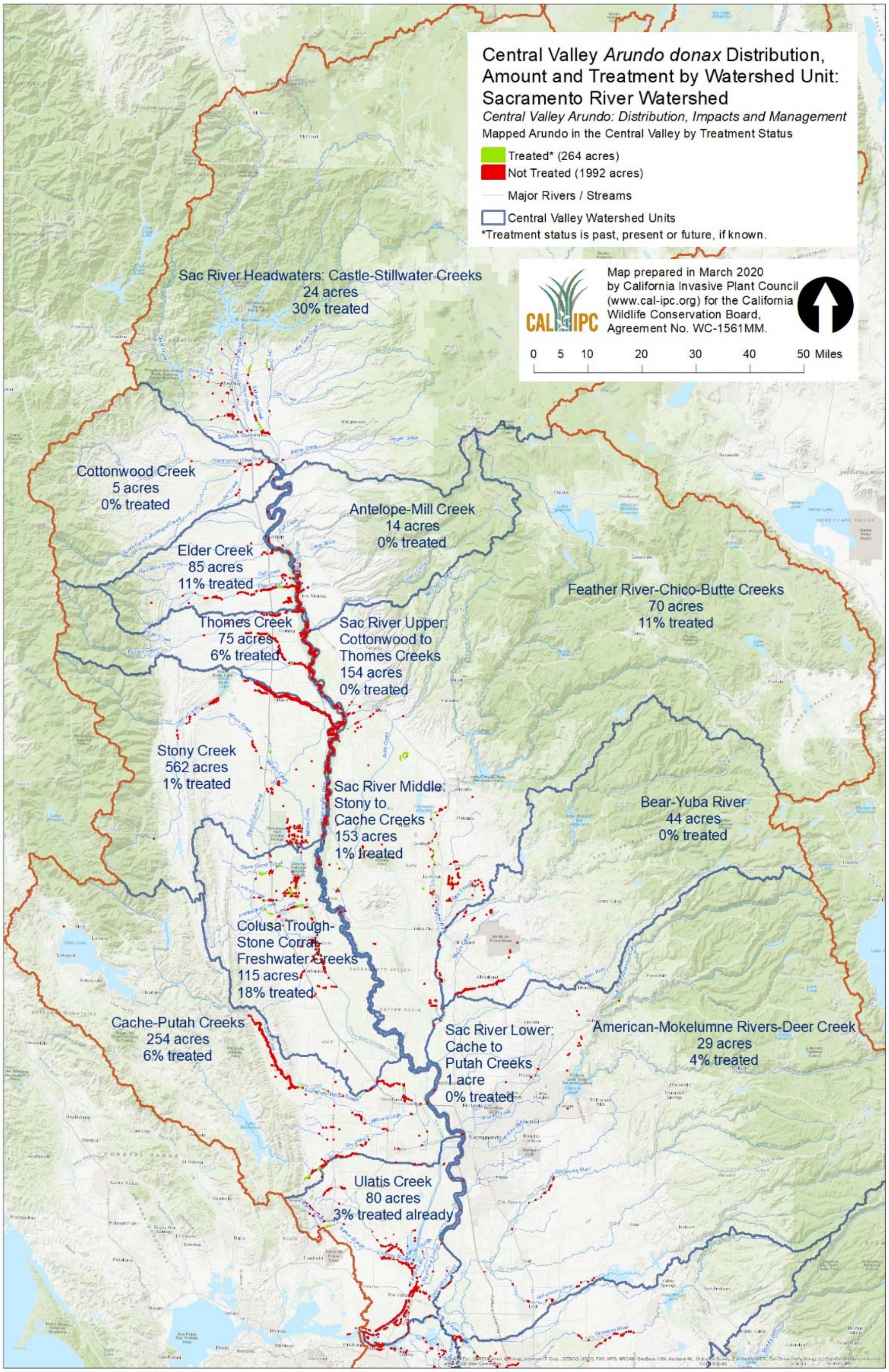


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Figure 3-7. Distribution of *Arundo* and evidence of treatment by watershed unit: Sacramento River watershed.

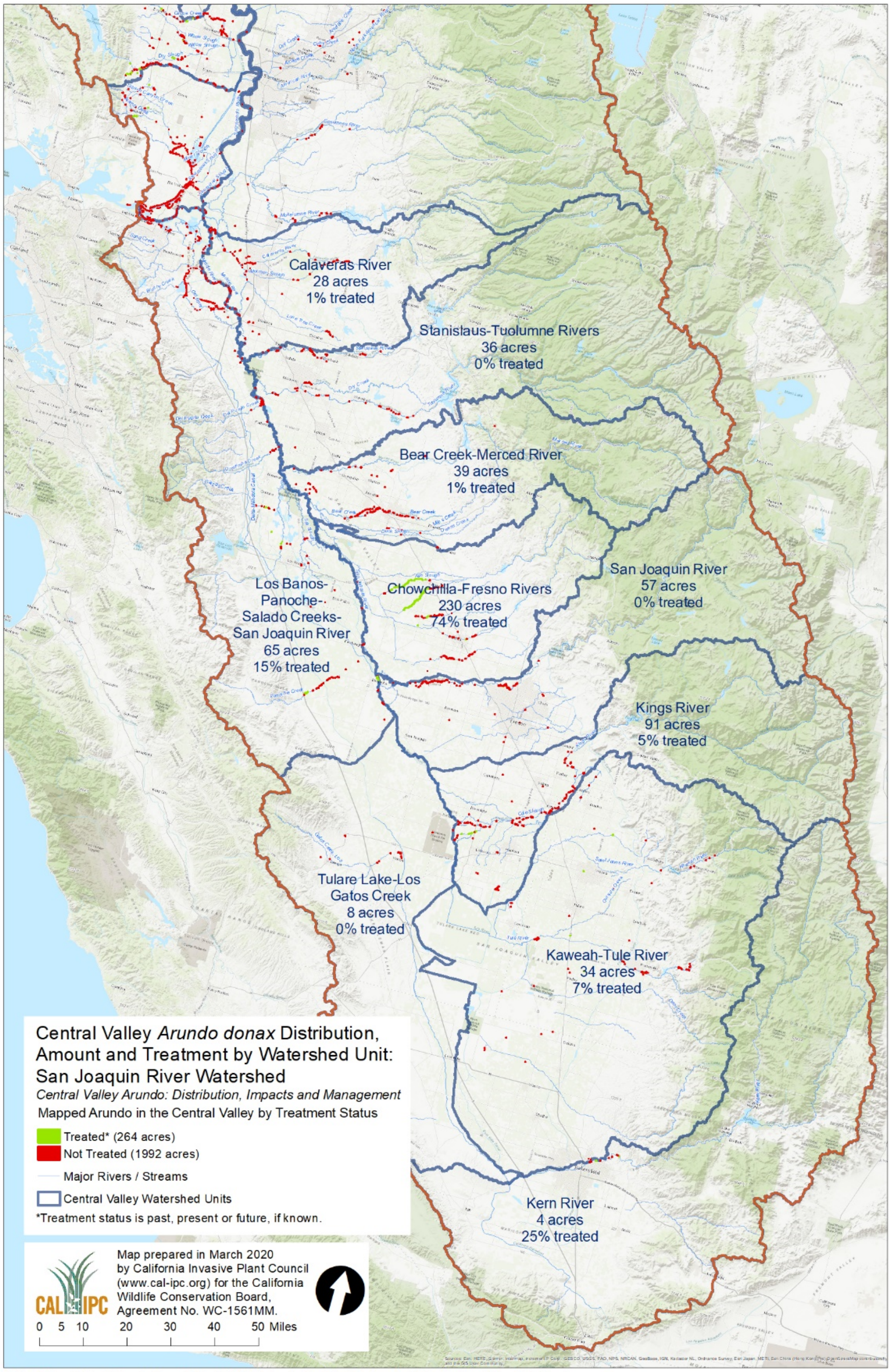

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Figure 3-8. Distribution of *Arundo* and evidence of treatment by watershed unit: San Joaquin River watershed.

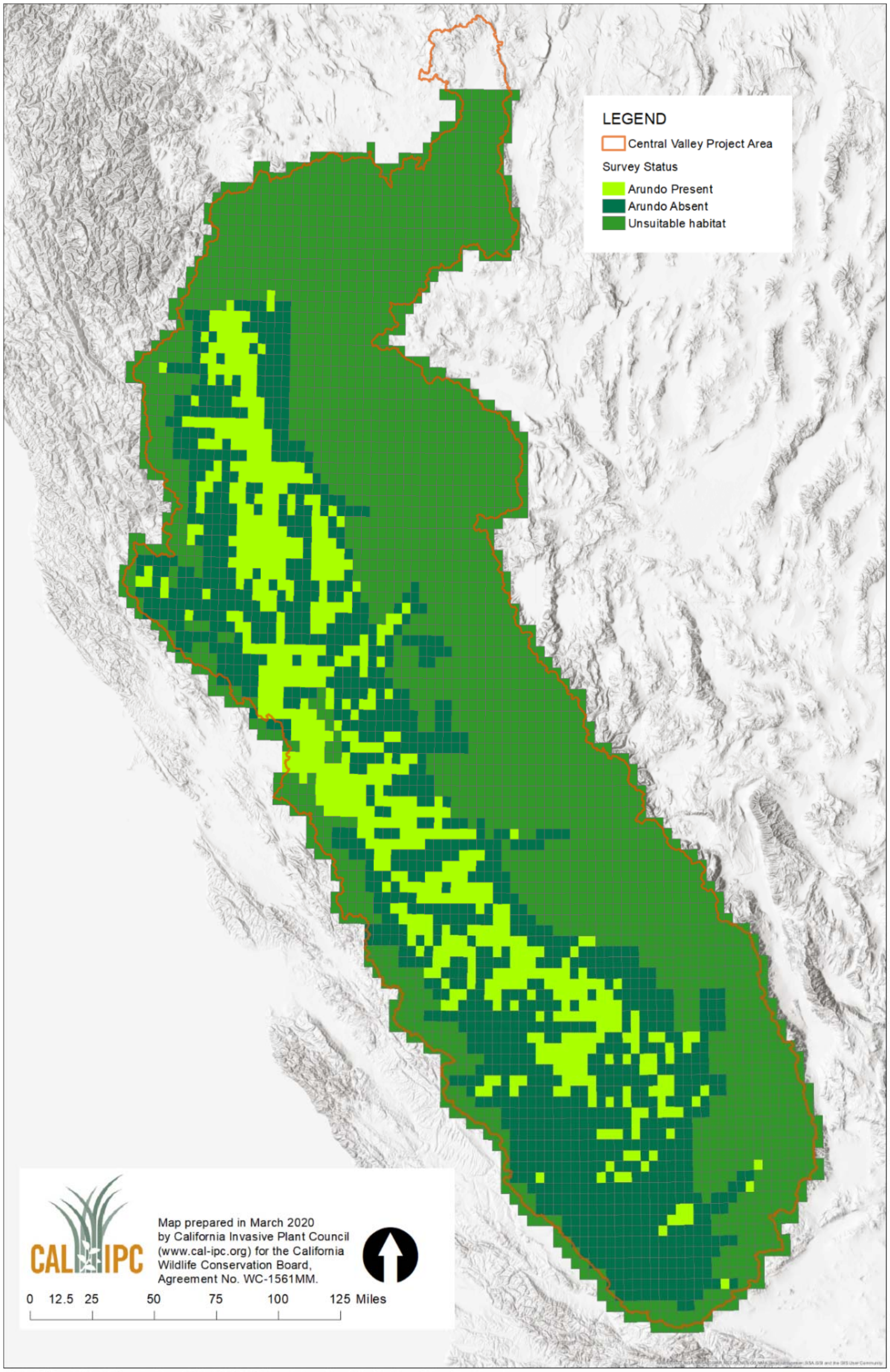

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Figure 3-9. *Arundo* distribution across DOQQs in the Central Valley project area.

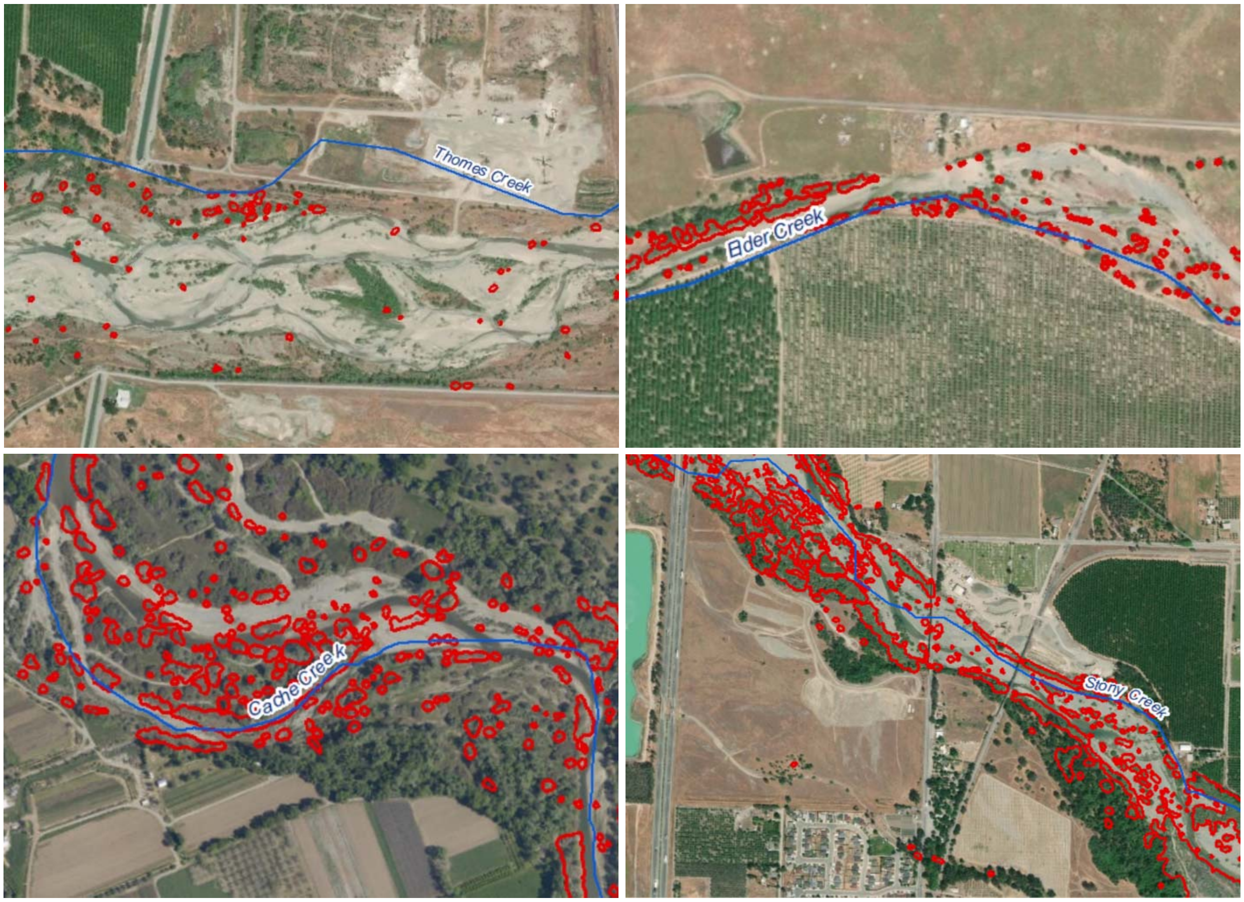


Figure 3-10. Abundant and patchy distribution of *Arundo* in braided stream systems along (clockwise from upper left): Thomes, Elder, Cache, and Stony Creek.

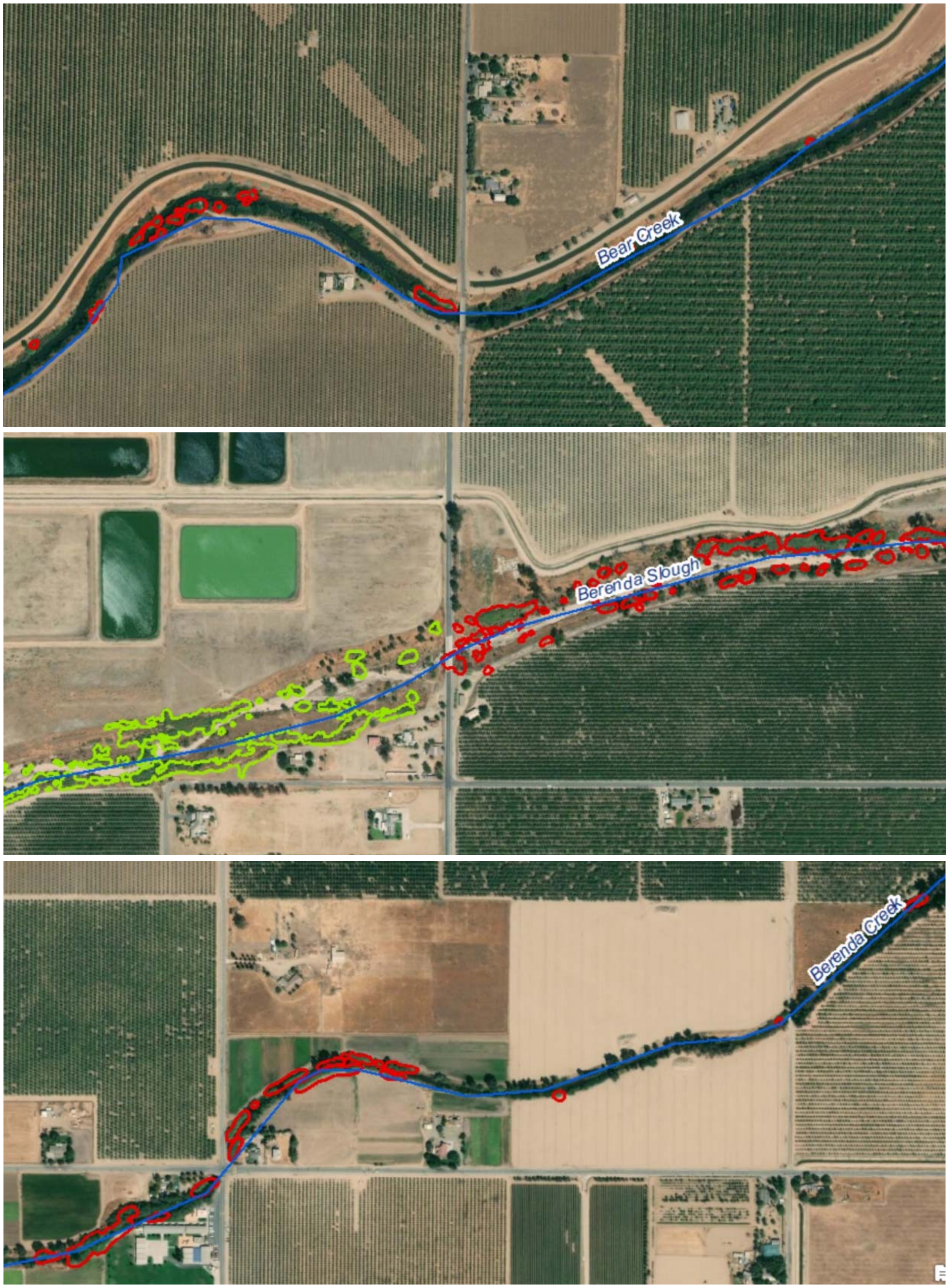


Figure 3-11. Extensive *Arundo* infestation along partially channelized streams in the San Joaquin River watershed. From top to bottom: Bear Creek, Berenda Slough, and Berenda Creek. Green outlined polygons show previously treated areas.

3.3 Data Management and Availability

GIS layers from our *Arundo* surveys in the Central Valley have been uploaded to three websites and are freely available to users from all. These are:

1. The California Department of Fish and Wildlife BIOS (Biogeographic Information & Observation System) web-based mapping application. The data can be viewed and printed from this platform along with multiple other data layers.

   Project title: *Arundo* Distribution – Central Valley [ds2822]

   Map Viewer: https://www.wildlife.ca.gov/Data/BIOS/?al=ds2822

   Metadata: https://map.dfg.ca.gov/metadata/ds2822.html

2. The California Invasive Plant Council website. This website also hosts a PDF version of this report and associated map books tied to the distribution data and listed species co-occurrences.

   Project webpage: https://www.cal-ipc.org/project/Arundo-mapping/

   Library webpage: https://www.cal-ipc.org/resources/library/

3. The Calflora online database.

   Website: https://www.calflora.org/

There is currently no funding to maintain or update the invasives GIS data set. If future revisions do occur, updates will be indicated on the Cal-IPC website.

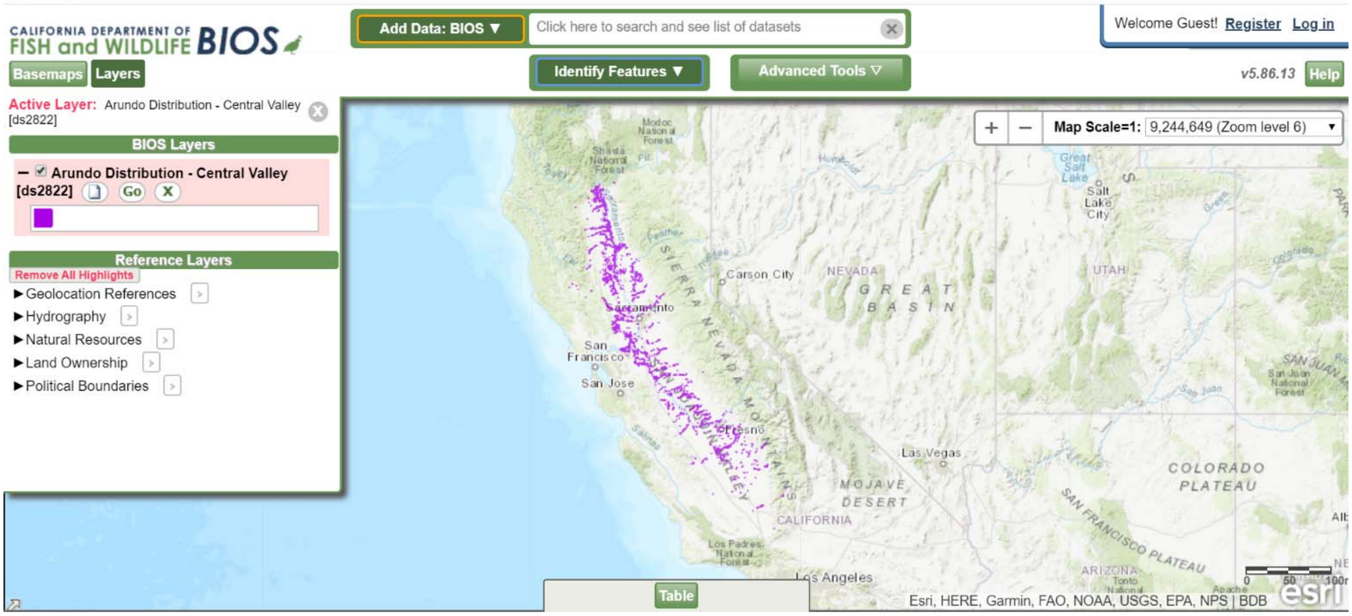
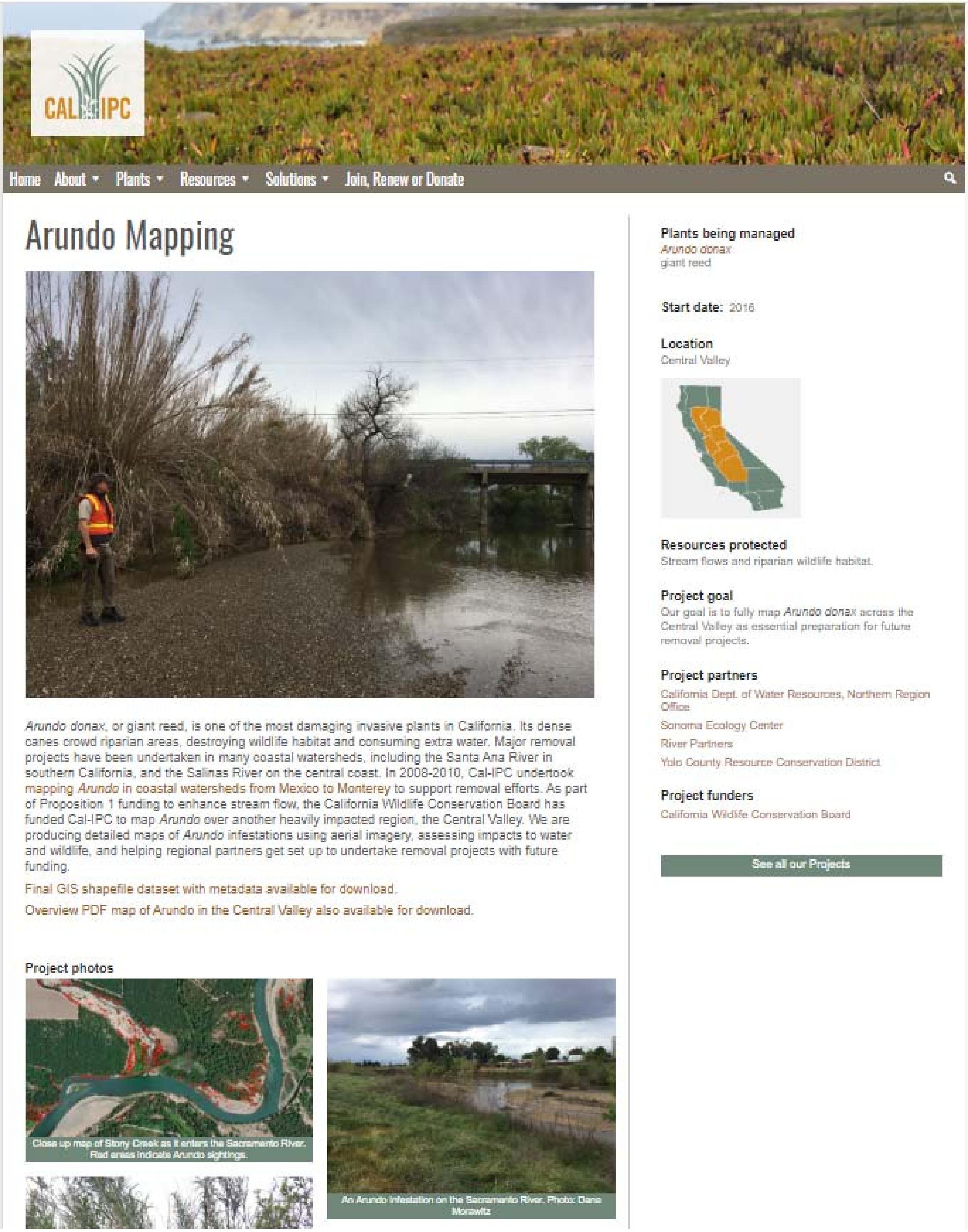


Figure 3-12. CDFW BIOS data viewer with invasive plant data set active.



Arundo Mapping

Arundo donax, or giant reed, is one of the most damaging invasive plants in California. Its dense canes crowd riparian areas, destroying wildlife habitat and consuming extra water. Major removal projects have been undertaken in many coastal watersheds, including the Santa Ana River in southern California, and the Salinas River on the central coast. In 2008-2010, Cal-IPC undertook mapping *Arundo* in coastal watersheds from Mexico to Monterey to support removal efforts. As part of Proposition 1 funding to enhance stream flow, the California Wildlife Conservation Board has funded Cal-IPC to map *Arundo* over another heavily impacted region, the Central Valley. We are producing detailed maps of *Arundo* infestations using aerial imagery, assessing impacts to water and wildlife, and helping regional partners get set up to undertake removal projects with future funding.

Final GIS shapefile dataset with metadata available for download.

Overview PDF map of Arundo in the Central Valley also available for download.

Project photos

Close up map of Stony Creek as it enters the Sacramento River. Red areas indicate Arundo sightings.

An Arundo infestation on the Sacramento River. Photo: Dana Morawitz

Plants being managed
Arundo donax
giant reed

Start date: 2016

Location
Central Valley

Resources protected
Stream flows and riparian wildlife habitat.

Project goal
Our goal is to fully map *Arundo donax* across the Central Valley as essential preparation for future removal projects.

Project partners
California Dept. of Water Resources, Northern Region Office
Sonoma Ecology Center
River Partners
Yolo County Resource Conservation District

Project funders
California Wildlife Conservation Board

Figure 3-13. Cal-IPC project webpage that links to *Arundo* data.

3.4 Discussion

The *Arundo* distribution data collected and summarized here for the Central Valley is critical to efforts to manage this species because effective control of these species requires knowing its regional distribution. Furthermore, its mapped distribution provides a baseline from which to track future change in its distribution and abundance.

As with any invasive plant management plan, accurate estimates of *Arundo* acreage allow for better project descriptions, budgets and rationalization of project needs (USFWS & Cal-IPC 2018). High quality spatial mapping also assists with environmental planning and permitting. Project proponents can now more precisely see where *Arundo* occurs, the parcels on which they occur, and sensitive species and other concerns can be addressed more specifically. State-level funding and project prioritization decisions may also be made in a broader context. The high-resolution mapping summarized here provides land managers with the prerequisites needed to plan and implement *Arundo* control programs that have a greater regional impact and long-term feasibility and longevity.

As noted earlier under the discussion of accuracy, this data set likely underrepresents the acreage of *Arundo*. The *Arundo* mapped accounts for stands that were visible in imagery or mapped during field reconnaissance. While there are very few instances of misclassification (other vegetation mapped as *Arundo*), we presume there were occurrences that were missed due to obstructed views or stands that were too small to see on the imagery. Previous work by the authors has indicated that detailed re-mapping of areas during control has typically indicated a 15-20% underestimation of *Arundo*. This data set may be slightly more accurate because aerial imagery has improved in quality and resolution within the last several years. It is highly unlikely that *Arundo* acreage has been over-estimated by this study.

Distribution and cover data will be used in the following chapters to estimate potential impact of this species on water use, geomorphology, fire and sensitive species. Impact scores and *Arundo* distribution will further be used to evaluate the costs and benefits of control versus no action and, in combination with feasibility assessments, to provide management recommendations for watershed units.

4 IMPACTS ON WATER RESOURCES

4.1 Determining Arundo Water Use

Water is a limited resource in the Central Valley, and the role that *Arundo* plays in water use is consequently of great interest to water managers, land managers, agricultural producers, natural resource experts and regulators alike. Plant water use estimates are inherently difficult and multiple methodologies have been developed to derive them (Allen et al. 1998). Some studies estimate water use in naturally occurring stands, while others examine it in a more controlled setting in constructed wetlands using tanks, fields, or greenhouses (typically conducted for biofuel and wastewater treatment research).

Water loss from plants is usually referred to as evapotranspiration and is comprised of both evaporation from the soil and plant surfaces and transpiration from plant gas exchange. In a mature stand of vegetation where much of the ground is shaded, evaporation (E_{stand}) of an area covered by vegetation is a good estimator of the amount of water loss specific to that vegetation via evapotranspiration because direct loss from soil is negligible (Allen et al. 1998). For the purposes of our water use calculations for *Arundo*, we considered stand transpiration and evapotranspiration as equivalent and accurate estimators of water loss due to *Arundo* in a system. Similarly, we consider water use and water loss to be equivalent, since the vast majority of water that *Arundo* uses is expelled rather than stored.

Stand-level transpiration rates in *Arundo* are affected by its biomass, cane density and height, and across both natural and agricultural settings. Local climate and available water resources will affect stand productivity (biomass) which will in turn affect water use/transpiration through an increase in leaf area and live tissue conducting water out of riparian systems. The 2011 Cal-IPC Coastal Watershed *Arundo* report summarized estimates from all known studies as well as its own and concluded that *Arundo* water use in the region was approximately 30 ft/yr/ac, an estimate that was within the range of other published studies and considered specific for the California coast. Several estimates have been published since then across a multitude of different conditions and using different measurement approaches. The following section provides a summary of water use for *Arundo*, based on numerous field and controlled experimental studies as well as a Central Valley specific-estimate developed by Cal-IPC using stand characteristics measured in the field.

4.1.1 Methods used to estimate water use

Evapotranspiration studies estimate water loss rates using either indirect or direct measurements. Indirect measurements use leaf porometry to track water loss (E_l) from leaf-gas exchange either *in situ* or in a laboratory chamber and scale measurements by leaf area index (LAI, a measure of leaf area per square meter). Direct measurements track water inflow and outflow from a plant stand or an area (here, E_{stand}) and require a special chamber (lysimeters, either in the field or the lab) in which all inputs and outputs can be controlled and measured.

Arundo transpiration studies using indirect measurements have estimated E_l rates of between 4.3 to 6.3 mmol/m^{2}s (Table 4-1). We used the lower end of this range (4.3 mmol water/m^{2}s) as a conservative estimate of water use to scale up to the stand level based on the leaf area index. Estimates of LAI for *Arundo* in the Central Valley are presented in Chapter 1 and follow field methods used in Cal-IPC (2011). E_{stand} can be inferred from indirect measurements as long as accurate data for stand density, biomass, LAI, and stand height exist.

Direct measurements of *Arundo* water use track the water budget of the system. These are important studies as E_{stand} is calculated using lysimeters (plants grown in tanks), where all water inputs/outputs are tracked to determine water use in a more controlled experimental setting. This allows the actual tracking of evapotranspiration by plants and is therefore not an extrapolation or scaled-up estimation. Drawbacks of these studies are that the systems are being measured are artificially planted *Arundo* stands, a constructed wetland, that are young/immature and that most studies to date harvest *Arundo* biomass yearly, so all canes are first year canes with lower stand stature, biomass, and total leaf area (see Table 4-1; Cal-IPC 2011). Indirect measurements of *Arundo* stand transpiration (E_{stand}) have been made for California and have ranged from 24.2 to 42.1 mm/day/m^2 (Table 4-1). Those for Texas were lower and reported at 9.1 mm/day/m^2. Lower values reflect smaller stature, density and biomass that is characteristic of *Arundo* on the Rio Grande.

Yearly water use (mm/yr/m^2) of *Arundo* stands is calculated based on growing season. Here, we normalized the data to a growing season of 244 days and 9 hr to allow better comparison between studies. In this report, E_{stand} was converted for all studies to annual water use by converting mm/day/m^2 to acre-feet/yr/ac. This data is presented here as annual water use (in acre feet) by an acre of *Arundo* (Ac-ft/yr/ac).

Table 4-1. Summary of *Arundo* stand characteristics and water use metrics.

Study	Location	(Dry) Stand Biomass (ton/ha)	Average cane height (m)	Average # live canes/m^2	LAI (m^2 leaf/m^2 ground)	Growing season (Days)	Transpiration: E_l (mmol/m^2/s) Ave seasonal (Peak, mid-day)	E_{stand} (mm/day) /m^2	E_{stand} (mm/day)/m^2 normalized 9hr	Estand (mm/year) /m2 normalized 244 days	Water use Arundo Ac-ft/yr/ac	Notes
Indirect calculation of stand-level transpiration, Arundo in natural setting												
Cal-IPC 2020	Central Valley	107.8	5.7	35.2	9.6	244, 9hr	Used 4.3	24.2	24.2	5,898	19.4	LAI adjusted to reflect 50% of stand footprint has canes (reflects smaller stand size).
Cal-IPC 2011	Coastal watersheds	153.1	6.4	41.5	14.9	244, 9hr	Used 4.3	37.5	37.5	9,154	30.0	LAI adjusted to reflect 70% of stand footprint has canes (reflects larger stand size).
Salinas 2018	Salinas Watershed	131.1	4.4	27	11.5	244, 9hr	Used 4.3	29.0	29.0	7,065	23.2	LAI adjusted to reflect 70% of stand footprint has canes (reflects larger stand size).
Abichandani 2007	Santa Clara River, CA			34.9	14.4	244 days, 10.2 hr	4.3 (1.9-5.8)	41.1	36.3	8,857	29.1	Transpiration (E), leaf-gas exchange measured.
Goolsby 2015	Rio Grande River, TX	78	2.97	29.7								11,100 g/m2. Scaled to 70% of stand footprint has canes.
Nackley et al. 2014	Lab, Seattle WA						5.96					Transpiration (E), leaf-gas exchange measured.
Sharma et al. 1998	India	36-167		53 to 82	12.6 to 28.7		Used 4.3		31.7 to 72.3	7,734 to 17,641	25 - 58	
Spencer 2006	16 sites across US.	171	3.37	74.5	11.2		Used 4.3	28.2	28.2	6,881	22.6	Leaf area is northern CA sites only.
Watts and Moore 2011	Rio Grande River, TX				4.1	244 days, 7.9 hr	4.3 (1.6-8.4)	9.1 (2-20)	10.3	2,519	8.3	Transpiration (E), leaf-gas exchange measured. Arundo stands on the Rio Grande are smaller in stature than California stands (see Goolsby 2009: BM = 78 t/ha, cane density 29.7, cane height 2.97). Low LAI reflect this.
Zimmerman (unpublished)	Napa River, CA				11.4	244 days, 9 hrs	6.3 (2.5-11)	42.1	42.1	10,262	33.7	Transpiration (E), leaf-gas exchange measured.
Direct measurement of evapotranspiration (ET), Arundo in a constructed wetland (CW)												
Christou et al. 2003	Greece & Italy	21.3								962	3.2	AG bio-fuel crop study: Yearly biomass output, all canes are first year canes, biomass re-grows each year impacting E stand/water use. Data 3 years/harvest cycles.
Milani et al. 2019	Sicily, Italy	104	4.4 (max at end of year)	31.3	(14.9 Cal-IPC lf area calc)			11.2 (23 peak)		2,740	9.0	Waste water study, constructed wetland. Yearly biomass output, all canes are first year canes, biomass re-grows each year impacting E stand/water use. Data 2 years/harvest cycles.
Triana et al., 2015	Pisa, Italy	25.9				210 days, 148.6 days, 9hr		Peak summer 12.4		1,083	3.6	AG bio-fuel crop study, constructed wetland. Yearly biomass output, all canes are first year canes, biomass re-grows each year impacting E stand/water use. Data 3 years/harvest cycles.
Tuttolomondo et al., 2015	Sicily, Italy	41.16	1.9	21		213 days, 9hr		Peak summer 47.1		4,274	14.0	AG bio-fuel crop study, constructed wetland. Yearly biomass output, all canes are first year canes, biomass re-grows each year impacting E stand/water use. Data for 2 years/harvest cycles.
Tzanakakis 2009	Iraklio, Greece	72.8								3,272	10.7	AG bio-fuel crop study: Biomass harvested after 3 yrs growth.

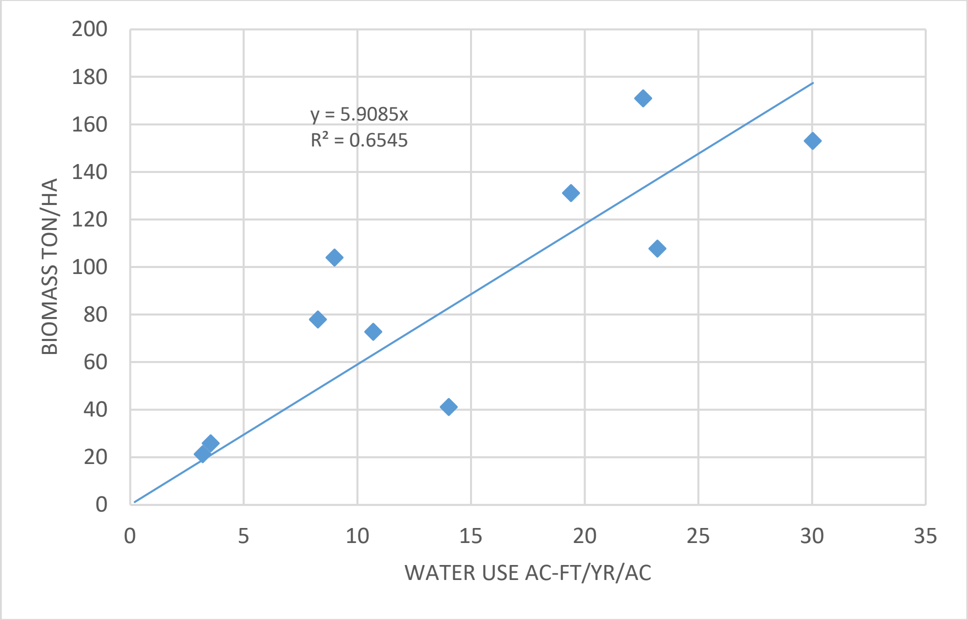


Figure 4-1. *Arundo* biomass and water use relationship. Points represent water use estimates from studies listed in Table 4-1.

4.1.2 Results and Discussion

Central Valley *Arundo* stands were estimated to have a biomass of 108 ton/ha, compared to 153 tons/ha for the coastal California watersheds (Table 4-1; Chapter 1). This may reflect a longer warmer growing season and possibly greater access to water resources along the coast. Average Central Valley cane height was lower at 5.7m (versus 6.4m), and cane density was lower at 35.2 (versus 41.5 canes/m^2). Additionally, a lower proportion of mapped acreage (50% vs 70%) was used for stand-based cane density as Central Valley *Arundo* stands occur as smaller clumps and with more canopy edge draping (canopy where no *Arundo* canes occur, see Chapter 1). This resulted in a Leaf Area Index of 9.6 m^2 leaf/m^2 for the Central Valley versus 14.9 m^2 leaf/m^2 for Coastal California.

Results from indirect calculations based on leaf transpiration demonstrate very high wateruse, ranging from 19.4 to 33.7 ac-ft/yr/ac, for naturally occurring California *Arundo* stands (Table 4-1). Water use for *Arundo* stands on the Rio Grande in Texas were lower, but still high at 8.3 ac-ft/yr/ac. This lower value also makes sense as monitored *Arundo* stands were of short stature and lower cane density. All of these water use values are dependent on *Arundo* having access to water and should be viewed as potential annual water use estimates. Water use in each stream/watershed should viewed in light of local water availability: the greater the water availability the greater the biomass production, which in turn is translated into higher water use. Many systems in the Central Valley are perennially flowing, either through runoff related to irrigation, frequent reservoir releases, or natural baseline flows. Other systems may be ephemeral or become ephemeral during drought.

We calculated potential annual *Arundo* water use in the Central Valley based on typical regional stand structure and biomass production, at 19.4 ac-ft/yr/ac. We used a new spreadsheet-based tool that was developed for this project. It calculates *Arundo* transpiration, equivalent to water use, using inputs for site and stand characteristics—live cane density, cane height, percent cover of cane area, and seasonal daylight. The tool can be used by land managers to calculate water use for their particular region by taking some field measurements and inputting them into the spreadsheet.

Our estimate is supported by other indirect water use measurement studies shown in Table 4-1. Central Valley *Arundo* stands used less water per acre year in comparison to coastal California and Salinas Watershed stands, reflecting lower biomass per acre.

Direct measurement of annual *Arundo* water use from biofuel and wastewater studies are lower, ranging from 3.2 to 14 ac-ft/yr/ac (Table 4-1). However, these estimates are for *Arundo* stands that were grown in constructed wetlands (the stands were very young and establishing for the first year) and they were harvested annually, had low biomass per acre, and were of very short stature (Table 4-1). Annually harvesting of *Arundo* biomass significantly reduces transpiration by reducing early and mid-season leaf area as the *Arundo* has to re-grow as well as committing the plant to a regrowth cycle rather than re-greening existing leaves (coming out of dormancy), secondary branch growth (and associated additional leaves), new cane growth (increasing cane density and leaf area), and overall stand height. Water use estimates from biofuel and waste-water studies are consistent with the strong linear relationship that exists between *Arundo* stand biomass to water use ($y= 5.9085x$, $R^2 = 0.6545$, Figure 4-1).

Both indirect and direct water use measurements demonstrate high water use by *Arundo*. Both types of studies are critical. Direct studies demonstrate high water use in a controlled system. Indirect studies take demonstrated water use and scale it to naturally occurring mature stands that have higher biomass. All studies, whether indirect or direct, demonstrate *Arundo*'s unique biomass generating capability, which if water is available translates into very high wateruse that is not a native component to Californian wetland systems.

4.2 *Arundo* Water Use in the Central Valley

Calculated final net water savings account for 'replacement vegetation' after *Arundo* has been controlled in a system. Calculations of net water savings are complex and best calculated regionally, as some systems are characterized as having significant open substrate (e.g. Stony Creek, Glenn County CA) while other areas may have high tree cover (e.g. Sacramento River). The final net water savings calculation should be made relative to other vegetation (tree, scrub, and herbaceous plants) as well as open substrate that will replace *Arundo* after control/removal (see Dudley & Cole 2018 for a more recent review). The value used in the 2011 Cal-IPC coastal watershed report of 4 ac-ft/yr/ac of replacement vegetation/open substrate is still the best current system-wide watershed-based value. Therefore, water savings from *Arundo* removal and subsequent replacement with other vegetation is estimated to result in a net water savings of 15.4 ac-ft/yr/ac for the Central Valley. Estimates of water savings were slightly higher, at 20 ac-ft/yr/ac, in the 2011 Cal-IPC report for coastal California. Nonetheless, 15.4 ac-ft/yr/ac represents a significant water savings and would be welcomed by both natural resource managers and the agricultural community.

To summarize *Arundo*'s impacts on water resources in the Central Valley:

- Central Valley *Arundo* stands were estimated to have a 50% stand footprint (canes growing in mapped cover), 108 ton/ha stand biomass, 5.7m cane height, 35 cane/meter cane density, 9.6 m^2leaf/m^2ground LAI.
- Measured stand characteristics were used to estimate Central Valley *Arundo* stand water use of 19.4 ft/yr/ac. Estimates are within the range calculated by other indirect measurement studies.
- Mature stands of *Arundo* have higher biomass than recently cut or young stands; stand biomass appears to be linearly correlated with stand-based water use, likely because of transpiration through canes and lateral branching/leaf production. This relationship helps tie indirect water use estimates to direct measurement systems, showing an overall agreement between *Arundo* stand size and water use.
- Water use estimates from direct measurement of transpiration are typically conducted from biofuel and wastewater stands that are annually harvested. Water use estimates for these are lower, likely as a result of lower per area biomass than mature, unmanaged stands. These studies are important as they still demonstrate very high water use as well as extremely high biomass productivity.
- Net potential water savings of *Arundo* control was estimated to be 15.4 ac-ft/yr/ac in the Central Valley (accounting for 4 ac-ft/yr/ac water use of 'replacement' vegetation) and represents a significant gain in local water resources.
- A spreadsheet-based model was developed that allows the user to input *Arundo* stand and site characteristics (live cane density, height, percent cover of cane area and seasonal daylight) that calculates annual *Arundo* water use (transpiration). This is a valuable tool for program managers as the user can generate specific water use estimates catered to their region.

We quantified additional water use attributable to *Arundo* by multiplying the acreage of *Arundo* by the extra 15.4 ac-ft/yr/ac. We calculated this for the total amount of *Arundo* mapped, including treated stands, and we also calculated it for just the *Arundo* that has not been treated (Table 4-2).

Table 4-2. Estimated water loss in the Central Valley as a result of *Arundo* cover.

	Arundo **Cover (acres)**		**Extra Water Use (ac ft/yr)**	
Watershed Units (north to south)	**Max.**	**Min.**	**Max.**	**Min.**
Sac River Headwaters: Castle-Stillwater Creeks	24	17	370	259
Cottonwood Creek	5	5	77	77
Elder Creek	85	76	1,309	1,165
Sac River Upper: Cottonwood to Thomes Creeks	154	154	2,372	2,372
Antelope-Mill Creek	14	14	216	216
Thomes Creek	75	71	1,155	1,086
Stony Creek	562	556	8,655	8,568
Feather River-Chico-Butte Creeks	70	62	1,078	959
Sac River Middle: Stony to Cache Creeks	153	151	2,356	2,333
Colusa Trough-Stone Corral-Freshwater Creeks	115	94	1,771	1,452
Bear-Yuba River	44	44	678	678
Cache-Putah Creeks	254	239	3,912	3,677
Sac River Lower: Cache to Putah Creeks	1	1	15	15
American-Mokelumne Rivers-Deer Creek	29	28	447	429
Ulatis Creek	80	78	1,232	1,195
Los Banos-Panoche-Salado Creeks-San Joaquin River	65	55	1,001	851
Calaveras River	28	28	431	427
Stanislaus-Tuolumne Rivers	36	36	554	554
Bear Creek-Merced River	39	39	601	595
Chowchilla-Fresno Rivers	230	60	3,542	921
San Joaquin River	57	57	878	878
Tulare Lake-Los Gatos Creek	8	8	123	123
Kings River	91	86	1,401	1,324
Kaweah-Tule River	34	32	524	487
Kern River	4	3	62	46
Grand Total	**2257**	**1993**	**34,758**	**30,686**

Notes: Based on acreage of *Arundo* calculated from mapping data and estimate of net additional water consumption at a rate of 15.4 acre-feet/year per acre or *Arundo* relative to native riparian vegetation. Maximum estimates are based on the total area of *Arundo* mapped. Minimum estimates only consist of areas with no evidence of treatment. Water use estimates are adjusted downward by 50% to account for the drape zone.

5 IMPACTS ON GEOMORPHOLOGY

The previous chapter described one aspect of *Arundo*'s impact on hydrology: its significant water use and the water savings that can be achieved by removing *Arundo*. In this chapter, we will specifically examine its impact on water flow through stream courses and waterways, its effect on sediment accumulation, and its effect on the physical structure of riparian systems in the Central Valley. Stands of *Arundo* affect the mechanics of stream flow and the dynamic processes that shape the surrounding land—the geomorphology of waterways—which, in turn, affects high flow behavior, local water retention, and flooding. Changes in geomorphology are relevant for several reasons. An altered flow regime affects both aquatic and terrestrial species. It can also affect groundwater recharge. Finally, changed geomorphology can affects flow dynamics during flood events.

California's Central Valley is a virtually flat basin comprising deep alluvial soils. Over a third of the state, including snowmelt from the western side of the Sierra Nevada, drains to the Central Valley. With upstream dams to allocate flows over dry summer months, the region serves as one of the nation's largest agricultural producers, especially for fruits and nuts. Irrigation uses a high portion of surface water for irrigation and in addition pumps groundwater (Kratzer & Shelton 1998).

Upper watersheds in the surrounding foothills flatten out as they flow into the valley. Of the *Arundo* mapped in the study area (which extended upstream to the uppermost *Arundo* populations), 97% was found below 500 feet in elevation and much of it was on the relatively flat valley floor (Figure 5-1).

Although many riverine areas in the Central Valley have been constrained by channelization for urban development, flood control, and agriculture, many retain potential for some of their historic character. For example, areas managed by the U.S. Fish and Wildlife Service as the Sacramento River National Wildlife Refuge Complex and areas in the region managed by the California Dept. of Fish and Wildlife as State Wildlife Areas protect riparian habitat for fish, migratory songbirds, river otter, turtles, beaver, pelicans, ospreys, Chinook salmon, Swainson's hawks, bank swallows and more. Furthermore, channelized waterways often are lined with riparian vegetation that represents a semblance of permanent habitat in an otherwise constantly changing and highly disturbed agricultural landscape. By changing river geomorphology, *Arundo* impacts this riparian habitat, even in channelized systems. An assessment of *Arundo* impacts to a set of sensitive species in the Central Valley are reviewed in a subsequent chapter.

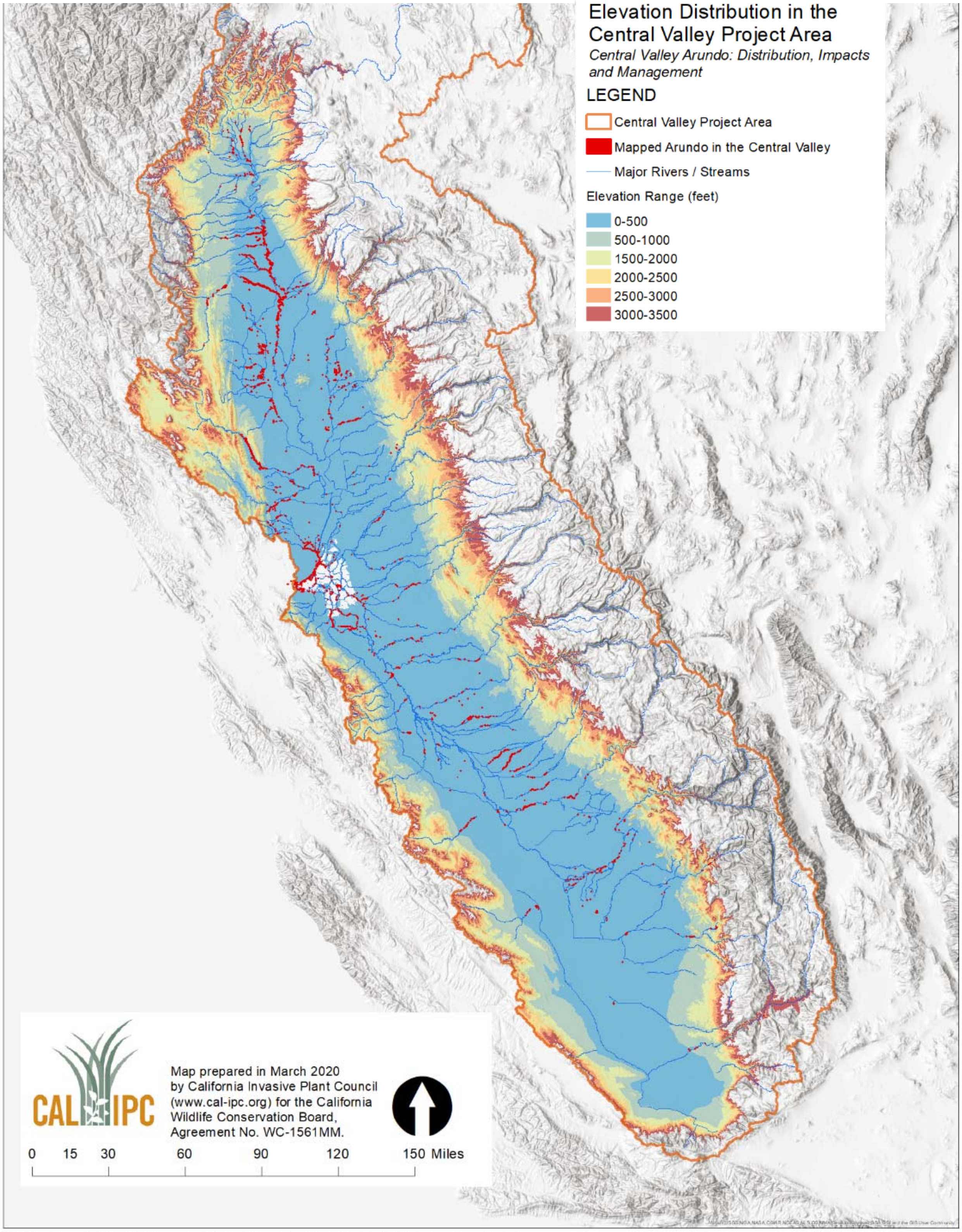


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Figure 5-1. Elevational range of the Central Valley in relation to *Arundo* distribution.

5.1 Studies of *Arundo*'s Impacts to Geomorphology

Much of our understanding of the effects of *Arundo* on river geomorphology is based on historical case studies, generally from analyses of maps or aerial photographs. These studies are imperfect in that *Arundo* is usually not the only significant impact on river systems, and the timeframe (generally less than 70 years) does not necessarily capture the impact of large (e.g. 100-year) floods. Nonetheless, they are the best available information that we have to date. Studies of *Arundo* impacts on geomorphology have primarily been from other regions of the American Southwest, where several major infestations of *Arundo* have garnered attention. The Green River in Utah and the Rio Grande River in Texas, for example, historically exhibited wide, shallow, laterally unstable braided channels with multiple flow paths around large, unvegetated sand and gravel bars but are now heavily impacted by *Arundo*. They serve as good model systems for the naturally flowing streambeds of the Central Valley because they are similar in structure (though engineering has altered geomorphology in the Central Valley in many places). When stream flow rates increase in meandering streamcourses, they can cause bank erosion and channelization, as has been demonstrated in the upper Sacramento River (Larson et al. 2006).

Studies on these rivers reported similar trends following infestation by *Arundo* (and tamarisk, another invasive plant found in the same riparian habitat): stands of *Arundo* and tamarisk slow the water flowing through their dense stands of stems and canes along streambeds. At lower speeds the water has less capacity to carry sediment, so some of the material suspended in the water settles out. This deposition fills in braided channels between shifting sand and gravel bars (vertical accretion) and concentrates flows into a single, more laterally stable channel with steep, root-stabilized banks. Waters flow faster in the narrower channel, resulting in more confined flows that can scour riverbeds and further deepen channels. On the rivers studied, few unvegetated sandbars remained. Secondary channels were eventually filled in with sediment, covered by vegetation, and attached to the adjacent floodplain. When high flows occur, the lack of secondary channels and the raised level of the floodplain results in a wider flooded area. Simpson et al. (2013) demonstrated the severity of this issue specifically in the Central Valley by showing through simulations that flooding increased by 10-19% as a result of *Arundo* in the Cache and and Stony Creek river systems.

In California, an historic analysis of the six most invaded coastal watersheds—the Salinas, Ventura, Santa Clara, Santa Margarita, Santa Luis Rey and Santa Ana Rivers—in the 2011 *Arundo* Impacts Report concluded that these watersheds experienced the same types of impacts as did the rivers from other studies: a reduction of riverine habitat due to land use change; a decline in active low flow channels as the waterway shifted from a braided form to single channels; a deepening of the low-flow channel; and an expansion of vegetated floodplains and terraces (Cal-IPC 2011).

In the late 1990s before *Arundo* control projects began, at low flows these three rivers had single channels that were bordered by heavily vegetated floodplains. Only a few reaches had less than 50% vegetation cover. Except where the rivers were confined by natural topography or levees, the floodplain was at least 10 times as wide as the low-flow channel (Cal-IPC 2011).

Arundo was most common in areas with shallower slopes. Slopes near the mouth were about one-fourth to one-eighth as steep as slopes in the most upstream reaches. In general, the highest *Arundo* concentrations occured where the stream slope levels out and the floodplain widens compared to the reach upstream. This pattern is thought to occur because the less steep, wider reach has much lower average velocities which promote deposition of *Arundo* propagules and increase the likelihood of *Arundo* establishment and propagation. *Arundo*, though it is a facultative wetland species, does not grow in perennial stream courses where its rhizomes are permanently submerged. This 'rivers-edge' pattern of establishment reinforces channelization.

Evidence from watersheds where *Arundo* has been removed show a reversal of these impacts. For instance, after *Arundo* was removed from the Santa Margarita River from 1997-2000, a large portion of floodplain turned back to unvegetated bars and the low-flow channel had shrunk in favor of a braided channel structure (Cal-IPC 2011).

5.2 Flooding and Bank Instability

A 5.5-mile reach of the Santa Margarita River near the Marine Corps Air Station was studied by hydraulic consultants beginning in the 1990s (NHC 1997a; 1997b; 2001). Historic establishment and spread of *Arundo* on the lower Santa Margarita River had narrowed the active river channel and simplified its river cross-section. The narrowing trend has been interrupted by occasional large floods which removed floodplain vegetation and widened the channel, such as occurred in 1969 and 1993. During the intervals between floods, *Arundo* out-competed native vegetation on the disturbed floodplains and grew back to form new mature stands.

The studies found that the first five feet in height of mature *Arundo* stand were so dense that they essentially eliminated flow conveyance during low and moderate floods on the portions of the floodplain that they occupy, increasing the portion of the flow passing through the low flow or active channel. During large peak flows, when water levels reach more than 5 feet above the floodplain surface, some flow is conveyed through the upper portions of mature *Arundo* stands but considerable roughness is created by the stems and leaves, slowing water over what would otherwise be a smoother and lower floodplain.

NHC created hydraulic modeling using the HEC-RAS (Hydrologic Engineering Center's River Analysis System) package to help determine flow behavior for future flood events. They altered values for surface roughness in the model and estimated changes in parameters like flow velocity and flow depth in both the main channel and in the floodplain, and the overall width of flooded area for a major (100-year) flow event in an *Arundo*-infested river. With full *Arundo* infestation, the model suggested that flows could be expected to be 4-5 feet higher in elevation than the baseline with native vegetation instead of *Arundo*. (This makes conceptual sense, given that the first 5 feet of height in mature *Arundo* stands can be so dense that they are impassable for floodwaters, effectively raising the height of the floodplain by 5 feet above the ground level.)

This hydraulic modeling study also included several observations about how river systems respond to *Arundo*. First, there appears to be a threshold for *Arundo* coverage before there are significant effects on hydraulics, but the exact portion of the floodplain that must be occupied in order to generate a significant impact is not fully understood. Second, the magnitude of *Arundo*'s impact (and the threshold for observing significant effects) depends on the overall floodplain and channel widths. Narrow total widths show less effect for a flood than do wide ones, likely because there is less conveyance on the narrow floodplains for the native vegetation scenario, so there is a smaller increase in flows in the main channel when *Arundo* coverage is complete.

In studying California's most invaded coastal watersheds for the 2011 *Arundo* Impacts Report, Cal-IPC used elevation and aerial imagery to classify land as one of the following fluvial landforms: low-flow channel; bars; floodplain; low terrace; and high terrace. We compared the location of *Arundo* stands to these landforms and determined that *Arundo* is relatively absent from the low-flow channel and bars and is almostly entirely found on the floodplain and the low terrace. *Arundo* seemed to be found most extensively in locations where the floodplain area expands significantly and/or where the slope of the stream decreases significantly. We developed several metrics—such as width of floodplain, change in floodplain width, and change in slope—that enabled us to score reaches for vulnerability to Arundo invasion. A similar reach-by-reach analysis may be useful in the future for individual Central Valley watersheds as they are assessed in more detail for management.

One of the important impacts from *Arundo* is its role in bank instability. *Arundo* has been found to have more root density and tensile strength than native willow in the upper 10 cm of bank, but the opposite below that depth (Brinke 2010). Stover et al. (2018) found that willow has about twice the the cohesion for week bank materials than does *Arundo*. This accounts for *Arundo* mats being more likely to erode from the bank during high flow events, on both natural and constructed banks, such as levees and canals. Brinke concluded that bank undercutting and cantilever failure were a primary bank erosion mechanism for *Arundo*-topped stream banks. During flood events, large pieces of *Arundo* biomass can be loosened and pushed downstream. If this biomass lodges against bridges or other infrastructure it can block water flow and result in significant damage. The River Road Bridge getting pushed off its foundation over the Santa Ana River in 2004 is one example of this risk.

Given the extensive area that drains through the Central Valley and its generally flat topography, flooding can be severe. Extensive levee systems are maintained to control flows and channels are periodically cleared and deepened to remove accumulated sediment deposits. Conservative costs for this maintenance are used in Chapter 8 to put an economic value on the geomorphological benefits—reduced flood levels—achieved through *Arundo* control and removal. *Arundo* contributes to levee and canal bank erosion, in which *Arundo* pulls away from bank surfaces and takes part of the levee or canal bank with it, which adds to maintenance costs. In addition, many roads and other infrastructure follow or cross waterways in the Central Valley, and the reduction in maintenance and repair costs are also estimated as one of the geomorphological benefits of *Arundo* control and removal.

Figure 5-2. River Road Bridge on the Santa Ana River in southern California, pushed off its foundation by floodwaters in 2004 when *Arundo* biomass lodged against it. Photo by Richard Zembal.

Figure 5-3. Low-lying bridges and roadways, like those shown along Berenda Creek and Berenda Slough in the San Joaquin Valley, are potentially vulnerable to damage from high flows exacerbated by *Arundo*'s impacts on stream geomorphology. Photo: Dana Morawitz

5.3 Groundwater Recharge

Groundwater recharge is the downward movement of water into the water table. In the Central Valley, where agriculture and other uses have pumped large amounts of water from the water table, the need for recharge has become a topic of significant concern, especially in the San Joaquin Valley where overpumping has resulted in groundwater overdraft and subsidence. Groundwater storage is important for managing droughts.

Streamflow in highly braided or wide channels have greater wetted perimeters and therefore greater access to infiltration pathways and subsurface storage. Recharge in these situations will generally lead to more infiltration than in a stream confined primarily to a narrower channel (Blasch et al. 2004). Guzman et al. (1989) modeled a channel narrowing scenario and calculated that a scenario with a channel narrowed by 38% would have 32% less infiltration.

Water that does not infiltrate and recharge the water table remains available as surface water for aquatic habitat, agricultural uses or municipal supply. Thus, it cannot be valued as water saved, as was done in

Chapter 4 for the water saved by removing *Arundo*. We do not have a clear way of valuing increased recharge, but we make conservative assumptions in Chapter 8 on cost-benefit analysis.

5.4 Scoring Arundo's Impact on Geomorphology

For our prioritization by watershed unit, we scored *Arundo*'s relative geomorphic impacts in each watershed unit. To do this, we combined three metrics: the total amount of *Arundo,* how densely it is spread over river miles, and how much of the *Arundo* is in large populations (over 0.5 acre). We assume that the more *Arundo* per river mile, and the more *Arundo* in larger populations, the greater the impact it will have on geomorphology. Scoring is shown in Table 5-1. Higher score indicates higher impact.

As described in Chapter 3, we derived an estimate of river miles for major waterways in each watershed unit as well as the *Arundo* acreage associated with those river miles. By dividing the acreage of *Arundo* associated with major waterways by the river miles for those waterways we can estimate the overall density of *Arundo* along the waterway. For geomorphology impacts, we focused on *Arundo* associated with major waterways, and less so on that associated with surrounding channels (see Figure 5-4).

We can also use GIS to determine the portion of *Arundo* stands (mapped polygons) that are larger than 0.5 acres, and the portion of the *Arundo* acreage in the watershed unit that is found in these larger stands. This also serves as a measure of how densely the *Arundo* currently grows in the watershed unit. Denser *Arundo* means more intensive impacts to stream flow and geomorphology during high-flow events.

The overall geomorphology impact score for each watershed is determined by first scoring each of the three metrics—total acreage of *Arundo*, acreage of *Arundo* per river mile, and portion of *Arundo* acreas in large stands—using natural breaks to provide relatively balanced number of scores at each level (0, 1, 2, 3, 4, and 5). The scores for each of these three metrics were then averaged with weightings of 40%, 30% and 30% respectively. Finally, these aggregate figures were scored from 0 to 5, shown in Table 5-1.

These scores are used in combination with impact scores from the other three impacts—water resources, fire, and sensitive species—in Chapter 9 as part of prioritizing watershed units for *Arundo* control.

Table 5-1. Scoring of *Arundo* impact on geomorphology.

Watershed units (north to south)	**Acres *Arundo***	**Invaded Miles[1]**	**Acres[2]**	**Portion[3]**	**Acres/ Mile[4]**	**% Acres in Lg. Stands[5]**	**Overall Score[6]**
Sac. River Headwaters: Castle-Stillwater	24	41	18	72%	0.44	2%	1
Cottonwood Creek	5	43	3	66%	0.08	0%	0
Elder Creek	85	33	73	86%	2.23	34%	4
Sac. River Upper: Cottonwood to Thomes	154	86	154	100%	1.80	21%	4
Antelope-Mill Creek	14	4	8	55%	1.73	12%	2
Thomes Creek	75	44	69	93%	1.58	30%	4
Stony Creek	562	67	520	93%	7.72	50%	5
Feather River-Chico-Butte Creeks	70	74	17	24%	0.23	30%	3
Sac River Middle: Stony to Cache Creek[7]	153	80	153	100%	1.91	41%	4
Colusa Trough-Stone Corral-Freshwater	114	34	42	37%	1.22	21%	4
Bear-Yuba River	44	29	34	77%	1.18	13%	2
Cache-Putah Creeks	254	57	205	80%	3.60	25%	5
Sac. River Lower: Cache to Putah Creeks[7]	1	76	1	100%	0.02	41%	0
American-Mokelumne Rivers-Deer Creek	29	56	16	55%	0.28	30%	3
Ulatis Creek[8]	80	6	0	1%	0.08	16%	2
Los Banos-Panoche-Salado Creeks-San	65	70	23	36%	0.33	20%	3
Calaveras River	28	94	22	77%	0.23	19%	2
Stanislaus-Tuolumne Rivers	36	164	35	97%	0.21	28%	3
Bear Creek-Merced River	39	134	31	78%	0.23	12%	1
Chowchilla-Fresno Rivers	230	147	229	99%	1.55	58%	5
San Joaquin River	57	40	53	93%	1.30	23%	3
Tulare Lake-Los Gatos Creek	8	18	1	13%	0.06	0%	0
Kings River	91	71	43	48%	0.61	30%	3
Kaweah-Tule River	34	57	20	57%	0.35	12%	1
Kern River	4	68	3	92%	0.05	0%	0

[1] Invaded river miles are aggregated across a portion of infested major waterways in each watershed unit, measured from the uppermost *Arundo* population on the waterway. For the Sacramento River reaches the entire length is used.

[2] Acres of *Arundo* associated with the river miles from infested major waterways in the watershed unit.

[3] Portion of the total *Arundo* in the watershed unit that is associated with major waterways. This is not used in scoring; it is presented here to show the range in how much of the *Arundo* in a watershed unit is associated with a major waterway.

[4] Acres of *Arundo* associated with major waterways divided by the river miles of those waterways measured from the uppermost *Arundo* population on the waterway. This is used in scoring.

[5] Portion of the total *Arundo* in the watershed unit that is in populations of larger than 0.5 acre. This is used in scoring.

[6] The final score is produced by first scoring three factors—total acreage of *Arundo*, acres of *Arundo* per river mile, and portion of *Arundo* in populations larger than 0.5 acre—using natural breaks and aimning for a relative balance in the number of scores at each level (0, 1, 2, 3, 4, and 5). The scores for these three factors were then averaged with a weighting of 40%, 30% and 30% respectively. These were then scored using the same approach. Higher score means more impact.

[7] The score for the middle and lower reaches of the Sacramento River was reduced because the waterway's scale is large.

[8] The stream layer we used in our analysis did not identify major waterways in the Ulatis Creek watershed unit.

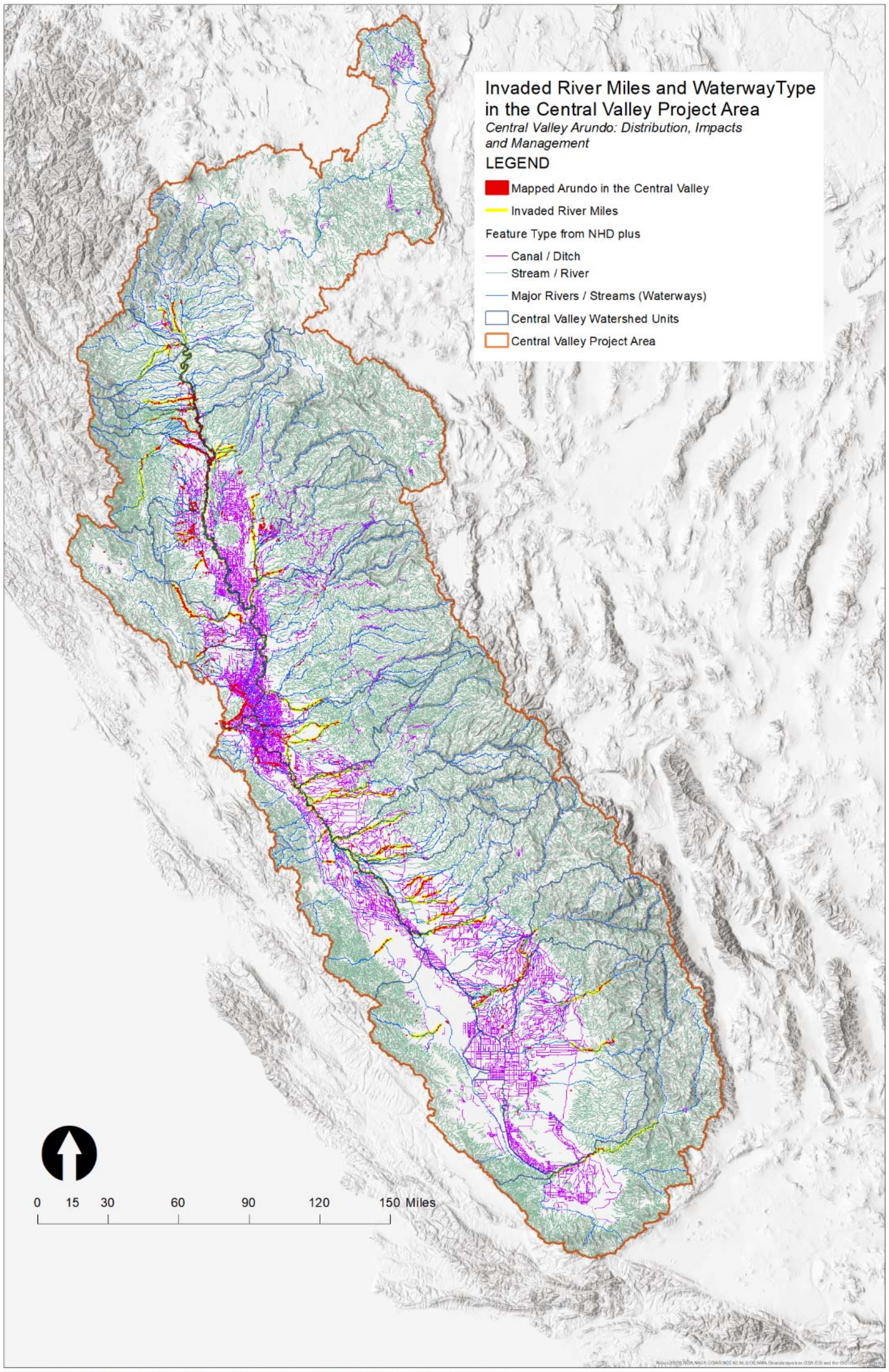

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Figure 5-4. Invaded waterways used for river miles in Table 5-1.

6 IMPACTS ON FIRE

Fire is one of the most discussed impacts related to *Arundo* invasion. This chapter will review available information about fuel loads, fuel structure, and wildfire incidents associated with *Arundo* as they relate to areas of infestation in the Central Valley. Impacts on fire are estimated for each watershed unit and are based on the acreage of *Arundo* cover that we mapped.

6.1 Fuel Load and Structure

Arundo invasion drastically increases fuel loads compared to un-invaded systems and *Arundo*'s regrowth after fire creates conditions that support frequent fires. The combination of higher fuel load and frequent ignitions (from transient encampments, discussed later in this chapter) creates a self-perpetuating fire cycle that quickly reduces cover of trees, shrubs, forbs, and open spaces that are otherwise typical of intact riparian ecosystems (Scott 1993, DiTomaso 1998, Brooks et al. 2004). As described in Chapter 1, *Arundo* stands in the Central Valley were found to have an average above ground dry biomass of 43.6 tons/acre as compared to young willow riparian forest, which has 15 tons/acre (Turhollow 1999). Our estimates fall within the range of other studies on *Arundo* biomass and reinforce recent reports of exceptionally high biomass production of this species relative to co-occurring native trees (Coffman et al. 2010, Turhollow 2000).

The introduction of *Arundo* into riparian habitat also adds a unique stand architecture that favors frequent fires (Figure 6-1). Riparian systems dominated by *Arundo* have vertical continuity of fuels (known as ladder fuels) and tremendous rapid regrowth potential, which can in turn increase the frequency and extent of fires (Brooks et al. 2004). After the Simi/Verdale wildfire along the Santa Clara River in 2003, Coffman et al. (2010) specifically reported on growth-rates of *Arundo* that were 3-4 times greater than that of native woody vegetation, leading to a rapid return of pre-fire fuel load and suppression of native tree recovery. Given that many native riparian trees such as willows (*Salix* spp.) are fire sensitive and regenerate from seed after severe fire, wildfire in riparian systems containing *Arundo* is especially devastating and is likely leading to type conversion in areas with recurring fire events.

Arundo stands contain a significant amount of energy and aboveground plant biomass in addition to having a well-ventilated, tall vegetative structure. Stands in the Central Valley contained a high number of dead canes, in contrast to those in coastal southern California. This was probably at least in part the result of recent drought cycle from 2011-2016, but regardless of the cause, it contributed more dry fuels to riparian sites. In the Sacramento Valley stands contained an average of 14 dead canes/m^2 while those in the San Joaquin Valley contained an average of 10 dead canes/m^2. This standing dead fuel is 25.4% of the total above-ground stand biomass. Along the more drought-impacted Salinas River, an average of 27 dead canes/m^2 were observed. Each dead cane also contributed leaves that have senesced, adding to a flammable thatch layer. Even live canes contribute to dead leaf litter, because primary canes typically senesce 2/3rds of their leaves with the production of branches in the second year of growth. A previous study reported 0 - 30% of total *Arundo* biomass to be from dead cane and leaf material (Spencer et al. 2006).

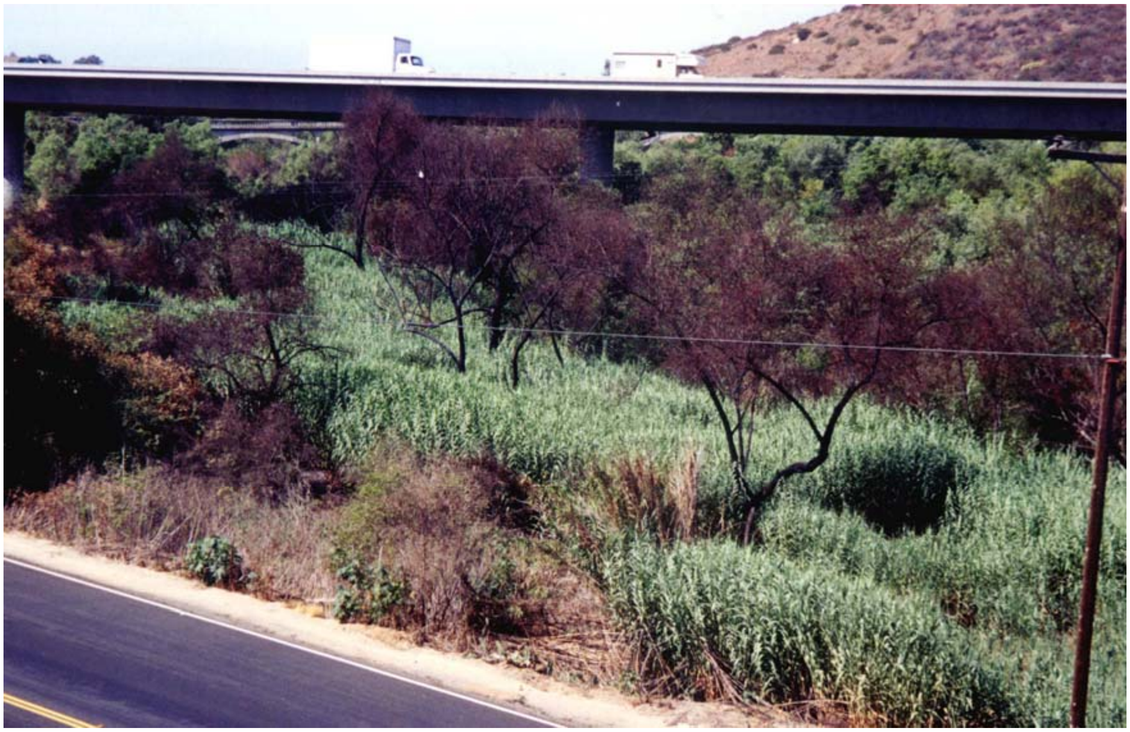

Figure 6-1. An example of type conversion of riparian habitat with wildfire. Green vegetation is *Arundo* resprouting after a fire on the San Luis Rey River. Native trees will quickly be excluded in these conditions, and after 2-3 years *Arundo* regrowth is capable of carrying another fire. Photo: J. Giessow.

6.2 Fire Conditions

The greatest risk of fire is from late summer through fall when stand moisture is low and when hot, dry, windy conditions prevail. Successive heavy rains reduce *Arundo* stand flammability, but *Arundo* stands have an architecture that allows above-ground plant material to dry quickly, while retaining carbohydrates and some water storage in their extensive rhizome system. The large amount of biomass per unit area along with a favorable structure for burning generates fires that burn intensely. Low intensity fires leave unburned material, but *Arundo* fires usually burn hot and leave little unburned biomass (see Cal-IPC 2011 report for photographs and detailed descriptions of fires associated with *Arundo*).

Fire conditions within *Arundo* stands in the Central Valley are similar to those in coastal southern California (see Cal-IPC 2011), though they differ in a few important ways. First, riparian vegetation belts in the Central Valley tend to be more isolated and are most often adjacent to agricultural lands, although some areas are in urban and wildland areas. Coastal *Arundo* stands are frequently in urban areas or wildland areas adjacent to upland vegetation, such as coastal sage scrub or oak woodlands, with a subset of riparian areas being in agricultural areas. Therefore, it is likely that *Arundo*'s role as a bridge to enable fire spread to adjacent landscapes is lower in the Central Valley, but that localized effects within riparian areas may be similar or even greater.

6.3 Spatial Distribution and Frequency of Arundo Fires

In order to compare fire data with the mapped distribution of *Arundo*, we downloaded fire and State Responsibility Area (SRA) boundary data from the California Department of Forest and Fire Protection (Cal Fire) online database (at https://frap.fire.ca.gov/frap-projects/fire-perimeters/ and https://egis.fire.ca.gov/arcgis/rest/services/FRAP/SRA/MapServer/layers, respectively). The fire data we used represented a comprehensive geodatabase of all reported fires larger than 10 acres in size that occurred within the boundaries of SRAs from 1970 to 2018, as well as incidental data collected for other fires beyond SRA boundaries. Much of the Central Valley basin is privately owned agricultural land. Substantial sections of the Sierra Nevada foothills are federally owned (Figures 6-2, 6-3). SRAs include cooperating state and private lands, but do not include federally owned land, most privately-owned agricultural lands, or lands owned by incorporated cities. Small wildfires (those less than 10 acres in size), are also typically not reported to the state database. Therefore, the data we used represent an underestimate of wildfires occurring in the region and are likely a poor representation of fire history in the Central Valley basin, where most *Arundo* occurs, but most land is also privately owned and used for agriculture. Nonetheless, the data presented here from Cal Fire represent the best available fire history for the area. We have further supplemented it with a handful of incidental reports and observations collected during the course of this project.

We used the fire data that overlapped the Central Valley project area. *Arundo* distribution data was overlaid and intersections of fires with *Arundo* were tallied. Note that SRA boundaries may have changed over time and that data collection has become more refined in recent years. *Arundo* distribution also represents current and not historic conditions. Our results cannot account for the possibility that *Arundo* invaded a site after a fire and did not occur there prior to it.

In total, 4,400 fires incidents occurred within Central Valley SRA from 1970 to 2018, which burned a formidable 8,807,829 total acres. Of these, 47 fires burned in areas with *Arundo*; these fires affected a total of 606,176 acres (see Figures 6-2, 6-3). The current amount of *Arundo* encompassed by those fires is only 18 acres, in contrast to 545 acres that overlapped and were found to have burned in coastal southern California over just a 10-year period (Cal-IPC 2011).

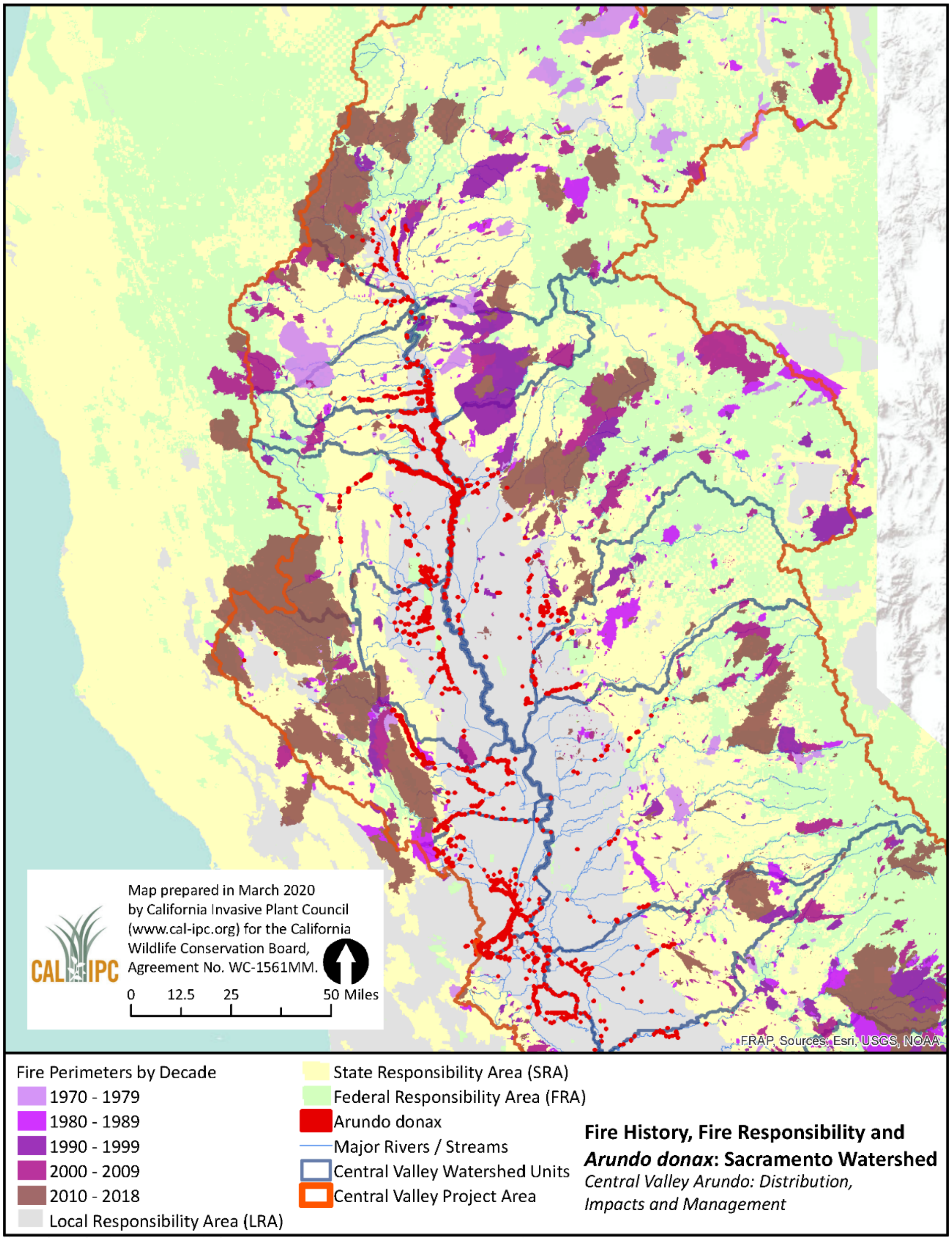

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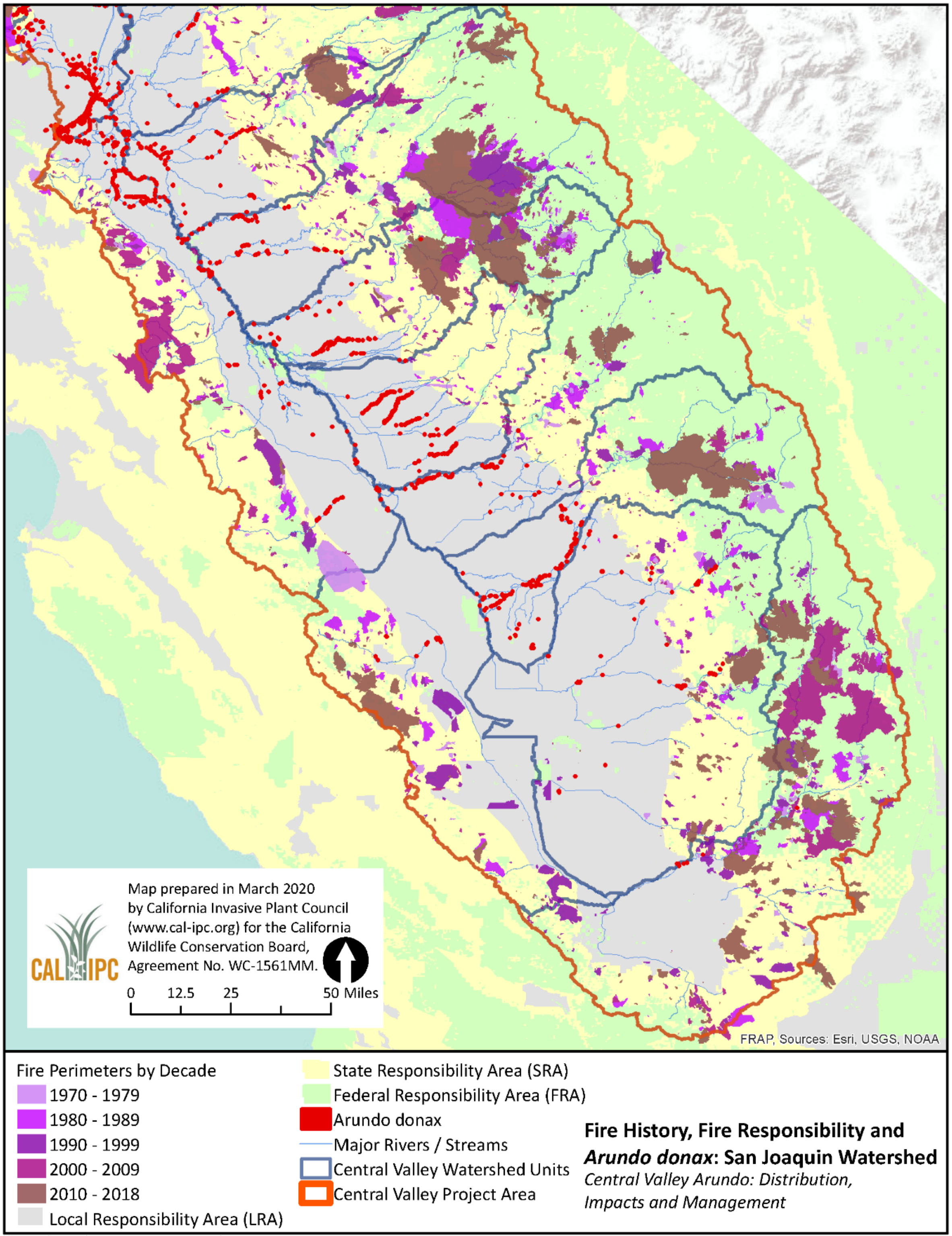
Figure 6-2. Spatial distribution of wildfires in and beyond State Responsibility Areas of the Sacramento Valley region of the Central Valley in relation to *Arundo* distribution. Data source: Cal Fire.



Map prepared in March 2020 by California Invasive Plant Council (www.cal-ipc.org) for the California Wildlife Conservation Board, Agreement No. WC-1561MM.

FRAP, Sources: Esri, USGS, NOAA

Fire History, Fire Responsibility and *Arundo donax*: San Joaquin Watershed
Central Valley Arundo: Distribution, Impacts and Management

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Figure 6-3. Spatial distribution of wildfires in and beyond State Responsibility Areas of the San Joaquin Valley region of the Central Valley in relation to *Arundo* distribution. Data source: Cal Fire.

It is reasonable to assume that low fuel loads in agricultural lands provide little opportunity for fires to move outside of the riparian zone. Grazing practices may reduce river-adjacent upland fuels and cropland and orchards are relatively fire resistant. Fire data qualitatively corroborated these assumptions in that fires in higher-elevation foothills appeared to be larger than in the regions of the Central Valley basin where fires were reported (Figure 6-2, 6-3). The Sierra Nevada foothills also support more contiguous woody vegetation and a topography that favors fire spread. To partially control for the inclusion of areas that were highly favorable to wildfire but less favorable for *Arundo*, we limited comparisons of fire size, number, and ignition source to only those wildfires with perimeters that intersected mapped *Arundo*.

Within fire areas that supported *Arundo*, we found no relationship between the size of a wildfire and the number of acres of *Arundo* they contained (Figure 6-4), suggesting that this species may not be a major factor driving fire spread in the region. This is not surprising given that most of these areas are in foothills with very low *Arundo* acreage. *Arundo* would not be expected to be driving the fire cycle in these areas.

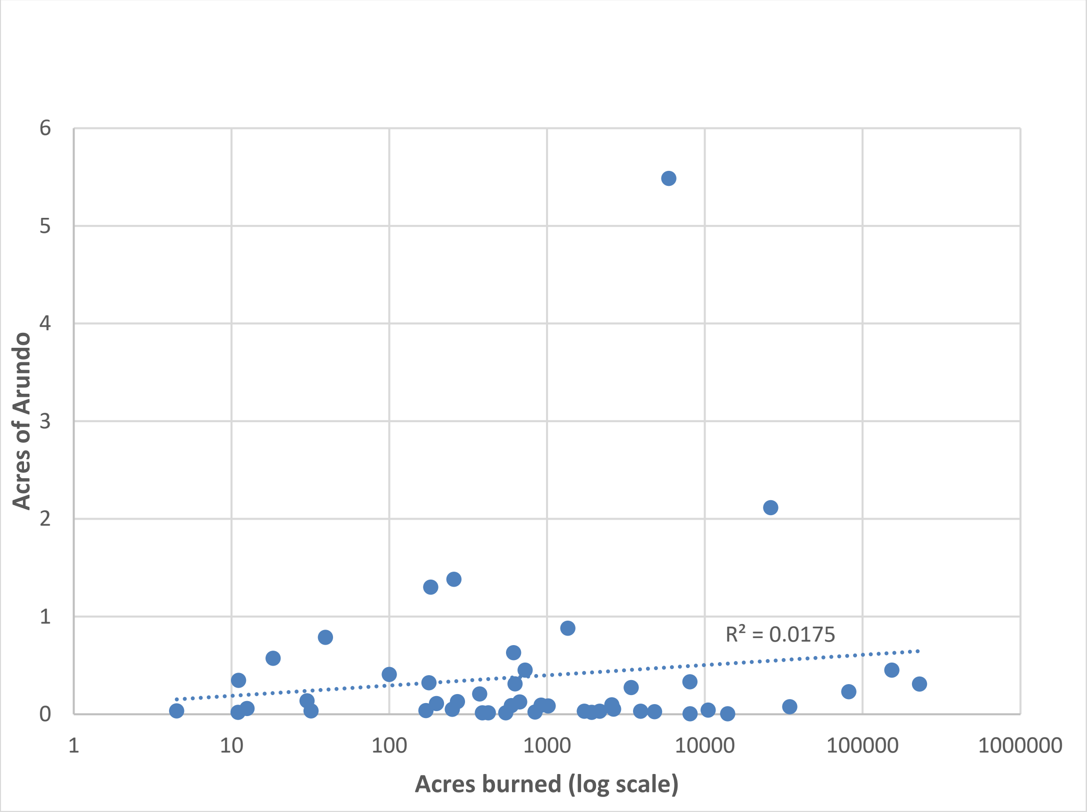

Figure 6-4. Relationship between the number of acres burned across 47 wildfires (1970-2018) and the number of acres of *Arundo* currently occurring in their perimeters. Data source: Cal Fire.

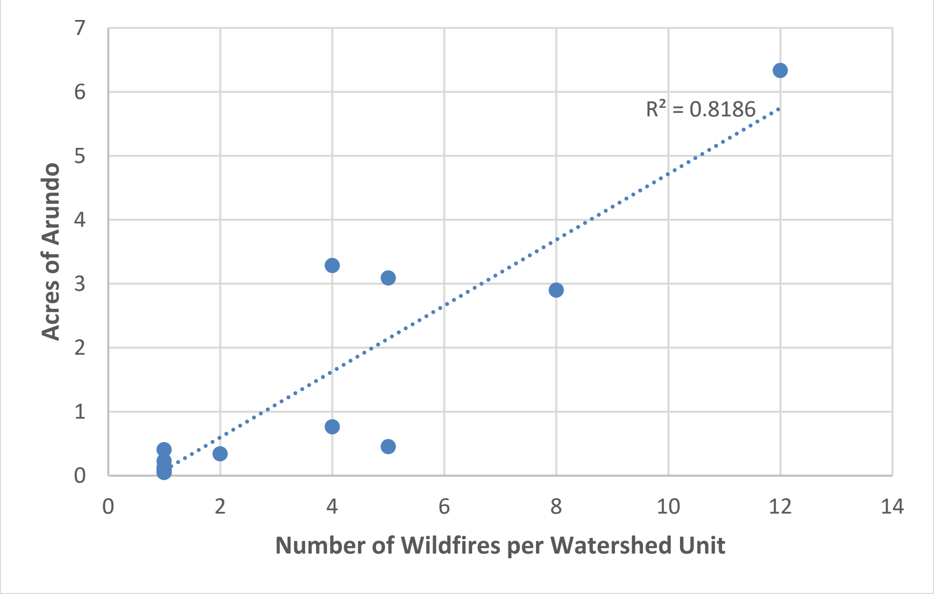

Figure 6-5. Relationship between number of wildfires (1970-2018) in each Watershed Unit and the number of acres of *Arundo* overlapping their perimeters. Data source: Cal Fire.

We did however find a strong relationship between the number of wildfires per Watershed Unit and the number of acres of *Arundo* that occurred in those fires (Figure 6-5). We cannot be certain as to whether *Arundo* is a leading (causal) or trailing indicator of fire or whether another unmeasured correlate is the causal agent for this relationship, but it is clear that the two factors are related.

Results are in line with conclusions about *Arundo*'s contributions to increased fire frequency, intensity and extent that were made regarding wildfire and *Arundo* in coastal southern California (Cal-IPC 2011) and other published studies (e.g., Dudley 2005, Coffman et al. 2010). However, cause and effect are more difficult to differentiate for the Central Valley because, unlike southern California, we had few first-hand accounts connecting *Arundo*, ignition sources and wildfire severity and extent.

Arundo was reported as being a significant fire hazard in a biological assessment for Stony Creek, which contains one of the largest contiguous stands of *Arundo* in the study areas (NRCS and Glenn County RCD, 2007). This report states, "Giant reed is also known to be a fire hazard in Lower Stony Creek. In at least one instance, embers originating from a giant reed fire near Road P ignited a fire a half-mile away."

6.4 Ignition Sources

Fires must have an ignition source in order to occur. Most wildfires now start from arson, campfires, vehicle fires, power lines, and other human activities (Cal Fire 2018 fire data, Keeley & Fotheringham 2001, Keeley & Fotheringham 2005). Ignition sources and patterns can, however, shift with cultural and behavioral shifts. Keeley and Syphard (2018) recently reported that although wildfire acreage has remained steady or increased (depending on region) the number of human-caused ignitions has decreased for all categories but powerline ignitions.

In coastal southern California, *Arundo* was shown to directly increase the probability of fire ignition via the human activities that take place in it (Cal-IPC 2011). Specifically, transient encampments set up within *Arundo* stands, which provide concealment, were the ignition sites for riparian fires. In addition to open fires (for cooking and heat), smoking, drug use and drug making (meta amphetamines), humans have also intentionally set fires to *Arundo* stands in this region. Given the overall lower population density in the Central Valley we assume that human-caused ignitions in *Arundo* stands are less frequent, but transient use of *Arundo* stands in and around urban areas in the Central Valley was documented during field reconnaissance for the study.

Wildfires from adjacent lands can ignite fires in riparian areas, and this happens more easily in *Arundo*-dominated riparian areas than in those with intact native vegetation (due to the amount and type of fuel that they each contain, as described earlier). The prevalence of agricultural land use in the Central Valley may reduce the chance of wildfires from adjacent uplands reaching much of the Central Valley basin. However, these are many cities and towns in the valley floor, and these areas typically have greater vegetation cover along with higher use by transients.

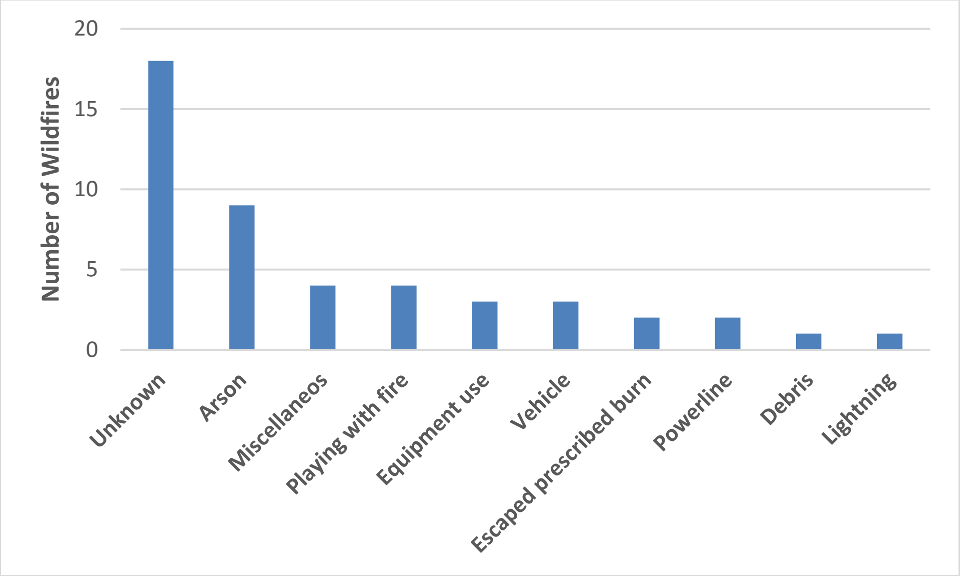

Figure 6-6. Causes of wildfires occurring in the Central Valley study area (1970-2018). Only wildfires containing *Arundo* are included (Data source: Cal Fire).

Figure 6-7. Campsite found during Central Valley field reconnaissance. Photo: J. Giessow.

Figure 6-8. Burned propane tank with some evidence of past fire and *Arundo* regrowth found during Central Valley field reconnaissance. Photo: J. Giessow.

Similar to other regions in the state, the ignition sources for wildfires intersecting *Arundo* stands in the Central Valley were primarily anthropogenic, with only a single fire in the last 48 years caused by lightning. However, we were not able to detect a signature of ignitions within *Arundo* stands as we had been able to do for coastal southern California sites (especially along the San Luis Rey River). The most commonly listed cause of fire was "unknown" followed by "arson" and "miscellaneous" (Figure 6-6). Casual observations from fieldwork associated with this project suggests that Central Valley *Arundo* stands do serve as shelters for homeless people and that campfires are lit in them (Figure 6-7, 6-8). Field visits to sites to collect *Arundo* stand structure data found open fires and transient activity at 4 of the 19 sites or 21% of locations visited (Figure 1-5, Chapter 1). This was a high proportion of sites and it demonstrates that *Arundo* and fire in the Central Valley are on a trajectory of increasing fire frequency, intensity, and size. Particularly if climatic trends toward hotter, windy conditions similar to Santa Ana fall weather conditions continue to occur in the Central Valley.

6.5 Impacts

There is clearly an association between fire and *Arundo* in other regions of the state, and it is likely that this association holds true for the Central Valley, though it is expressed more weakly as most systems have substantially less acreage. As reviewed in this chapter, *Arundo* introduces highly flammable biomass into riparian systems and increases their fuel load drastically. Field visits to sites to collect *Arundo* stand structure data found open fires and transient activity at 4 of the 19 sites or 21% of locations visited (Figure 1-5, Chapter 1). It also supports a self-perpetuating rapid-fire cycle because of its tolerance to burning and its rapid regrowth rate. Few native riparian plant species can persist in this environment long-term. In the Central Valley, fine-scale fire data are limited, but the data which are available show a positive association between number of wildfires and *Arundo* cover. Because of the more discontinuous pattern of flammable vegetation in the Central Valley compared to the previously assessed regions in coastal southern California, we down weighted the impact of *Arundo* on fire. Its impact is likely to be high at a local scale, but less strongly associated with either causing larger wildfires or being ignited by adjacent fires.

We scored the impact of *Arundo* on fire for each watershed unit based on (1) the amount of *Arundo* present in the watershed unit, (2) the number of *Arundo* stands larger than 0.5 acres in size, and (3) the number of past fires recorded from 1970-2008 whose footprint overlapped with *Arundo* stands (see Table 6-1).

Table 6-1. Scoring for *Arundo* impact on fire.

Watershed Units (north to south)	**Arundo Acres**	**Stands >0.5ac**	**Fires 1970-2018**[1]	**Score**[2]
Sac. River Headwaters: Castle-Stillwater Creeks	24	1	5	1
Cottonwood Creek	5	0	1	0
Elder Creek	85	32	2	3
Sac. River Upper: Cottonwood to Thomes	154	31	0	3
Antelope-Mill Creek	14	2	1	0
Thomes Creek	75	22	0	2
Stony Creek	562	185	1	5
Feather River-Chico-Butte Creeks	70	20	8	3
Sac. River Middle: Stony to Cache Creek	153	49	0	3
Colusa Trough-Stone Corral-Freshwater Creeks	115	24	0	3
Bear-Yuba River	44	9	4	1
Cache-Putah Creeks	254	55	12	4
Sac. River Lower: Cache to Putah Creeks	1	1	0	0
American-Mokelumne Rivers-Deer Creek	29	7	1	1
Ulatis Creek	80	12	4	2
Los Banos-Panoche-Salado Creeks-San Joaquin River	65	13	0	2
Calaveras River	28	5	1	1
Stanislaus-Tuolumne Rivers	36	10	0	1
Bear Creek-Merced River	39	7	1	1
Chowchilla-Fresno Rivers	230	78	0	4
San Joaquin River	57	16	0	2
Tulare Lake-Los Gatos Creek	8	0	1	0
Kings River	91	32	0	3
Kaweah-Tule River	34	6	0	1
Kern River	4	0	5	0
Grand Total	**2,256**	**617**	**47**	**27**

[1] Number of fires refers only to the number of fires reported to CALFIRE that overlapped with *Arundo* acreage.

[2] Score derived from subscores for total *Arundo* acres, number of large stands, and number of past fires, weighted 50%, 40% and 10% respectively.

One watershed unit—Stony Creek—scored very high (score of 5) because of its extensive acreage of *Arundo*, and the number of large stands. Two watershed units scored high (score of 4): Cache-Putah Creeks and Chowchilla-Fresno Rivers. These systems have a high number of large stands of *Arundo*, frequently occurring as nearly continuous bands of *Arundo* that are a significant fire threat, particularly as seen on Capay Valley portions of Cache Creek. These areas would experience severe *Arundo* fire impacts locally and have the potential to contribute to landscape-level fires.

Note that the Chowchilla-Fresno River watershed unit has had significant *Arundo* control work completed, but our scoring is based on peak acreage of *Arundo*, so treated *Arundo* is counted as part of the total acreage. This area has high likelihood of ignition with urban areas intermixed with agriculture.

Five watershed units scored medium high (score of 3): Sacramento River Upper: Cottonwood to Thomes; Sacramento River Middle: Stony to Cache Creek; Colusa Trough-Stone Corral-Freshwater Creeks; Kings River; and Elder Creek. These areas have nearly continuous bands for small areas (under ¼ mile), and a large number of *Arundo* stands >0.5 acres. Local fires could have significant impacts and it is possible that landscape level fires could be conveyed, depending on location of the *Arundo* stand.

Five watershed units scored medium (score of 2). These watershed units have scattered stands of *Arundo* that are larger than 0.5 acres. *Arundo* fire impacts would be localized. Six watershed units scored low (score of 1). These watershed units have scattered stands of *Arundo* that are typically of a smaller size, most are under a half-acre. *Arundo* fire impacts would be very localized, landscape level fire contributions are unlikely. Six watershed units scored very low (score of 0). These watershed units have scattered stands of *Arundo* that are typically very small (most under ¼ acre) and unlikely to contribute to local or landscape level fires to any significant degree.

7 IMPACTS ON SENSITIVE SPECIES

7.1 Sensitive Species in the Central Valley

Arundo invasion into Central Valley riparian areas can alter both abiotic and biotic processes impacting sensitive species. Abiotic impacts caused by *Arundo* are explored in proceeding chapters and they include: water (Chapter 4), geomorphology (Chapter 5), and fire (Chapter 6). Abiotic impacts can alter the entire ecosystem, so these impacts—when they occur—can be severe. Biotic impacts range from competition and displacement, to interfering in reproduction, to restricting movement and/or dispersal. These changes, in turn, impact riparian flora and fauna. The Central Valley supports many sensitive plant and animal species whose populations have declined as a result of human modification of the landscape (land use change: agriculture and urbanization) and management of water (hydrological engineering practices), agriculture, and biotic changes, such as invasion by and transformation of habitat by an invasive species such as *Arundo*. In this section, we focus on *Arundo* impacts to sensitive species in the region.

We identified all taxa occurring in the Central Valley study area that were listed by Federal or State regulators as threatened or endangered and overlaid their known distribution data over the distribution of *Arundo* mapped across the region (CDFW Biogeographic Data Branch as of 8-7-2019). There were no federally listed plant species in riparian areas that are impacted by *Arundo,* so we supplemented rare plant information with the California Rare Plant Rank (CRPR; a scoring system developed by the California Native Plant Society and adopted by the California Department of Fish and Wildlife). Lastly, we added rarity rankings from the International Union for Conservation of Nature (IUCN), when they existed. A total of 24 sensitive species that occurred in Central Valley riparian habitat where *Arundo* could occur were examined (see Table 7-1). They represent six taxonomic groups: two herps, one insect, six birds, five fish, five mammals, and five plants. Full species descriptions and impact evaluations are found in Appendix B. These species and taxonomic groups serve as a proxy for gauging impacts to riparian fauna and flora across the Central Valley.

We scored each of the 24 species based on their estimated vulnerability to being impacted by *Arundo*. These "Impact Scores" were based on the ecology of each species. Each sensitive species' distribution in the Central Valley project area was then examined in the context of the distribution of *Arundo* at the watershed unit scale in order to arrive at an "Overlap Score". The Impact Score for a given species and the Overlap Score for that species in a given watershed unit were then multiplied to generate an "Impact-by-Watershed Score" for that species in that watershed unit. These scores are then aggregated across species for each watershed unit to as a basis for assigning an overall "Cumulative Impact Score" for *Arundo*'s impacts on sensitive species in that watershed unit. The Impact-by-Watershed scores can all be summed across watersheds for each species to gauge the level of impact on that species across the entire region.

Table 7-1. Sensitive species in Central Valley riparian areas.

Taxon Group	Common Name	Federal Listing	State Listing	Other Listing
Insect	valley elderberry longhorn beetle	T	-	-
Bird	tricolored blackbird	C	T	IUCN “EN”
Bird	western yellow-billed cuckoo	T	E	-
Bird	California black rail	-	T	-
Bird	bank swallow	-	T	-
Bird	least Bell's vireo	E	E	-
Bird	western snowy plover	T	-	IUCN “NT”
Mammal	riparian (San Joaquin Valley) woodrat	E	-	-
Mammal	riparian brush rabbit	E	E	-
Mammal	San Joaquin kit fox	E	T	-
Mammal	salt-marsh harvest mouse	E	E	IUCN “EN”
Mammal	Buena Vista Lake ornate shrew	E	-	-
Herp	giant garter snake	T	T	IUCN “VU”
Herp	California red-legged frog	T	-	IUCN “VU”
Fish	Delta smelt	T	E	IUCN “CR”
Fish	steelhead Central Valley DPS	T	-	-
Fish	Chinook salmon Central Valley spring-run ESU	T	T	-
Fish	Chinook salmon Sacramento River winter-run ESU	E	E	-
Fish	longfin smelt	C	T	-
Plant	Mason's lilaeopsis	-	-	CRPR 1B.1
Plant	Delta tule pea	-	-	CRPR 1B.2
Plant	Suisun Marsh aster	-	-	CRPR 1B.2
Plant	wooly rose-mallow	-	-	CRPR 1B.2
Plant	Sanford's arrowhead	-	-	CRPR 1B.2

T=Threatened, E=Endangered, C=Candidate , IUCN = International Union for Conservation of Nature, CRPR = California Rare Plant Rank, “NT”=near threatened, “VU”=vulnerable, ”EN”=endangered, ”CR”=critically endangered,1B.1=Plants rare, threatened, or endangered in California or elsewhere and seriously endangered in CA. 1B.2= Plants rare, threatened, or endangered in California or elsewhere and fairly endangered in CA.

7.2 Scoring Schemes for Sensitive Species Impact and Overlap

7.2.1 Scheme for Impact Score

To evaluate the impacts of *Arundo* on sensitive species, we reviewed documents prepared by the U.S. Fish and Wildlife Service (USFWS) and California Department of Fish & Wildlife (CDFW) during their evaluations for listing and recovery. Information from the California Native Plant Society (CNPS) was also used for evaluation of sensitive plants. The documents used include: Critical Habitat Designations, Recovery Plans, Incremental Reviews (5-year, 10-year, etc.), and Biological Opinions (Section 7 and 10) issued for projects that may adversely impact listed species. A significant amount of the data presented in this chapter is taken directly from numerous Biological Opinions issued by the USFWS.

Table 7-2. Scoring scheme for impact on sensitive species.

Score	Impact Level	Impacts
10	Very severe	Very significant alteration of abiotic structure and biological function, and direct take of individuals
9	Severe	Significant alteration of abiotic structure and biological function and direct take of individuals
8	Very high	Alteration of abiotic structure and biological function, direct take possible
7	High	Alteration of abiotic structure and biological function (impacts on general ecological needs, reproduction, diet, or movement)
6	Moderate/High	Moderate alteration of abiotic structure and/or biological function (impacts on general ecological needs, reproduction, diet, or movement)
5	Moderate	Minor alteration of abiotic structure and/or moderate alteration of biological function (impacts on general ecological needs, reproduction, diet, or movement)
4	Low/Moderate	Minor alteration of biological function (impacts on general ecological needs, reproduction, diet, or movement)
3	Low	Slight or potential alteration of biological function (impacts on general ecological needs, reproduction, diet, or movement)
2	Very low	Potential alteration of biological function (impacts on general ecological needs, reproduction, diet, or movement)
1	Very low/ Improbable	Difficult to discern any interaction with *Arundo*
0	None	No interaction

Information from USFWS documents, the 2011 *Arundo* Impact Report on coastal southern Californian watersheds (Cal-IPC 2011), published literature, and expert opinions were used to determine the Impact Score for each species on a 10-point scale (Table 7-2). We evaluated both abiotic (water, fire, and geomorphic processes) and biotic (reproduction, competition, displacement, and movement) impacts on the species. This evaluation for each sensitive species includes a discussion of general ecological and habitat needs, reproduction, movement, range and other impacts/threats, and how *Arundo* may interact with that component of the species life history. Higher scores reflect more significant *Arundo* impacts to the evaluated sensitive species, such as physical displacement, increased fire, modification of geomorphic processes, water availability, being a barrier to movement, etc. Full evaluations for each of our selected sensitive species are presented in Appendix B.

7.2.2 Scheme for Overlap Score

The Overlap Score captures the degree to which the sensitive species directly overlaps with, or is down stream of, mapped *Arundo* infestations. Using GIS, we compared sensitive species data—extensive survey data collected for sensitive species (uploaded and available in the CDFW BIOS data set and Calflora.org)—with the *Arundo* spatial data we collected for this study. Critical habitat areas, when designated, were also reviewed. Maps of GIS data for sensitive species occurrence in relation to *Arundo* distribution are presented in Appendix C. To characterize the level of interaction between each sensitive species and *Arundo*, a watershed-specific Overlap Score was scored (Table 7-3). This metric characterizes the abundance of *Arundo* and the occurrences of the sensitive species, with a focus on overlap in spatial distribution in the watershed unit. This addresses the question: Does the sensitive species occur in the watershed unit and is there *Arundo* that could be impacting the sensitive species? The score captures the level of interaction between *Arundo* and the listed species. This analysis was done by viewing and interpreting the *Arundo* data and CNDDB data for each individual species over aerial imagery. This allowed examination of connectivity between mapped *Arundo* stands and sensitive species occurrences through water features and infrastructure. It also allowed review of sensitive species habitat characteristics, and how these are related to the *Arundo* distribution. Because five different taxonomic groups are used, there is marked variation in how species use and move through the landscape. It was not possible to use distance to *Arundo* metrics to determine impact on a species, as distance does not necessarily relate to connectivity. Sensitive species occurrence data was also used to interpret likely distributions, where appropriate, based on suitable habitat affinity, as not all species have uniform survey work. This was only done with a watershed unit and is similar to critical habitat area designations.

A high score (10) requires frequent occurrence of the sensitive species within portions of the watershed that have high *Arundo* abundance. Low scores are given for species that have low occurrences within areas of low *Arundo* cover. Intermediate scores are given for co-occurrence, where there are moderate levels of abundance for *Arundo* and/or sensitive species. Species that are restricted to upper reaches of a watershed, above where *Arundo* occurs, would be ranked with a low score (0 or 1), even if the watershed has high *Arundo* abundance overall. Species that occur at or near the lower end of the watershed may not have significant co-occurrence with *Arundo* stands, but they may have *Arundo* upstream of them that is modifying abiotic processes or generating *Arundo* biomass that flows into the sensitive species habitat (*Arundo* debris or modified hydrology). These interactions, which are often for marsh, slough, and estuarine sensitive species, can have a full range of overlap/interaction scores from low to high.

Table 7-3. Scoring scheme for overlap between *Arundo* and sensitive species.

Overlap Score	***Arundo* abundance** (near or upstream of sensitive species)	**Sensitive species occurrences** (near or downstream of *Arundo*)	**Interaction Level**
10	Very High	High (core area)	High interaction
9	High	High	High interaction
8	High	Moderate	High interaction
7	Moderate	High	High interaction
6	Moderate	Moderate	Moderate interaction
5	Low	High	Moderate interaction
4	High/Moderate	Moderate/Low	Moderate interaction
3	Low	Moderate	Moderate interaction
2	Low	Low	Low interaction
1	Very low	Low	Potential interaction
0	None recorded	Not recorded	No interaction

7.3 Scores for Sensitive Species Impact and Overlap by Watershed

7.3.1 Impact Scores

Within the study area, all 24 sensitive species evaluated were found to be impacted at some level by the presence of *Arundo* (Table 7-4). By taxon, insects were the most impacted with a score of 8.0, but the sample size was a single species (n=1). Birds (5.7, n=6) and plants (5.0, n=5) had moderate/high to moderate impacts. Mammals (4.0, n=5), fish (3.0, n=5), and herps (2.5, n=2) had low/moderate to low average scores by taxa.

Sensitive insects were represented by a single species, valley elderberry longhorn beetle. Its impact score was very high, the second highest impact score for an individual species. The very high impact score resulted from *Arundo* impacts on the elderberry beetle's obligate host plant elderberry. *Arundo* and elderberry prefer the same riparian habitat, high energy floodplain and terraces in low gradient riparian systems. This results in direct displacement of elderberry by *Arundo*, as well as a wide range of abiotic impacts associated with flood, water use, and fire.

Table 7-4. *Arundo* Impact Score for each species with sum and average for each taxa group.

Taxa Group	Common Name	Impact Score	Summary for Taxa Group
Insect	valley elderberry longhorn beetle	8	Avg. = 8.0 n = 1
Avian	tricolored blackbird	4	Avg. = 5.7 n = 6
Avian	western yellow-billed cuckoo	7	
Avian	California black rail	3	
Avian	bank swallow	7	
Avian	least Bell's vireo	9	
Avian	western snowy plover	4	
Plant	Mason's lilaeopsis	5	Avg. = 5.0 n = 5
Plant	Delta tule pea	6	
Plant	Suisun Marsh aster	6	
Plant	wooly rose-mallow	6	
Plant	Sanford's arrowhead	2	
Mammal	riparian (San Joaquin Valley) woodrat	6	Avg. = 4.0 n = 5
Mammal	riparian brush rabbit	6	
Mammal	San Joaquin kit fox	3	
Mammal	salt-marsh harvest mouse	3	
Mammal	Buena Vista Lake ornate shrew	2	
Fish	Delta smelt	1	Avg. = 3 n = 5
Fish	steelhead Central Valley DPS	5	
Fish	Chinook salmon Central Valley spring-run ESU	5	
Fish	Chinook salmon Sacramento River winter-run ESU	3	
Fish	longfin smelt	1	
Herp	giant garter snake	3	Avg. 2.5 n = 2
Herp	California red-legged frog	2	

Sensitive bird species were represented by six species. These species fell into two general classes based on the wetland habitat that they use. Species that use riparian habitat had impact scores that ranged from high to severe, reflecting both abiotic and biotic impacts. This included bank swallow, least Bell's vireo, and yellow-billed cuckoo. These three sensitive species have three of the top four highest *Arundo* impact scores. Species that use estuary and marsh areas were also impacted by *Arundo*, usually as a function of biomass accumulating in habitat areas (discharged from upstream riparian areas), but also to a lesser degree from *Arundo* growing in estuaries or marshes on levees and dikes adjacent to them. Avian species that use marsh and estuary habitat had impact scores ranging from moderate to low, and included tricolored black bird, California black rail, and western snowy plover. Avian species were also, as a group, susceptible to physical changes in habitat structure; *Arundo* altered perch availability, access to nest sites, and nesting substrate.

Sensitive plants were represented by five species. *Arundo* impact scores of moderate/high and moderate were recorded for four species (Mason's lilaeopsis, Delta tule pea, Suisun Marsh aster, and woolly rose-mallow). These scores are quite high given that *Arundo* does strongly occur in the marsh/estuary habitats that the four sensitive species are found in. All four species are impacted by *Arundo* overhanging sensitive species habitat from adjacent riparian habitat, typically levees, berms and stream banks. This results in impacts where the two habitat types are adjacent, which is very common in Delta and marsh areas on the valley floor. *Arundo* biomass can also cover marsh/estuary habitat after flood events. One species, Sanford's arrowhead, occurs in low energy marsh/pond habitat (typically with standing water) that had a very low impact score, as *Arundo* has few impacts on that habitat type.

Sensitive mammals were represented by five species. Two of these species, the riparian brush rabbit and riparian woodrat, occur only in valley floor riparian habitat, and had moderate/high impact scores due to a range of impacts. The other three mammal species (San Joaquin kit fox, salt-marsh harvest mouse and Buena Vista lake ornate shrew) have low to very low impact scores as *Arundo* does not strongly impact habitat used by the species, their movement or other life history traits.

Sensitive fish were represented by five species. Fish had fairly uniform impact scores, ranging from moderate to very low. *Arundo* can impact channel form and depth, which is a significant change to habitat structure, but this impact is seen most strongly at headwaters and on tributaries to the Sacramento and San Joaquin Rivers, and only where riparian areas are wide enough to contain floodplains. Sensitive fish species that occupy tributaries for part of their life cycle have higher *Arundo* impact scores (Chinook spring run and steelhead). *Arundo* biomass and shading also have possible effects on habitat quality for rearing and feeding for these species, and to a lesser degree on the Chinook winter run. Sensitive fish species that are more restricted to the Delta (Delta and longfin smelt), which are characterized by wide deep channel forms with large perennial flows, are not strongly impacted by *Arundo*.

Sensitive herps were represented by two species, one snake (giant garter snake) and one frog (red-legged frog). Both species had low impact scores, but for different reasons. Red-legged frogs typically occur in low-energy high-elevation portions of upper watersheds, commonly in foothill riparian areas and cattle ponds. These areas are not typically invaded by *Arundo*. Giant garter snakes, in contrast, are typically found low in the watershed, in wetland habitat consisting of sloughs and marshes. These habitats have largely disappeared as a result of waterway engineering and are now bounded by dikes and levees. Wet, low energy hydrologic areas are also a wetland type not preferred by *Arundo*, although it does occur as scattered stands along them. In these upper and lower watershed areas, *Arundo* is less likely to directly impact species, alter abiotic processes, or generate/aggregate enough biomass to degrade habitat significantly.

7.3.2 Overlap Scores

Sensitive species' Overlap Scores are presented below in Table 7-5 and characterize the degree of overlap between *Arundo* and each sensitive species at the watershed scale. Very different patterns emerged for different species and taxonomic groups. Two sensitive species were broadly distributed, with records in most watershed units: valley elderberry longhorn beetle (23 of 25 units) and tricolored black bird (22 of 25). The next widest ranging species were steelhead Central Valley DPS (18 of 25) and Chinook Central Valley spring-run ESU (14 of 25). Four sensitive species occurred on eight to 11 watersheds. Sixteen species occurred on six watersheds or less, 13 of which had very restricted distributions, occurring on four watersheds or less.

We subdivided the Central Valley study area into three broader geographic units to better analyze regional patterns in sensitive species occurrence. These were: Sacramento Valley, with 11 species; San Joaquin Valley, with 11 species; and the Delta Region, with 20 species. The Delta region's greater diversity was not just reflected in an aggregation of Sacramento and San Joaquin species, but also included a group of plant species that were Delta-specific in distribution. The Sacramento region had strong avian and fish diversity and weaker mammal and plant diversity, and the San Joaquin region had strong mammal diversity and weaker fish, avian, and plant diversity.

7.4 Impact by Species and Watershed

7.4.1 Impact-by-Watershed Scores

For each watershed, the Impact Score for each species was multiplied by its Overlap Score to generate an Impact-by-Watershed Score (Table 7-6). This metric captures *Arundo* impacts on each sensitive species at the watershed unit scale. Impact-by-Watershed Scores ranged from a high of 72 to a low of 0. The highest score possible would be 100 (10 impact x 10 overlap).

7.4.2 Cumulative Impact by Species

By summing Impact-by-Watershed scores across watershed units we can categorize the cumulative magnitude of *Arundo* impacts to each species across the Central Valley (Table 7-7). Scores range from four to 928. The highest possible score would be 2,500. These results are stratified into four classes from severe to low impact based on natural breaks in the data (Figure 7-1).

The valley elderberry longhorn beetle had a "severe" cumulative impact score (total score of 928) reflecting both a very high *Arundo* impact score and a wide and significant overlapping spatial distribution with *Arundo*, spanning 23 watershed units. The severity of the impact across the Central Valley stands out at twice the magnitude of the next impacted species.

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Table 7-5. Overlap scores for sensitive species.

Category	Common name	*Arundo* Impact Score	Castle-Stillwater Creeks-Sac River headwaters	Cottonwood Creek	Elder Creek	Sac. River Upper: Cottonwood to Thomes	Antelope-Mill Creek	Thomes Creek	Stony Creek	Feather River-Chico-Butte Creeks	Sac River Middle: Stony to Cache Creek	Colusa Trough-Stone Corral-Freshwater Creeks	Bear-Yuba River	Cache-Putah Creeks	Sac. River Lower: Cache to Putah Creeks	American-Mokelumne Rivers-Deer Creek	Ulatis Creek	Los Banos-Panoche-Salado Creeks-San Joaquin River	Calaveras River	Stanislaus-Tuolumne Rivers	Bear Creek-Merced River	Chowchilla-Fresno Rivers	San Joaquin River	Tulare Lake-Los Gatos Creek	Kings River	Kaweah-Tule River	Kern River	Count	Rank
			SACRAMENTO VALLEY													DELTA				SAN JOAQUIN VALLEY									
Herp	giant garter snake	3							2	6		9	4	6		4	4	8	2				6		4			11	5
Herp	California red-legged frog	2																2										1	13
Insect	valley elderberry longhorn beetle	8	4		4	8	3	3	4	9	6	4	6	6	2	7	2	6	7	7	6	2	5		5	6	4	23	1
Bird	tricolored blackbird	4	2		4	4	4	4	4	5		8	2	5		3	1	4	2	2	2	1	1	3	2	4	2	22	2
Bird	western yellow-billed cuckoo	7				4				5	6		4														1	5	9
Bird	California black rail	3								5			3			3	3	4	3									6	8
Bird	bank swallow	7	8			9		2		9	7		9	9		7	3					3						10	6
Bird	least Bell's vireo	9												3				3		1	1							4	10
Bird	western snowy plover	4																						1	1	2		3	11
Fish	Delta smelt	1														2	6	4	4									4	10
Fish	steelhead - Central Valley DPS	5	7	5	4	5	3	7	7	7	4		6	4	1	3	5	4	4	4	4							18	3
Fish	Chinook salmon - Central Valley spring-run ESU	4	8	5	4	3	3	4	4	8	3		5		1	3	3	3										14	4
Fish	Chinook salmon - Sacramento River winter-run ESU	3	6			6					3				1													4	10
Fish	longfin smelt	1													2	2	6	4	4									5	9
Mammal	riparian (San Joaquin Valley) woodrat	6																		4								1	13
Mammal	riparian brush rabbit	6														1		4	1	4								4	10
Mammal	San Joaquin kit fox	3																3		3	3	3	4	3	6	8		8	8
Mammal	salt-marsh harvest mouse	3															5	2										2	12
Mammal	Buena Vista Lake ornate shrew	2																					2	3	2	3		4	10
Plant	Mason's lilaeopsis	5														3	7	7	5									4	10
Plant	Delta tule pea	6														4	7	6	3									4	10
Plant	Suisun Marsh aster	6														4	7	6	4									4	10
Plant	Wooly rose-mallow	6				2			2	5		4				3	2	6	3									8	7
Plant	Sanford's arrowhead	2		1												3	5											3	11
		Sum by watershed:	**35**	**11**	**16**	**41**	**13**	**20**	**23**	**59**	**29**	**25**	**39**	**33**	**7**	**52**	**66**	**76**	**42**	**25**	**16**	**9**	**18**	**10**	**20**	**23**	**7**		

Table 7-6. Impact-by-Watershed scores for each sensitive species by watershed unit.

Category	Common name	*Arundo* Impact	Castle-Stillwater Creeks-Sac River headwaters	Cottonwood Creek	Elder Creek	Sac. River Upper: Cottonwood to Thomes	Antelope-Mill Creek	Thomes Creek	Stony Creek	Feather River-Chico-Butte Creeks	Sac River Middle: Stony to Cache Creek	Colusa Trough-Stone Corral-Freshwater Creeks	Bear-Yuba River	Cache-Putah Creeks	Sac. River Lower: Cache to Putah Creeks	American-Mokelumne Rivers-Deer Creek	Ulatis Creek	Los Banos-Panoche-Salado Creeks-San Joaquin River	Calaveras River	Stanislaus-Tuolumne Rivers	Bear Creek-Merced River	Chowchilla-Fresno Rivers	San Joaquin River	Tulare Lake-Los Gatos Creek	Kings River	Kaweah-Tule River	Kern River	Sum
			SACRAMENTO VALLEY													DELTA				SAN JOAQUIN VALLEY								
Herp	giant garter snake	**3**							6	18		27	12	18		12	12	24	6				18		12			**165**
Herp	California red-legged frog	**2**																4										**4**
Insect	valley elderberry longhorn beetle	**8**	32		32	64	24	24	32	72	48	32	48	48	16	56	16	48	56	56	48	16	40		40	48	32	**928**
Bird	tricolored blackbird	**4**	8		16	16	16	16	16	20		32	8	20		12	4	16	8	8	8	4	4	12	8	16	8	**276**
Bird	western yellow-billed cuckoo	**7**				28				35	42		28														7	**140**
Bird	California black rail	**3**								15			9			9	9	12	9									**63**
Bird	bank swallow	**7**	56			63		14	0	63	49	0	63	63		49	21					21						**462**
Bird	least Bell's vireo	**9**												27				27		9	9							**72**
Bird	western snowy plover	**4**																						4	4	8		**16**
Fish	Delta smelt	**1**														2	6	4	4									**16**
Fish	steelhead - Central Valley DPS	**5**	35	25	20	25	15	35	35	35	20	30	20	20	5	15	25	20	20	20	20							**420**
Fish	Chinook salmon - Central Valley spring-run ESU	**5**	40	25	20	15	15	20	20	40	15	25			5	15	15	15										**285**
Fish	Chinook salmon - Sacramento River winter-run ESU	**3**	18			18					9				3													**48**
Fish	longfin smelt	**1**													2	2	6	4	4									**18**
Mammal	riparian (San Joaquin Valley) woodrat	**6**																		24								**24**
Mammal	riparian brush rabbit	**6**														6		24	6	24								**60**
Mammal	San Joaquin kit fox	**3**																9		9	9	9	12	9	18	24		**99**
Mammal	salt-marsh harvest mouse	**3**															15	6										**21**
Mammal	Buena Vista Lake ornate shrew	**2**																					4	6	4	6		**20**
Plant	Mason's lilaeopsis	**5**														15	35	35	25									**110**
Plant	Delta tule pea	**6**														24	42	36	18									**120**
Plant	Suisun Marsh aster	**6**														24	42	36	24									**126**
Plant	Wooly rose-mallow	**6**				12			12	30		24				18	12	36	18									**162**
Plant	Sanford's arrowhead	**2**		2												6	10											**18**
		Sum by watershed:	**189**	**52**	**88**	**241**	**70**	**109**	**121**	**328**	**183**	**115**	**223**	**196**	**31**	**265**	**270**	**356**	**198**	**150**	**94**	**50**	**78**	**31**	**86**	**102**	**47**	**3673**

Four species were categorized as 'high' cumulative impact scores for the Central Valley: bank swallow (462), steelhead Central Valley-DPS (420), Chinook salmon spring run ESU (285), and tricolored blackbird (276). Bank swallow had a high *Arundo* impact score and overlapped with *Arundo* in 10 watersheds. Where it overlapped it did so strongly, resulting in a high cumulative impact score. Steelhead have a moderate *Arundo* impact score but occurred on 18 watersheds with moderate abundance. Chinook have a moderate *Arundo* impact score and occurred on 14 watersheds

Table 7-7. Cumulative Impact-by-Watershed scores for each species summed across all watersheds, with sum and average for each taxa group.

Taxa Group	Common Name	Cumulative Impact-by-Watershed Score	Summary for Taxa Group
Insect	valley elderberry longhorn beetle	928	Sum = 928 Avg. = 928
Bird	tricolored blackbird	276	Sum = 1,029 Avg. = 171
Bird	western yellow-billed cuckoo	140	
Bird	California black rail	63	
Bird	bank swallow	462	
Bird	least Bell's vireo	72	
Bird	western snowy plover	16	
Fish	Delta smelt	16	Sum = 787 Avg. = 157.4
Fish	steelhead Central Valley DPS	420	
Fish	Chinook salmon Central Valley spring-run ESU	285	
Fish	Chinook salmon Sacramento River winter-run ESU	48	
Fish	longfin smelt	18	
Plant	Mason's lilaeopsis	110	Sum = 536 Avg. = 107
Plant	Delta tule pea	120	
Plant	Suisun Marsh aster	126	
Plant	Woolly rose-mallow	162	
Plant	Sanford's arrowhead	18	
Herp	giant garter snake	165	Sum = 169 Avg. = 85
Herp	California red-legged frog	4	
Mammal	riparian (San Joaquin Valley) woodrat	24	Sum = 224 Avg. = 45
Mammal	riparian brush rabbit	60	
Mammal	San Joaquin kit fox	99	
Mammal	salt-marsh harvest mouse	21	
Mammal	Buena Vista Lake ornate shrew	20	
	Grand Total:	**3,673**	

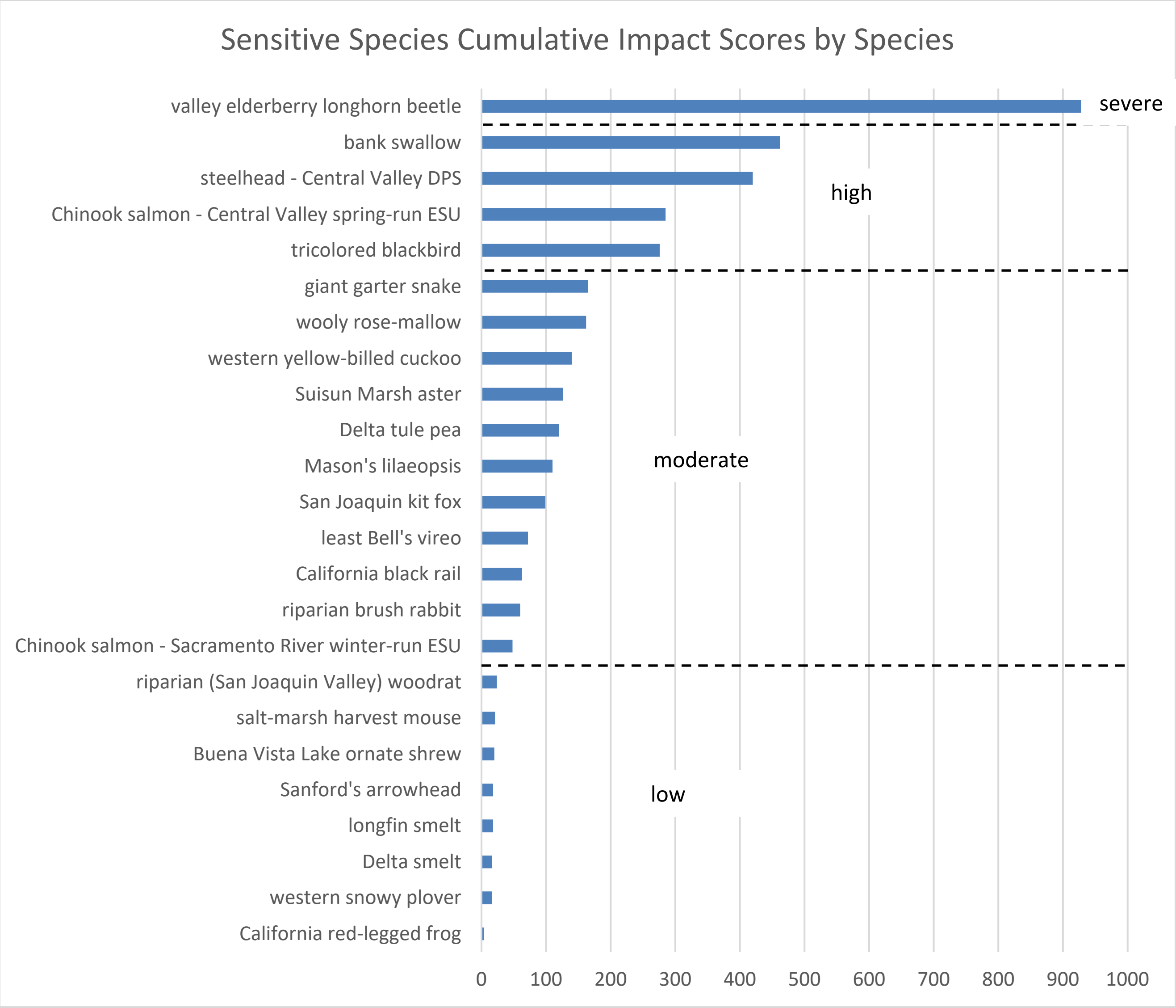

Figure 7-1. Cumulative impact scores by sensitive species across Central Valley watersheds.

with moderate abundance. Tricolored blackbird has a moderate *Arundo* impact score but occurred on 23 watersheds with moderate abundance.

Eleven species have 'moderate' cumulative impact scores across the Central Valley: giant garter snake (165), wooly rose-mallow (162), western yellow-billed cuckoo (140), Suisun Marsh aster (126), Delta tule pea (120), Mason's lilaeopsis (110), San Joaquin fox (99), least Bell's vireo (72), California black rail (63), riparian brush rabbit (60), and Chinook salmon Sacramento River winter run ESU (48).

Eight species have low cumulative impact scores across the valley: riparian woodrat (24), salt-marsh harvest mouse (21), Buena Vista Lake ornate shrew (20), Sanford's arrowhead (18), longfin smelt (18), Delta smelt (16), western snowy plover (16), and California red-legged frog (4).

Cumulative sensitive species impact scores across watersheds (Table 7-6) generated different rankings than the straight impact scores (Table 7-4). Avian species have the highest cumulative summation (severe at 1,029) and the second highest average (171). Insects have the second highest summary score and highest average (very high at 928), but there is only one species representing the group. These two taxa groups also have the highest individual *Arundo* impact score averages, but they were in switched positions. Avian and insect taxon groups are well separated from all other taxon in terms of cumulative impact scores. Fish have the third highest summary score (787) and the third highest average (157). The fish cumulative ranking score (3rd rank) was significantly higher in comparison to the initial impact score (5th rank). Figure 7-1 shows the species in order of cumulative impact across the Central Valley region.

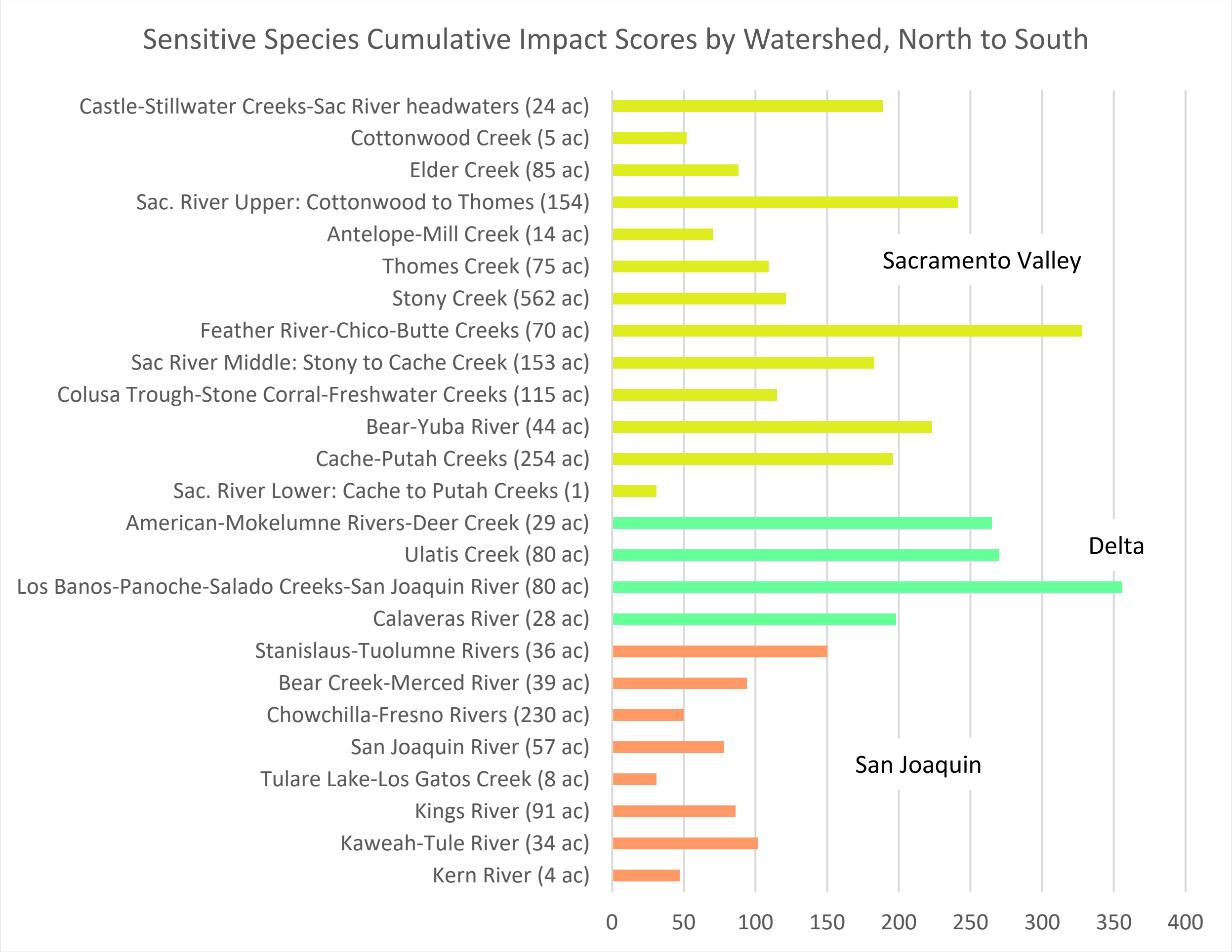

Figure 7-2. Cumulative sensitive species impact scores by watershed unit for the Central Valley, north to south. Green bars indicate watershed units in the Delta region, yellow bars are in the Sacramento Valley and orange bars are in the San Joaquin Valley.

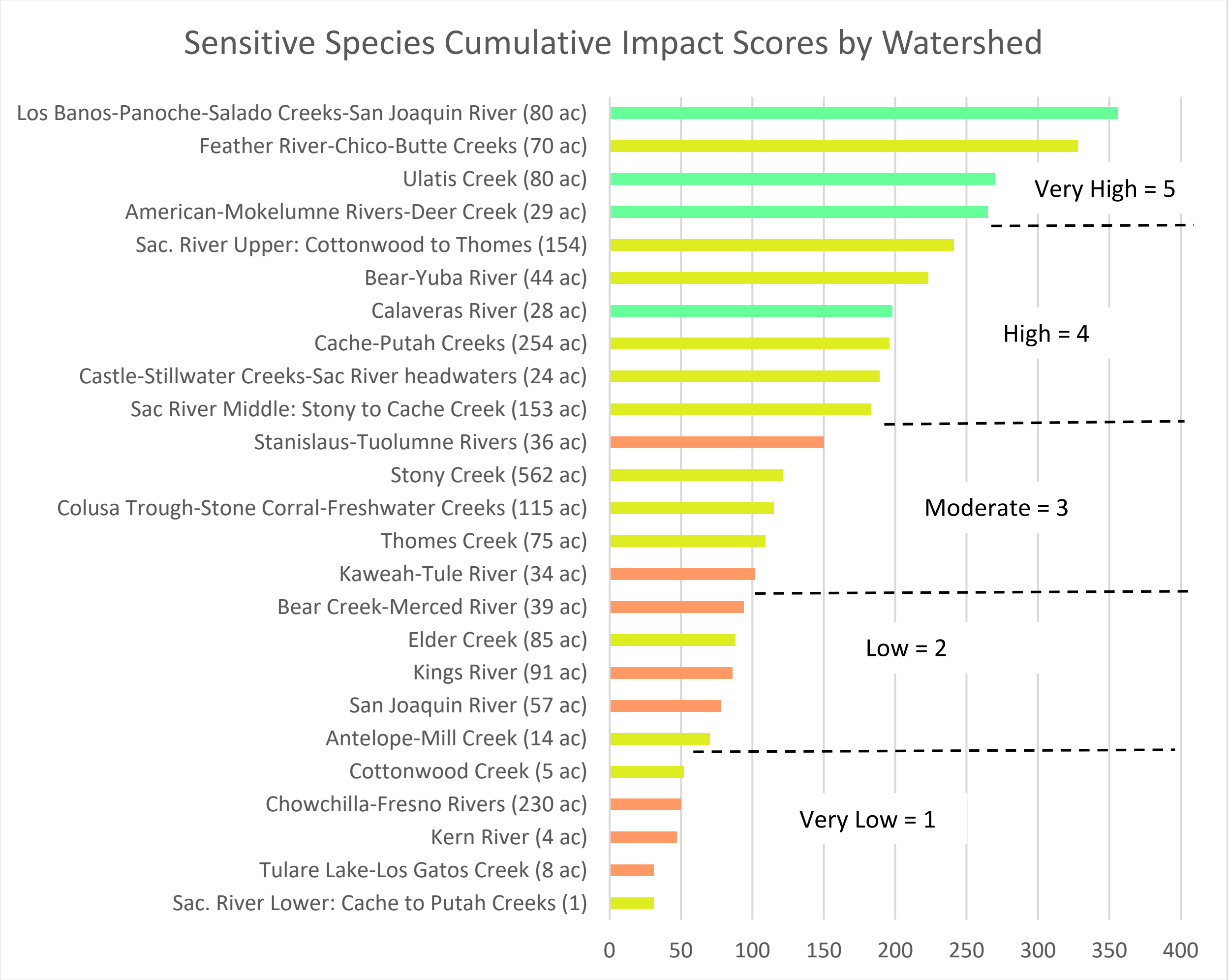

Figure 7-3. Cumulative sensitive species impact scores by watershed unit for the Central Valley, by score. Green bars indicate watershed units in the Delta region, yellow bars are in the Sacramento Valley and orange bars are in the San Joaquin Valley. Watershed units are broken out into categories for overall impact scores from 0-5 for use in prioritization in Chapter 9.

7.4.2 Cumulative Impact by Watershed

We can also aggregate Impact-by-Watershed Scores by watershed unit to get a sense of the level of impact *Arundo* has on sensitive species in the watershed units. Watershed totals for cumulative *Arundo* impact scores on sensitive species are shown in Figures 7-2 and 7-3. The Delta region, with its high scoring in all taxonomic groups, has the highest representation of watersheds with severe to high cumulative *Arundo* impact scores. All four of the Delta watersheds scored in this elevated impact range. Sacramento Valley watersheds also had high cumulative species impact scores with six of the nine watershed groups scoring in the high to severe range. San Joaquin Valley watersheds scored lower, with the highest ranking being moderate and most watersheds scoring in the low range. Impact-by-Watershed scores are stratified into four classes from very high to very low (Figure

7-3) and scored on a 5-point scale like the impacts assessed in the previous three chapters in order to be integrated into prioritization in Chapter 9.

7.5 Impacts Discussion

Arundo impacts are very severe (Sensitive Species Impact Score of 10) to moderate/high (score of 6) for nine out of the 24 evaluated sensitive species (Table 7-4). This indicates that *Arundo*'s modification of abiotic and biotic ecosystem processes is likely having significant impacts on a wide range of species. The results for the Central Valley are slightly lower compared to coastal watersheds from Monterey to San Diego, where 11 out of 22 evaluated species scored in this range (Cal-IPC 2011).

Sensitive species such as valley elderberry long-horned beetle, bank swallow, least Bell's vireo, and yellow-billed cuckoo that are dependent on riparian habitat, particularly those present in high energy/low gradient riparian areas, have the highest impact scores. This is similar to the findings of the coastal watershed *Arundo* impact report (Cal-IPC 2011). Mammals were more impacted in the Central Valley than was observed in the coastal study. Two species, riparian woodrat and riparian brush rabbit, are riparian obligate/dependent and had impact scores of moderate/high. Compared to the coastal study, plants have higher *Arundo* impacts in the Central Valley *Arundo* impact analysis. Most of these plants (four of five) have moderate to moderate/high impact scores. These plants tend to occur in adjacent habitat, such as marsh and estuary, which is directly affected by *Arundo* overhanging from banks and levees, thus physically impacting the sensitive plant species. *Arundo* biomass deposited in marsh and estuaries also impacts these species. Recognizing impacts to adjacent and downstream habitat types is important and was observed in the coastal watershed study as well, but for different taxa and species. *Arundo* impact scores for fish were similar in the two reports, with scores in the moderate to low range. Fish are impacted through modification of fluvial processes, water availability, and *Arundo* biomass, particularly fish species that have spawning and rearing in freshwater systems (steelhead and Chinook salmon).

The cumulative impact scores, which account for the interaction in actual distribution of *Arundo* in Central Valley watershed units and the individual sensitive species, highlight the species that are under significant pressure across the study area. Five species stand out with severe to high cumulative *Arundo* impact scores: valley elderberry long-horned beetle, bank swallow, steelhead Central Valley DPS, Chinook salmon Central Valley spring-run ESU and tricolored blackbird. Tricolored blackbird and the two fish species demonstrate that sensitive species with moderate impact scores can have high cumulative impact scores if the sensitive species and *Arundo* co-occur over significant portions of the region.

Sensitive species with moderate cumulative impact scores tended to be species with moderate impact scores that occurred over multiple watershed units, but usually in one geographic region. All four plants fit this pattern, occurring in the Delta region. Giant garter snake, found only in the lower

Sacramento Valley and Delta, also showed this pattern. There were 13 sensitive species with cumulative impact scores of low. These typically had either low *Arundo* impact scores (Buena Vista Lake ornate shrew) or very limited spatial distributions (riparian woodrat), or both (Delta smelt).

There does not appear to be a correlation between high cumulative impact scores and high *Arundo* acreage on watershed units. Figure 7-4 plots the cumulative impact score of each watershed against the acreage of *Arundo* in the watershed. The very low R^2 value (0.0039) shows a lack of correlation. For instance, Stony Creek's has very high *Arundo* acreage but its cumulative impact score is only moderate.

The Delta region watershed units have the most uniform and highest cumulative impact scores taken as a region. This is a region where work could, and perhaps should, occur out of the typical "start at the top of the watershed and work your way down"' control progression. Many areas within the Delta are also smaller tributaries or side channels with little or no connectivity to flows from upstream that could re-infest treatment areas. These areas can have work initiated without the threat of re-invasion from upstream sources. The Delta watershed units also have manageable *Arundo* acreage to tackle under a control program or project (ranging from 28 to 80 acres for the four watersheds).

Many of the watershed units in the Sacramento Valley also have high cumulative impact scores. While the mainstem of the Sacramento River is downstream of its many tributaries, the tributaries themselves are fairly isolated such that *Arundo* control projects can be undertaken minimal risk of being re-infested from upstream.

The San Joaquin Valley, as a region, has the lowest ranking watershed units in terms of cumulative impact scores. The region has fewer sensitive species present and some watersheds with very little *Arundo* acreage, which provides less opportunity for co-occurrence. Watershed units with less than 10 acres of *Arundo* have very little interaction with sensitive species, which would be expected.

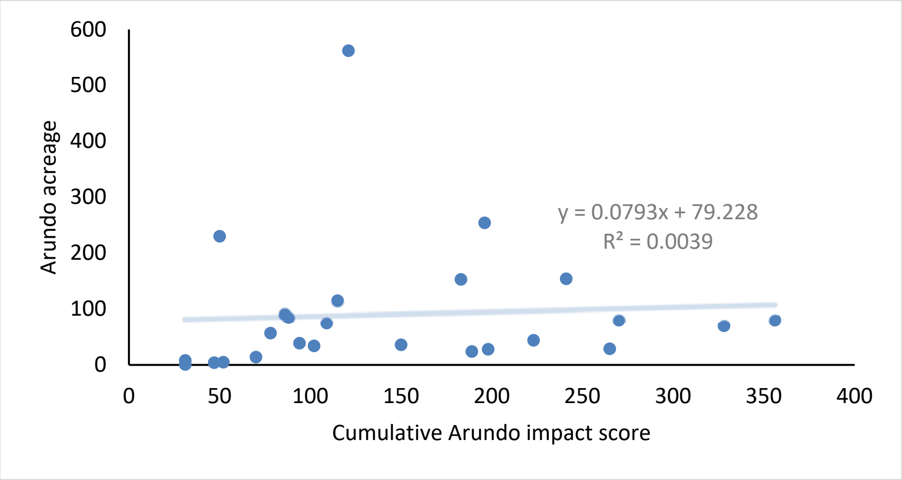

Figure 7-4. Correlation between *Arundo* acreage and cumulative impact score by watershed units.

8 COST-BENEFIT ANALYSIS

A cost-benefit analysis (CBA) can be used to assess the net benefit of controlling *Arundo* (based on the negative impacts that are removed) weighed against the cost of control. With the relatively fine-scale mapping that we have completed for the Central Valley, a CBA can be further used to prioritize specific areas for control (in our case, watershed units and sections therein) in a way that maximizes benefit.

In our previous report (Cal-IPC 2011) we estimated costs and benefits of *Arundo* control for coastal southern California based on available data and mapping information from the region. We compiled information from previous studies which were particularly helpful in deriving estimates. Seawright (2009) found an up-to-eightfold benefit relative to the cost of treatment based on water savings along the Rio Grande River in Texas, where the extent of *Arundo*'s invasion is massive (see Chapter 2, Figure 2-1). Swezey (2008) found a benefit-to-cost ratio of nearly 4:1 for the Santa Clara River watershed. We arrived at a benefit-to-cost ratio estimate of nearly 2:1 for coastal watersheds in California from Monterey to Mexico (Cal-IPC 2011). Bell et al. (2016) estimated costs and benefits for *Arundo* control on the Santa Clara River in southern California. They modeled benefits from water savings, reduced fire risk, and decreased flooding risk. They arrived at a range of results, most falling below a benefit-cost-ratio of 1:1. It is apparent that monetizing many benefit types is not an exact science. Furthermore, it is difficult to capture or all potential benefits *Arundo* control, especially when they may long-term, subtle, or difficult to measure. For instance, none of the above studies included benefits to wildlife or sensitive species. Bell et al. (2016) point out this oversight and recommend including it in the future.

Here, we estimate benefits and costs of controlling *Arundo* in the Central Valley. In calculating benefit, we use a time horizon of 20 years. We assume that inflation affects the dollar value of both costs and benefits equally so do not apply a discount rate. Increased labor costs will result in higher cost of implementation in the future if action is delayed, and impacts from *Arundo* on water use, geomorphology, fire, and sensitive species will also increase if its spread is left unchecked, especially with expected future increases in development, associated infrastructure needs, and the associated rise in the value of finite resources that *Arundo* affects. Given that both will increase in opposing directions, we assume for simplicity that changes in the costs of control and the benefits of control cancel each other out. Similarly, as *Arundo* spreads, both impacts and costs will increase (though the benefit-to-cost ratio may remain constant), so early action is preferable for reducing impacts and costs.

8.1 Cost of *Arundo* Control

8.1.1 Costs of Integrated Mechanical/Chemical Control

The cost of *Arundo* control using an integrated approach with mechanical and chemical tools was estimated as $25,000 per net acre in the Cal-IPC (2011) report. (At the time, nearly $70 million had already been spent controlling *Arundo* over the previous 15 years; at this point the total invested is well over $100 million.) Since then, inflation and labor costs have increased and there is additional awareness of the need for long-term maintenance after initial control. Therefore, our current estimate of cost for a control program is $35,000/acre.

Although treatment accounts for most of the cost—80%—project management costs are not insignificant given the needs for acquiring permits and landowner permissions, as well as managing a restoration project at the landscape scale. *Arundo* control costs are high relative to removal costs for other weeds for several reasons: *Arundo* stands have high biomass per acre, the plants are difficult to control, it exists in sensitive habitat that is highly regulated, and is is distributed across a landscape with diverse land ownerships. This cost will vary between projects but remains a good average estimate.

Removal costs can vary substantially between watersheds and projects. This is a result of different treatment approaches, methods for dealing with biomass, overall efficiency and availability of labor resources, and whether re-vegetation work is included in the project. Thus, the average cost per acre for removal should be used cautiously, especially for smaller projects where fixed management costs are not amortized over many acres. An *Arundo* removal project typically is budgeted for 5 years and includes initial reduction or removal of biomass, followed by annual visits to treat regrowth aggressively. Smaller infestation can be treated and left in place. Up-front permitting and post-control follow-up work are essential and are included in our per-acre cost estimate. Expenses are front-loaded with large equipment usually being needed in the first year for biomass reduction (mowing) or removal (cutting, hauling and chipping) and large-scale treatment. Nearly all large-scale projects use multiple methods as determined by site access and stand size. To date, we know of no accounts of successful *Arundo* control conducted at scale (> 10 acres) that do not utilize both chemical and mechanical tools. Mechanical techniques such as grading, scraping, and tilling, are dangerously counterproductive because they dislodge and fragment rhizomes leading to dispersal during flood events (e.g., Simoes 2014).

8.1.2 Cost of Biological Control

In addition to direct control using mechanical and chemical tools, biological control agents could in the future reduce *Arundo* cover at enough sites to reduce the cost of control somewhat (see Chapter 2). Currently, a stem-feeding shoot fly, a stem-boring wasp, and a scale are all found locally in California feeding on *Arundo*. Although preliminary results from Texas are promising, these biocontrol agents are currently neither widespread nor damaging enough to reduce *Arundo* stands noticeably.

The development of biological control agents cost millions of dollars and typically takes decades of development. It requires foreign exploration, host-specificity testing in quarantine labs, a long approval process, and, finally an establishment phase in the field that can take years. It is important to also note that *Arundo* would not be eliminated from systems but would continue to exist at lower cane densities and heights. Biocontrol agents would stress stands but not eradicated them. *Arundo* does not have viable seed, so an entire class of biocontrol agents cannot be used. When successful, biocontrol's benefits are also large and operate at a scale far larger than that of the watershed units described here. For the purposes of this report, we have not included the costs or benefits of biological control of

Arundo beyond reviewing its status, but we are hopeful that it will ultimately help to curb the expansion of this species and reduce the costs of controlling it.

Table 8-1. Estimated cost of *Arundo* control by watershed unit.

Watershed Unit (north to south)	**Acres**[1]	**Cost of Control**
Sac. River Headwaters: Castle-Stillwater Creeks	17	$588,000
Cottonwood Creek	5	$175,000
Elder Creek	76	$2,647,750
Sac. River Upper: Cottonwood to Thomes Creeks	154	$5,390,000
Antelope-Mill Creek	14	$490,000
Thomes Creek	71	$2,467,500
Stony Creek	556	$19,473,300
Feather River-Chico-Butte Creeks	62	$2,180,500
Sac River Middle: Stony to Cache Creek	151	$5,301,450
Colusa Trough-Stone Corral-Freshwater Creeks	94	$3,300,500
Bear-Yuba River	44	$1,540,000
Cache-Putah Creeks	239	$8,356,600
Sac. River Lower: Cache to Putah Creeks	1	$35,000
American-Mokelumne Rivers-Deer Creek	28	$974,400
Ulatis Creek	78	$2,716,000
Los Banos-Panoche-Salado Creeks-San Joaquin River	55	$1,933,750
Calaveras River	28	$970,200
Stanislaus-Tuolumne Rivers	36	$1,260,000
Bear Creek-Merced River	39	$1,351,350
Chowchilla-Fresno Rivers	60	$2,093,000
San Joaquin River	57	$1,995,000
Tulare Lake-Los Gatos Creek	8	$280,000
Kings River	86	$3,010,000
Kaweah-Tule River	32	$1,106,700
Kern River	3	$105,000
GRAND TOTAL	**1,993**	$**69,741,000**

[1] Cost is calculated based on the untreated *Arundo* acreage, which is used in benefit calculations as well.

8.2 Benefits

This report has described *Arundo*'s impacts to water, geomorphology, wildfire, and sensitive species. Controlling *Arundo* provides benefit by eliminating these impacts. The sections below monetize the benefits of eliminating *Arundo*'s impacts: reduced water loss in riparian systems, reduced sediment trapping; reduced flood damage; reduced fire damage; and improved habitat for sensitive species.

8.2.1 Benefit from Reducing Impacts on Water

Water is the most fought-over resource the Central Valley. Water use by *Arundo* in the Central Valley was estimated in Chapter 4, and totals between 30,786 and 34,758 acre-feet/year (the lower figure just includes *Arundo* that shows no signs of treatment to date, the larger figure includes all mapped *Arundo*). The calculated water savings from *Arundo* control, though less than that estimated for coastal southern California, are significant. As a comparison, Central Valley food crops utilize between 2-4 acre-feet/year/acre, native riparian vegetation utilizes 4 acre-feet/year/acre under wet conditions, and *Arundo*, in wet conditions, will utilize 19.4 acre-feet/year/acre. We assume that areas where *Arundo* is removed are replaced with native vegetation, resulting in a net savings of 15.4 acre-feet/year/acre.

Water saved by controlling *Arundo* becomes available for other uses. It may improve wildlife habitat, especially for endangered salmon, steelhead, and other fish, and support recreation, agriculture, and municipal needs. Reduced water consumption and reduced channeling from *Arundo* (which can also increase rates of groundwater recharge) helps provide a more resilient long-term water resource for agriculture and municipal use.

Putting a monetary value on water saved by *Arundo* control in each watershed would ideally mean assessing the all benefits generated by the saved water in that location. For this study we do not attempt to make such a location-specific valuation but rather use a flat cost of $50 per acre-foot of water saved as was done in the 2011 *Arundo* Impacts Study. Water for Central Valley agriculture is highly subsidized, with producers typically paying $40 to $75 per acre-foot, though City of Los Angeles offered Sacramento Valley Rice Farmers as much as $700 per acre-foot for their water in 2017 during a drought. As a comparison, residential customers in Sacramento pay close to $1,000 per acre-foot and those for the South Bay area pay over $2000 per acre-foot for potable water. Our estimate value is in line with previous studies on *Arundo* control (e.g., Seawright, 2009, who valued water at $50-$200 per acre foot) and, if anything undervalues the future cost of this limited resource.

To estimate the water savings of *Arundo* in each watershed, we multiplied the acreage of *Arundo* by $50/acre-foot and then multiplied by 20 years (Table 8-2). To be conservative in our calculations, we used the minimum acreage recorded, not counting *Arundo* acreage that had evidence of past treatment. This benefit totals $29 million in savings across the region.

8.2.2 Benefit from Reducing Impacts on Geomorphology

As outlined in Chapter 5, *Arundo* impacts the geomorphology of waterways. In particular, its impacts on flow conveyance increase flood damage, and its propensity for promoting bank failure can seriously damage levee walls and other infrastructure, such as downstream bridges.

Dense *Arundo* stands reduce flow conveyance significantly. They do this by directly impeding flow, reducing conveyance (filling part of the stream profile) and by trapping sediments that raise floodplains. *Arundo* slows waterflow which reduces sediment transport, particularly in low-gradient

Table 8-2. Estimated 20-year benefit from reducing impact to water by controlling *Arundo*.

Watershed Units (north to south)	**Annual Water Savings**[1] ***(acre-feet/year/acre)***	**20-Year Benefit**[2] ***(@ $50/ac ft)***
Sac River Headwaters: Castle-Stillwater Creeks	259	$258,720
Cottonwood Creek	77	$77,000
Elder Creek	1165	$1,165,010
Sac River Upper: Cottonwood to Thomes Creeks	2372	$2,371,600
Antelope-Mill Creek	216	$215,600
Thomes Creek	1086	$1,085,700
Stony Creek	8568	$8,568,252
Feather River-Chico-Butte Creeks	959	$959,420
Sac River Middle: Stony to Cache Creeks	2333	$2,332,638
Colusa Trough-Stone Corral-Freshwater Creeks	1452	$1,452,220
Bear-Yuba River	678	$677,600
Cache-Putah Creeks	3677	$3,676,904
Sac River Lower: Cache to Putah Creeks	15	$15,400
American-Mokelumne Rivers-Deer Creek	429	$428,736
Ulatis Creek	1195	$1,195,040
Los Banos-Panoche-Salado Creeks-San Joaquin River	851	$850,850
Calaveras River	427	$426,888
Stanislaus-Tuolumne Rivers	554	$554,400
Bear Creek-Merced River	595	$594,594
Chowchilla-Fresno Rivers	921	$920,920
San Joaquin River	878	$877,800
Tulare Lake-Los Gatos Creek	123	$123,200
Kings River	1324	$1,324,400
Kaweah-Tule River	487	$486,948
Kern River	46	$46,200
TOTAL	**30,686**	**$30,686,040**

[1] Estimated increase in per area water use by *Arundo* relative to native riparian vegetation, based on only untreated acres mapped to be conservative.

[2] Estimated per acre cost of water using $50/acre-foot.

areas where *Arundo* cover is high (>40%). Localized sediment trapping occurs in portions of these highly invaded reaches, resulting in a loss of flow conveyance. Channelized systems frequently have large stands of *Arundo* on their bank faces. These stands diminish the flow capacity of the engineered structure, leading to over bank flows (flooding) during high flow events. For example, in extreme situations with large dense *Arundo* stands on both banks (filling a large portion of the stream profile), an engineered channel might fail (over bank flows) during a 50-year event, when it was designed to function in a 100-year event.

Many Central Valley areas are highly urbanized or have large-scale agricultural operations. Where significant infrastructure is present and areas are managed for flood risk, agencies (particularly USACE, municipalities, and counties) may be forced to undertake sediment removal and vegetation clearing to maintain flow conveyance.

For example, levees on the San Luis Rey River in southern California were designed to contain flows from a 120-year flood event. *Arundo* growth reduced the capacity of the levees to being able to contain only a 90-year event (USACE pers. comm. 2009). This can result in areas being designated as "high flood risk" which raises insurance costs (or areas can even be designated as "uninsurable") and lowers property values. When sediment removal and vegetation clearing are not permitted or are considered too costly, the alternative is building new levees or increasing existing levee heights. Along both the Santa Margarita River and the San Luis Rey River, modification or installation of levee structures and vegetation clearing programs have been necessary to maintain flow conveyance. Likewise, the Salinas River has had channel maintenance activities undertaken to reduce flood risk and bank or bridge failure (discussed in the following section).

River systems in the Central Valley, including the extensive network of man-made canals (approximately 18,000 miles in the region per our GIS—see Chapter 3 for sources), also require extensive management, and these management needs will increase as *Arundo* spreads further. The cost of implementing sediment removal and vegetation clearing is high, including not just the removal work itself but also the work to obtain complicated regulatory clearance and the mitigation for impacts to habitat. The costs for alternative activities, such as increasing levee heights or constructing new levees, are typically even higher and are not included here. Vegetation clearing activities are not *Arundo* control, most programs merely reduce or cut above ground biomass. It is repeated periodically indefinitely.

As described in Chapter 5, *Arundo*'s relatively shallow roots and heavy biomass can contribute to bank failure, which results in clumps of *Arundo* floating downstream. When these lodge against infrastructure, such as a bridge, power poles, sewer, gas, and water lines, the force of water against the obstruction can cause significant damage to infrastructure. Rather than trying to estimate a cost for this impact, we focus on estimating a cost for reduced maintenance need.

We have not found specific cost valuation data for the costs of levee maintenance over time, but the Public Policy Institute of California (2017) estimates that the gap in funding alone is $800 million to $1 billion annually. We use the lower figure as an estimate for the total cost of maintenance of man-made waterways across the region. This is conservative for two reason: first, the figure represents only the gap in funding, and assuming that there is some level of funding currently going toward this maintenance, the total costs are even higher, and second, the figure does not include maintenance needs for irrigation canals. (Table 8-3 shows miles of man-made waterways—mainly irrigation canals for agriculture—in each watershed unit.) We estimate that *Arundo* infests 1% of Central Valley waterways, so the cost of maintaining flood management for these waterways is 1% × $800 million = $8 million/year.

How much does Arundo affect this maintenance expense? Spencer et al. (2013) modeled the impact of *Arundo* infestations on flooding and estimate that *Arundo* increases flooded area between 10% and 19%. Thus, for our assessment, we assume that *Arundo* increases maintenance expense by 10%, or

$800,000/year. Over 20 years this potential savings amounts to $16 million. We allocate this by watershed unit in proportion to the number of *Arundo* stands in the watershed unit over 0.5 acres in size.

Table 8-3. Estimated 20-year benefit from reducing impact to geomorphology by controlling *Arundo*.

Watershed Units (north to south)	**Canals**[1] (miles)	**Stands >0.5 acre**	**20-Year Benefit**
Sac River Headwaters: Castle-Stillwater Creeks	370	1	$25,932
Cottonwood Creek	29	0	$0
Elder Creek	35	32	$829,822
Sac River Upper: Cottonwood to Thomes Creeks	2	31	$803,890
Antelope-Mill Creek	10	2	$51,864
Thomes Creek	71	22	$570,502
Stony Creek	351	185	$4,797,407
Feather River-Chico-Butte Creeks	1,992	20	$518,639
Sac River Middle: Stony to Cache Creeks	8	49	$1,270,665
Colusa Trough-Stone Corral-Freshwater Creeks	703	24	$622,366
Bear-Yuba River	489	9	$233,387
Cache-Putah Creeks	587	55	$1,426,256
Sac River Lower: Cache to Putah Creeks	35	1	$25,932
American-Mokelumne Rivers-Deer Creek	1,657	7	$181,524
Ulatis Creek	1,238	12	$311,183
Los Banos-Panoche-Salado Creeks-San Joaquin	2,293	13	$337,115
Calaveras River	862	5	$129,660
Stanislaus-Tuolumne Rivers	771	10	$259,319
Bear Creek-Merced River	329	7	$181,524
Chowchilla-Fresno Rivers	506	78	$2,022,690
San Joaquin River	712	16	$414,911
Tulare Lake-Los Gatos Creek	567	0	$0
Kings River	892	32	$829,822
Kaweah-Tule River	2,907	6	$155,592
Kern River	614	0	$0
TOTAL	**18,029**	**617**	**$16,000,000**

[1] Canal miles are shown for informational purposes only; they are not included in estimate of benefit.

8.2.3 Benefit from Reducing Impacts on Fire

In Chapter 6 we reviewed the potential impacts of *Arundo* on wildfire in the Central Valley. Because wildfires on private agricultural lands and in city jurisdictions are not consistently reported to the state database (CALFIRE), the available data is not comprehensive. We are limited to making assumptions in order to estimate the impact of *Arundo* on wildfire (and thus the benefit of reducing wildfire damage by controlling *Arundo*). Yet we know from other regions, first-hand observations in the Central Valley, and incidental reports, that *Arundo* stands provide ignition locations (e.g., through campfires) and highly flashy fuels that carry fires where they would otherwise not spread.

Gerbert et al. (2007) estimated that the cost of fire suppression of larger wildfires (>100 acre) averaged $2114/acre. They found that costs per acre changed inversely to fire size and that the value of structures within 20 miles strongly affected the cost of suppression. The costs of small wildfires are not captured here and are significantly higher on a per acre basis because small acreage bears the entire mobilization cost of a fire response crew. Since the time of the 2007 study, costs have also risen dramatically.

The fire impact scores derived in Chapter 6 were based on the amount of *Arundo* found in each watershed unit, the number of *Arundo* patches that were greater than 0.5 acres, and the historic number of fires known from that watershed unit that overlap with *Arundo* stands.

We use a per acre approach to estimation modified from Cal-IPC (2011) to conservatively monetize the fire-related benefits of *Arundo* control. For small fires that start in *Arundo* stands, we monetize the benefits of both reduced fire-fighting costs and reduced damage to riparian habitat. The prior coastal study also monetized the benefit of reduced damage to acres of *Arundo*-invaded riparian habitat expected to burn in larger wildfires started elsewhere that burn through riparian habitat. For this study, we do not assess this benefit because most Central Valley *Arundo* infestations occur in the midst of agricultural land that is much less prone to landscape-level wildfires than the chaparral, coastal sage scrub, and urban development bordering many southern California coastal rivers. However, we do factor in the higher cost of fire response due to the high probability that manmade structures will be nearby.

For fire response mobilization and suppression, we use a cost of $50,000 per fire event. We estimate the number of events over a 20-year period for each watershed based on the number of *Arundo* stands larger than 0.5 acre found in the watershed unit. From the fire history 1970-2008 there were 47 recorded fires, or 1.2 fires per year, in *Arundo* across the Central Valley. We assume that this is an undercount by a factor of ten, since most small local fires outside State Responsibility Areas do not make it into the CALFIRE database. Thus, we estimate that an additional 12 fires triggering fire response occur in the Central Valley per year, or 240 fires over 20 years, as a result of *Arundo*. These fires are allocated among the watershed units based on the number on stands over 0.5 acres.

Wildfires starting in *Arundo*-dominated habitat are assumed to stay relatively small because of the non-contiguous nature of most flammable vegetation in the agricultural reaches of the Central Valley. We assume each fire event burns two acres of *Arundo*-dominated riparian habitat, valued at $20,000 per acre, and two acres of uninvaded riparian habitat, valued at $80,000 per acre. These values are based on mitigation costs associated with restoring riparian habitat, excluding easements and land purchase (Cal-IPC 2011). We assume that fire degrades these habitats for a period of ten years, half of our 20-year time horizon for estimating benefits, so we use 50% of the full value of the habitat. Thus, habitat damage is $50,000 per fire event. Overall the acres of *Arundo* represented by these fires is approximately 20% of the current *Arundo* mapped in the Central Valley, so our assumption amounts to an estimate that 20% of the region's *Arundo* will burn over a 20-year period (though an area could burn more than once).

In total, the benefit of reducing *Arundo*-initiated fires by controlling all *Arundo* in the Central Valley was estimated at $36 million over 20 years.

Table 8-4. Estimated 20-year benefit from reducing impact to fire by controlling *Arundo*.

Watershed Units (north to south)	**Stands >0.5 acre**	**Fewer fires**	**Response Benefit**	**Habitat Benefit**	**Total Benefit**
Sac. River Headwaters: Castle-Stillwater Creeks	1	0.4	$19,449	$38,898	$58,347
Cottonwood Creek	0	0.0	$ -	$ -	$ -
Elder Creek	32	12.4	$622,366	$1,244,733	$1,867,099
Sac. River Upper: Cottonwood to Thomes	31	12.1	$602,917	$1,205,835	$1,808,752
Antelope-Mill Creek	2	0.8	$38,898	$77,796	$116,694
Thomes Creek	22	8.6	$427,877	$855,754	$1,283,630
Stony Creek	185	72.0	$3,598,055	$7,196,110	$10,794,165
Feather River-Chico-Butte Creeks	20	7.8	$388,979	$777,958	$1,166,937
Sac. River Middle: Stony to Cache Creek	49	19.1	$952,998	$1,905,997	$2,858,995
Colusa Trough-Stone Corral-Freshwater Creeks	24	9.3	$466,775	$933,549	$1,400,324
Bear-Yuba River	9	3.5	$175,041	$350,081	$525,122
Cache-Putah Creeks	55	21.4	$1,069,692	$2,139,384	$3,209,076
Sac. River Lower: Cache to Putah Creeks	1	0.4	$19,449	$38,898	$58,347
American-Mokelumne Rivers-Deer Creek	7	2.7	$136,143	$272,285	$408,428
Ulatis Creek	12	4.7	$233,387	$466,775	$700,162
Los Banos-Panoche-Salado Creeks-San Joaquin River	13	5.1	$252,836	$505,673	$758,509
Calaveras River	5	1.9	$97,245	$194,489	$291,734
Stanislaus-Tuolumne Rivers	10	3.9	$194,489	$388,979	$583,468
Bear Creek-Merced River	7	2.7	$136,143	$272,285	$408,428
Chowchilla-Fresno Rivers	78	30.3	$1,517,018	$3,034,036	$4,551,053
San Joaquin River	16	6.2	$311,183	$622,366	$933,549
Tulare Lake-Los Gatos Creek	0	0.0	$ -	$ -	$ -
Kings River	32	12.4	$622,366	$1,244,733	$1,867,099
Kaweah-Tule River	6	2.3	$116,694	$233,387	$350,081
Kern River	0	0.0	$ -	$ -	$ -
TOTAL	**617**	**240.0**	**$12,000,000**	**$24,000,000**	**$36,000,000**

8.2.4 Benefit from Reducing Impact on Sensitive Species

Chapter 7 described the impacts to each of 24 sensitive species. These impacts are more difficult to monetize than abiotic impacts like loss of water or damage to infrastructure. Ideally the cost would be based on the summed cost of protecting these 24 species over a 20 year period, adjusted for the impact of *Arundo* estimated for each. Unfortunately, we do not have the data available to make these cost estimates. So, instead we value the habitat that they occur in. In the previous section, we valued uninvaded riparian habitat at $80,000/acre and *Arundo*-dominated riparian habitat at $20,000/acre based on the estimated value of riparian habitat for mitigation required to compensate for development elsewhere. This would suggest a habitat improvement value of $60,000/acre for controlling *Arundo*. However, to be conservative, we will adopt a value of $15,000/acre. This lower value accounts for the fact that not all acres of *Arundo* in the Central Valley are situated in prime riparian habitat and the recognition that mitigation values are not realistic to extend across broad regions. We use total acres, including treated *Arundo*, since unless it is physically removed it will continue to impact habitat.

The benefit per watershed is shown in Table 8-5. The total 20-year benefit calculated for reducing impacts on sensitive species is estimated to be approximately $34 million.

Table 8-5. Estimated 20-year benefit from reducing impact to sensitive species by controlling *Arundo*.

Watershed Units (north to south)	***Arundo* Acres**	**Habitat Benefit**[1]
Sac. River Headwaters: Castle-Stillwater Creeks	24	$360,000
Cottonwood Creek	5	$75,000
Elder Creek	85	$1,275,000
Sac. River Upper: Cottonwood to Thomes	154	$2,310,000
Antelope-Mill Creek	14	$210,000
Thomes Creek	75	$1,125,000
Stony Creek	562	$8,430,000
Feather River-Chico-Butte Creeks	70	$1,050,000
Sac. River Middle: Stony to Cache Creek	153	$2,295,000
Colusa Trough-Stone Corral-Freshwater Creeks	115	$1,725,000
Bear-Yuba River	44	$660,000
Cache-Putah Creeks	254	$3,810,000
Sac. River Lower: Cache to Putah Creeks	1	$15,000
American-Mokelumne Rivers-Deer Creek	29	$435,000
Ulatis Creek	80	$1,200,000
Los Banos-Panoche-Salado Creeks-San Joaquin River	65	$975,000
Calaveras River	28	$420,000
Stanislaus-Tuolumne Rivers	36	$540,000
Bear Creek-Merced River	39	$585,000
Chowchilla-Fresno Rivers	230	$3,450,000
San Joaquin River	57	$855,000
Tulare Lake-Los Gatos Creek	8	$120,000
Kings River	91	$1,365,000
Kaweah-Tule River	34	$510,000
Kern River	4	$60,000
TOTAL	**2,256**	$33,855,000

[1] Habitat benefit valued at $15,000 per acre of *Arundo* controlled.

8.3 Benefit-to-Cost Ratio

Table 8-6 compiles the benefits for each watershed unit from *Arundo* control on reducing impacts to water, geomorphology, fire and sensitive species. The total benefit of controlling *Arundo* across the Central Valley is estimated at $115 million over 20 years. We endeavored to use conservative estimates for each factor.

The table also compiles the cost of *Arundo* control in each watershed unit, and derives a benefit-to-cost ration for each watershed unit. These vary from 0.9 to 1.9 (excluding the outlier value of 3.3 for the very small infestation on the Sacramento River Lower: Cache to Putah Creeks watershed unit). Overall for the entire Central Valley our calculations result in a benefit-to-cost ratio of 1.7:1.

Our previous study in southern California coastal waterways arrived at an approximate benefit-to-cost ratio of 1.9:1 (Cal-IPC 2011). In part this is due to a higher benefit to sensitive species in that region than in the Central Valley and a higher probability of large fires associated with larger contiguous *Arundo* stands and adjacent upland vegetation. There are also a greater number of smaller populations in the Central Valley, while many of the coastal waterways have semi-continuous bands of *Arundo* along them.

As mentioned at the beginning of the chapter, monetizing the benefits of *Arundo* control is inexact, and additional efforts to establish a standard methodology would be useful. In addition, costs of uncommon, catastrophic events, such as rare, large wildfires or 100-year floods, and long-term changes in riparian function are difficult to capture in cost estimates.

Table 8-6. Estimated 20-year benefits and cost from *Arundo* control.

Watershed Unit (north to south)	**Benefit Water**	**Benefit Geo.**	**Benefit Fire**	**Benefit Sens. Spp.**	**Benefit Total**	**Control Cost**	**Benefit-to-Cost**
Sac. River Headwaters: Castle-Stillwater Creeks	$258,720	$25,932	$58,347	$360,000	$702,999	$588,000	1.2
Cottonwood Creek	$77,000	-	-	$75,000	$152,000	$175,000	0.9
Elder Creek	$1,165,010	$829,822	$1,867,099	$1,275,000	$5,136,931	$2,647,750	1.9
Sac. River Upper: Cottonwood to Thomes	$2,371,600	$803,890	$1,808,752	$2,310,000	$7,294,242	$5,390,000	1.4
Antelope-Mill Creek	$215,600	$51,864	$116,694	$210,000	$594,158	$490,000	1.2
Thomes Creek	$1,085,700	$570,502	$1,283,630	$1,125,000	$4,064,832	$2,467,500	1.6
Stony Creek	$8,568,252	$4,797,407	$10,794,165	$8,430,000	$32,589,824	$19,473,300	1.7
Feather River-Chico-Butte Creeks	$959,420	$518,639	$1,166,937	$1,050,000	$3,694,996	$2,180,500	1.7
Sac. River Middle: Stony to Cache Creek	$2,332,638	$1,270,665	$2,858,995	$2,295,000	$8,757,298	$5,301,450	1.7
Colusa Trough-Stone Corral-Freshwater Creeks	$1,452,220	$622,366	$1,400,324	$1,725,000	$5,199,910	$3,300,500	1.6
Bear-Yuba River	$677,600	$233,387	$525,122	$660,000	$2,096,109	$1,540,000	1.4
Cache-Putah Creeks	$3,676,904	$1,426,256	$3,209,076	$3,810,000	$12,122,236	$8,356,600	1.5
Sac. River Lower: Cache to Putah Creeks	$15,400	$25,932	$58,347	$15,000	$114,679	$35,000	3.3
American-Mokelumne Rivers-Deer Creek	$428,736	$181,524	$408,428	$435,000	$1,453,688	$974,400	1.5
Ulatis Creek	$1,195,040	$311,183	$700,162	$1,200,000	$3,406,385	$2,716,000	1.3
Los Banos-Panoche-Salado Creeks-San Joaquin River	$850,850	$337,115	$758,509	$975,000	$2,921,474	$1,933,750	1.5
Calaveras River	$426,888	$129,660	$291,734	$420,000	$1,268,282	$970,200	1.3
Stanislaus-Tuolumne Rivers	$554,400	$259,319	$583,468	$540,000	$1,937,187	$1,260,000	1.5
Bear Creek-Merced River	$594,594	$181,524	$408,428	$585,000	$1,769,546	$1,351,350	1.3
Chowchilla-Fresno Rivers	$920,920	$2,022,690	$4,551,053	$3,450,000	$10,944,663	$2,093,000	5.2
San Joaquin River	$877,800	$414,911	$933,549	$855,000	$3,081,260	$1,995,000	1.5
Tulare Lake-Los Gatos Creek	$123,200	-	-	$120,000	$243,200	$280,000	0.9
Kings River	$1,324,400	$829,822	$1,867,099	$1,365,000	$5,386,321	$3,010,000	1.8
Kaweah-Tule River	$486,948	$155,592	$350,081	$510,000	$1,502,621	$1,106,700	1.4
Kern River	$46,200	-	-	$60,000	$106,200	$105,000	1.0
TOTAL	**$30,686,040**	**$16,000,000**	**$36,000,000**	**$33,855,000**	**$115,216,640**	**$69,741,000**	**1.7**

9 MANAGEMENT RECOMMENDATIONS

9.1 Recommendations for Watershed-Based *Arundo* Control Programs

9.1.1 General Recommendations

Arundo is reliant on asexual propagation, typically spreading from rhizome fragments. Accordingly control programs that start at the top of watersheds are more efficient and effective over the long-term. An optimal watershed-based program starts on the upper reaches of a watershed and proceeds downstream, controlling all populations along the way. A 'top-down' approach is more critical on watersheds with large *Arundo* acreage (>50 acres), where a program consists of many separate projects or phases. Initiating control in the middle or lower portion of a watershed, when significant *Arundo* is upstream that can disperse in a large flood event, is a situation to be avoided when possible.

Real-world conditions may require modification of the ideal 'top-down' treatment approach in some situations. This can happen, for instance, when middle or lower watershed areas have a commitment from an entity to carry on long-term maintenance (such as an NGO, or a public entity). Many programs start on heavily invaded middle portions of a watershed, and then address scattered upstream infestations in a later program phase. Watersheds with lower *Arundo* acreage can be initiated in a more haphazard fashion, as the risk of material dispersing downstream into treated areas is lower. The key to a successful *Arundo* program is that it develops a strategy to address all *Arundo* on the watershed. Partial work in a watershed—especially low in a watershed—only makes sense if there is a strong expectation that the next phase will be able to be implemented.

All *Arundo* on rivers, streams, canals, or other wetland hydrologically connected to the watershed system should be controlled. If rhizome material can be dispersed downstream, that source should be controlled. Some programs do not control scattered infestations that are found away from waterways, since these are less likely to spread. Ideally control efforts will target these populations as well since any material is a potential source of propagules. Contaminated soil (fill) and/or yard waste that is disposed of improperly, such as dumping or filling in creeks or waste areas, are a pathway of spread and reintroduction.

Once all *Arundo* in a given watershed has been controlled and eradication achieved there is still a need to remain alert for new introductions that can occur from other watersheds via contaminated fill, yard waste, or intentional planting. (Planting *Arundo* is illegal since the plant is listed by the California Dept. of Food & Agriculture as a noxious weed, but this is not known by everyone and enforcement is limited.)

To summarize, the general goals of watershed-based control programs should be the following, with site-specific exceptions. Good distribution data is available for all Central Valley watersheds (data from this project). The data provided with this report is currently accurate and will remain useful for quite some time (for at least 10-20 years). *Arundo* spreads to new areas episodically, following large flood events. Even in these situations, most *Arundo* stands remain where they are with scattered new locations popping up where rhizomes are dispersed. For general planning, the current data set is more than sufficient. For detailed planning, project specific verification should be carried out, for instance, to clarify property ownership or develop budgets and determine site appropriate control methods.

Control programs should attempt to achieve eradication of all *Arundo* on entire watersheds, because this is the most efficient use of limited resources. Control programs should begin *Arundo* removal in upper watershed areas and proceed downstream. This is most important in large, highly invaded watersheds that may require a decade or more to carry out implementation. Populations in small watersheds, or in large watersheds with little acreage of *Arundo*, can be controlled in any order if everything is controlled within a relatively short timeframe that reduces the risk of *Arundo* spread.

Removal efforts in large watersheds will need to break implementation into a series of phased control projects, each tackling a defined sub-section of the overall watershed. The program still ideally begins in the upper reaches and proceeds to middle and then lower sub-sections but within a sub-section control may occur "out of order" if there are benefits to doing so, for instance, to create a fuel break.

Programs should strive to achieve 100% control within project areas. This is a difficult objective and requires long-term commitment and substantial tracking. Most *Arundo* is controlled after 5–10 years of work, but new re-sprouts may still be found, particularly if project areas are large. Areas need to be checked and re-treated for 20 years to assure 100% control. Control and surveying may occur at three-year intervals for older project areas.

Some watersheds may have high-value habitat areas where *Arundo* may be controlled before the larger program has reached the area, even though significant untreated *Arundo* remains upstream. This scenario typically occurs in a situation where a land management entity (NGO, land conservancy, or public agency) has a requirement to maintain a portion of a river for mitigation or biological function. Projects/managing entities should budget for periodic treatment of new *Arundo* invasion into such areas. Re-invasion is most likely after large flow events, so any such events should trigger subsequent resurveying and treatment.

Wildfires remove *Arundo* biomass, the most complicated and expensive component of *Arundo* control programs. Accordingly, the first year or two after a fire offers an excellent opportunity for *Arundo* control. Biomass reduction is often the most expensive component of a control project so there can be significant cost savings. In addition, thickly infested areas can be much more accessible than they were before the fire event. Vegetation quickly regrows after the fire event, so this opportunity should be acted on in the first year. Typically, by year three after a fire the opportunity has passed, or gotten worse, as most vegetation has re-sprouted and filled back in up to a height of 8 to 20 feet.

9.1.2 Lead Entity

For a watershed-based control program to succeed it typically needs either a single lead entity or an organization that brings together and coordinates with multiple partners. Larger watersheds without a lead entity or formal coordination have been unable to implement meaningful watershed-based *Arundo* control. There are five main functions that a program lead fills: securing and administering funds via grants; obtaining and holding necessary permits; contracting with firms that can perform removal tasks; securing long-term access permission to properties where *Arundo* is found; and tracking *Arundo* over the long term. Inability to perform any one of these roles is a significant problem. Groups that are not allowed to receive public funds, hold CEQA and other permits, obtain landowner right of entry agreements (ROEs), or garner broad support among watershed stakeholders should not attempt to lead watershed based *Arundo* removal projects. Control programs on watersheds with more than 50 acres of *Arundo*, or *Arundo* on more than 100 properties, will likely only succeed with a strong lead entity.

Resource Conservation Districts (RCDs) have the right mix of capabilities to be a lead entity and many RCDs have lead watershed based *Arundo* control in the state. Only some RCDs in the Central Valley region have sufficient overall capacity to build and manage large watershed-based programs. Most of these larger stable RCDs are in the Sacramento Valley, but even here they cover about half of the valley. RCDs in most of San Joaquin and part of Sacramento Valley are small operations and do not have experience with major projects of this scale. Some areas have no active RCD at all. RCDs are usually county based, but some have much smaller district boundaries (see Figure 9-1).

County Agricultural Commissioner offices (CACs or County Ag Departments) may also have the appropriate suite of capabilities to run a watershed-based control program, but they are typically underfunded for this broad range of responsibilities. Completing the regulatory process, securing all Right of Entry agreements (ROEs), hiring and managing contractors doing the work, and securing competitive grants requires significant time and focus. Leading a large watershed-scale program is a big challenge for any CAC. There have been a few mid-size watershed-based programs, but County Ag Departments have typically been better suited to leading smaller programs or being a partner in a larger program. County Ag Departments are very well suited to assisting with long term retreatments. County Ag Departments are always county based geographically and holding ROEs or working in adjacent counties can be difficult or even prohibited.

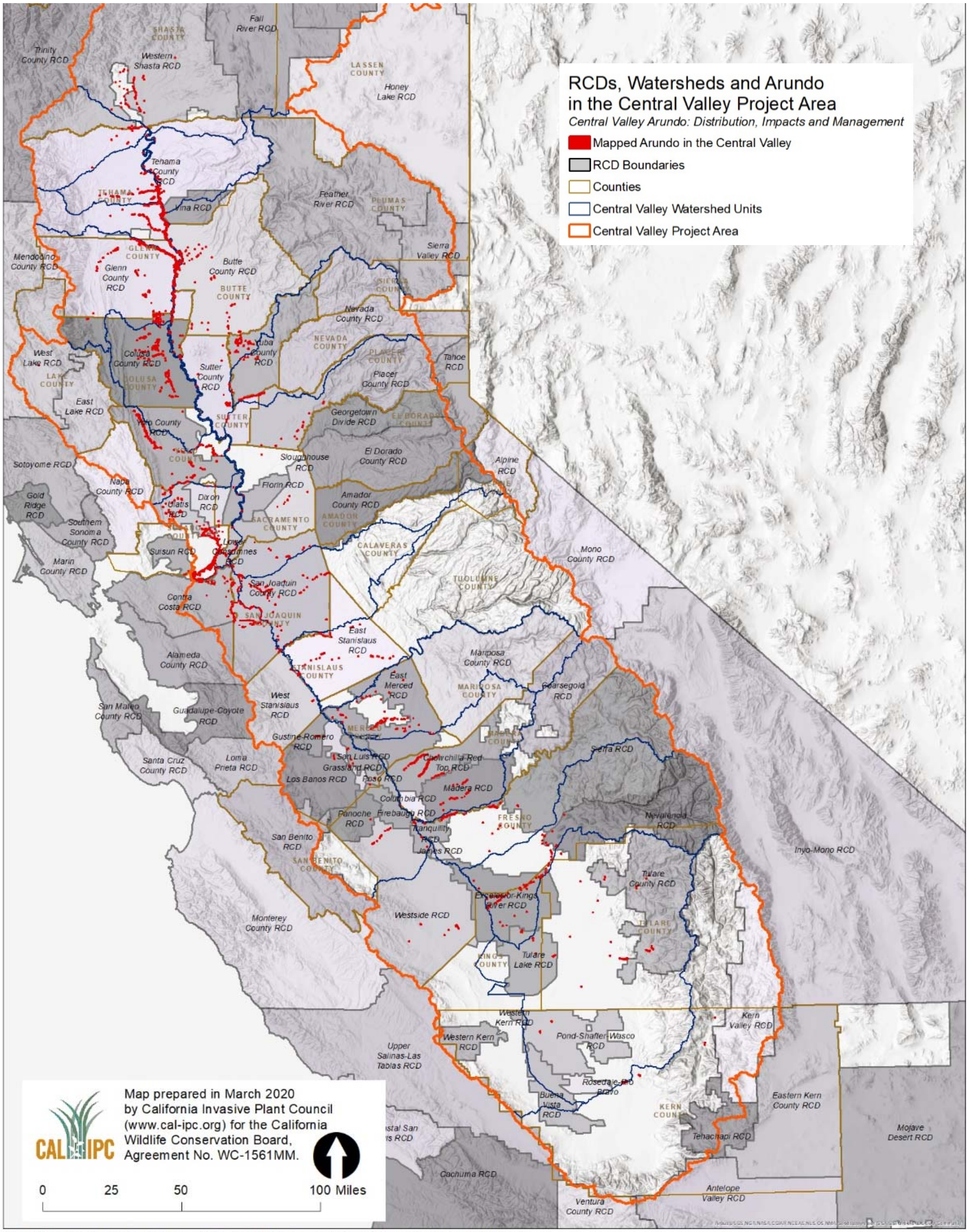

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Figure 9-1. RCD boundaries in relation to watershed units and counties.

Large well-established non-government organizations (NGOs) can serve as a program lead coordinator, but they do need a government entity to serve as the lead agency for CEQA permitting. There are multiple examples of large to small programs being managed by NPOs. A long-term commitment, and extensive restoration, grant and regulatory experience are needed. NPOs may have less restrictive geographic boundaries, which can be a benefit in some situations. In the San Joaquin Valley, the notable lead is River Partners, an NGO which has been controlling *Arundo* along the San Joaquin River and tributaries since 2010. They have successfully controlled a significant portion of the *Arundo* present, but they have not been able to implement a full watershed-wide approach as they have focused on public lands and not obtaining ROEs for work on private land. Building on their success to date is one of the promising paths forward. Partnership with the San Joaquin River Conservancy or an active RCD may be a way to leverage increased private property participation.

The watersheds in the Central Valley are large, and in many cases a single RCD or CAC does not cover the entire infestation in a watershed. This poses a need for cooperation between multiple RCDs or CACs which can be an additional challenge.

Both RCDs and CACs work hard to form trusted relationships with local landowners which is essential for implementing *Arundo* removal projects. However, the signed ROEs required by some state grants (like those from WCB) pose a special challenge. Unlike the local relationships, these formal ROEs require signed paperwork giving the entity access to their property over a long timeframe for work related activities. This is can be a hurdle for some property owners.

From our communications with RCDs and CACs across the Central Valley region, it was clear that RCDs were more likely to become program leads. They are not pulled in as many directions as CACs are, with their duties ranging from predator and pathogen control to weights and measures to cannabis. RCDs are focused on protecting natural and agricultural resources through stewardship. What they often lack in capacity they make up for in alignment. Thus, most of the potential watershed program leads we identify are RCDs. CACs will be valuable partners but are unlikely to currently serve as leads in most situations. In the Sacramento Valley Yolo County RCD has initiated an *Arundo* program on the Cache Creek and Putah Creek watersheds (obtaining permits and seeking implementation funding). Western Shasta RCD has also obtained CEQA and has past partner experience. Other RCDs, such as Glenn and Butte RCDs, expect to learn from their experience. Outside of the Central Valley, several RCDs have built programs: Monterey County RCD, Mission RCD (northern San Diego County), and Santa Ana River RCDs. Each of these RCD has received multiple state grants to control thousands of acres of *Arundo* on coastal watersheds. All of these RCDS have obtained access permission for over 95% of landowners for the program areas that they operate in.

9.1.3 Permitting

Watershed programs seeking to control *Arundo* are required to obtain regulatory clearance from multiple agencies. Even though *Arundo* control work restores habitat, saves water and reduces fire risk, the work areas are in sensitive wetland habitat. The regulatory process assures that impacts to habitat, water and potential cultural resources are avoided and minimized. Permits and conditions are highly dependent on the methods being used to control *Arundo*, as well as the specific resources in the program area. Generalized information is presented below for how *Arundo* control programs have fulfilled regulatory obligations. Each project lead will have to navigate this process. There is currently no regional permit covering *Arundo* control work for the Central Valley. In the absence of a programmatic EIR and clear permissions from associated agencies, a program will obtain permits from or consult with:

CEQA: Any on-the-ground implementation project requires CEQA to be completed. This generally results in the preparation and adoption of a Mitigated Negative Declaration (MND). For small projects a Notice of Exemption (NOE) may be prepared and posted. Environmental Impact Reports (EIRs) are rarely required. Completion of an MND can take anywhere from two to twelve months to complete. A NOE can be prepared and posted quickly (under a week). CEQA covers the broadest range of topics from habitat and species protection, to air quality to cultural and tribal resources. CEQA documents donot expire (unless the document preparer sets a self-imposed expiration date), although they can require an amendment if conditions under the original analysis change.

California Dept. of Fish and Wildlife (CDFW) Streambed Alteration Agreement (SAA) 1600: This is nearly always required for *Arundo* control programs, as project work typically occurs in riparian habitat. This process can take two to six months. Typically, CEQA should be completed prior to submitting an application for an SAA. Most watershed programs obtain a "Standard Agreement" for 5 years, and then obtain a 5-year extension. Some programs obtain longer term agreements (10 year), but these require a more extensive review process. A CDFW SAA does not authorize "take" of a sensitive species; any take authorization requires consultation with CESA (see below). CDFW's definition of "take" differs from Federal guidelines and should be reviewed independently.

U.S. Fish and Wildlife Service: A Section 7 consultation (which requires Federal to Federal agency consultation), Section 10 incidental take permit, or a Technical Assistance Letter may be obtained if federally listed species are present in the project area. The Federal definition of "take" should be reviewed and understood by project leads, as it differs from the state definition (CDFW). If take or harassment of listed species is likely to occur, a Section 7/10 is required and this can take six-twelve months (under Section 7, with a federal nexus typically through USACE, USFWS, or NRCS) to several years (Section 10, Habitat Conservation Plan (HCP). In some areas, existing HCPs that contain work authorization for invasives control/restoration could potentially be utilized by *Arundo* programs. However, this approach frequently does not work, as for the Yolo HCP, where the cost structure and procedures in place are not compatible with proposed work. More likely, an HCP analysis would be used in support of issuing a Technical Assistance Letter or in completing Section 7 consultation. If endangered species are present but impacts (take) can be avoided, a Technical Assistance Letter can be used to outline protective measures. This can be completed in one to three months. USFWS consultation and letters do not expire, but the Service could request a revision if current conditions change.

California Endangered Species Act (CESA): The California Department of Fish and Wildlife may require concurrence with agreements and protective measures outlined by the USFWS. If take of a state-listed species cannot be avoided, an Incidental Take Permit may be required. The permit allows a permittee to take a CESA-listed species if such taking is incidental to, and not the purpose of, carrying out an otherwise lawful activity. Permittees must implement species-specific minimization and avoidance measures, and fully mitigate the impacts of the project.

National Marine Fisheries Service: The National Oceanic and Atmospheric Administration (NOAA) may require consultation for marine fish species that migrate into freshwater systems.

Army Corps of Engineers (USACE) 404 Permit: A 404 permit may be required for larger control programs using heavy equipment in waters of the US. Recently, Monterey County was not required to get a permit for their Salinas River program by the San Francisco USACE office. Recent USACE guidance in Southern California has reaffirmed that a 404 permit is not usually needed for mowing vegetation. In Southern California (San Diego County north to San Luis Obispo County) a Regional General Permit (RGP 41) has been issued for control work on *Arundo* and other invasive plants. This permit does not exist for the Central Valley. A nationwide permit would be the likely pathway to follow if USACE required a permit for *Arundo* reduction using mowing equipment in Waters of the US. If a USACE permit is required for a project, a Federal nexus is created, allowing a project to potentially initiate a Section 7 Consultation between USACE as USFWS.

State Water Control Board or Regional Water Quality Control Board (RWQCB) 401 Certification. *Arundo* control programs typically make an assessment if application of herbicides during project activities could result in discharge to water. If discharge could occur programs typically obtain an authorization to work under the Non-point Discharge Permit (NPDES) for invasive plant control. This permit requires public posting of a monitoring program plan, methods and herbicides to be used, and reporting. Once adopted, annual fees are paid, monitoring occurs, and monitoring reports are prepared and submitted for years when treatments occur by open water.

Other permits: Additional project or watershed-specific permits may be required, such as California's Office of Historic Preservation (OHP) notification, Central Valley Flood Protection Board permit or compliance with municipal or county codes and permits.

The number and complexity of regulatory permits for carrying out *Arundo* control makes it imperative that program leads are familiar with navigating the permitting process and can manage permitting requirements competently and efficiently. Given the number of permits that are required for larger programs, it is of substantial benefit if watershed-wide permits can be obtained (as opposed to obtaining multiple permits from the same agency to complete work in phases). *Arundo* control is a long-term process, with projects implementing initial work lasting three to five years and typically taking an additional 10-15 years of re-treatments.

In general, the goals are to obtain program permits that (1) cover the broadest geographic area possible, such as watershed-wide or county-wide permits, (2) cover the longest time period possible, and (3) cover all methods that could be used for *Arundo* control as appropriate for your program.

Programs on larger systems with significant *Arundo* acreage may take 10-20 years to complete all initial control. For this reason, obtaining the longest duration permits (particularly for CDFW 1600) is the most efficient use of resources.

Funding agencies frequently will not fund projects that have permitting "in process" or projects that expect to obtain permits after being awarded funding. Having approved and active permits in place from all required regulatory agencies is a primary indicator of a program's ability to execute work on a timetable for a specific project. However, this can pose a significant burden on local entities that have little funding to put toward this first step so planning grants are helpful. At a minimum, CEQA must be completed for state-funded projects.

9.1.4 Property Access

Property access is critical for *Arundo* control efforts. Access is needed not only for initial control but also for ongoing retreatments to ensure all *Arundo* is eradicated. Agencies owning public lands are typically willing partners. Private landowners, however, can be more complicated. Most private landowners ultimately grant access for project work (>90% for established programs). Many property owners immediately grant permission, as it is work being done at no cost to them, and it is being done legally (with permits). But many landowners are initially skeptical of outside entry to their land. In many areas of the Central Valley, RCDs and CACs have gained enough trust over time to get individual landowner permission to enter their property to implement weed abatement if it's important. However, this permission is not always documented on paper, it is based on verbal authorization.

Undertaking a project with state funds presents requirements for documenting landowner permission, typically a Right of Entry agreement (ROE) signed by the landowner that allows not only the project lead and work crews to enter the property, but the state itself to visit the property for a number of years. This is a very challenging ask for some property owners. Concerns include the access for anyone but the trusted local partners, the duration of the access for a decade or more, and the very fact of having access permission on paper and legally binding.

In many areas of the state project proponents have been able to overcome these concerns and have had good success in convincing landowners to participate. It's not clear if this is possible in all areas in the Central Valley. Many RCDs anticipate a fair amount of resistance to participation. But this is a common sentiment of newly initiated programs. Over time, landowners come on board as they see the work occur and that other landowners are happy with the process and results. Some *Arundo* work has been undertaken in the past, but not as full-watershed efforts and not always with good follow up with re-treatments. Some of these 'false starts' also shape local sentiment of landowners; this needs to be repaired. Whether a well-planned and executed watershed-wide effort would engage all local landowners or not remains to be seen.

Greater access could likely be achieved if the state is able to change state grant requirements to address current barriers to participation. This would be accomplished by removing the need for formal ROEs giving the state access. Funding agencies like WCB would then rely on local partners (RCDs, CACs and nonprofits) to maintain their own access to affected properties and to oversee the success of implementation, which can be shared via photo point monitoring. Though this undoubtably raises legal issues it may be a necessary step in order to make private land access for *Arundo* removal possible.

9.2 Priority Ranking of Watershed-Based *Arundo* Control Projects

For this effort we broke the Central Valley into 25 watershed units to facilitate local planning and analysis of impacts and capacity. Of these, 22 are organized around the watersheds of major tributaries to the Sacramento River and San Joaquin River and three are mainstem reaches of the Sacramento River itself. (These mainstem reaches are not "watersheds" but were deemed to be important as standalone management units.) These watershed units are shown on maps in Appendix A and form the basis for assessing benefits and challenges of *Arundo* removal in different areas as presented below.

9.2.1 Factors Considered: Impacts and Capacity

Ranking watershed unit areas is an exercise that accounts for (1) *Arundo*'s impacts and (2) local capacity to successfully build and implement a removal program. Multiple impacts from *Arundo* invasion have been outlined in this report. Some impacts are directly tied to the level of *Arundo* invasion (abiotic impacts of geomorphology, flooding, fire and water use) while other impacts are tied to specific species co-occurring with *Arundo* (biotic impacts to listed species). It should be noted that there are impacts beyond the primary impacts rated here, such as damage to canals, levees, bridges, and other infrastructure typically caused during flood and fire events. These impacts are quantified in the CBA chapter and the magnitude and level of risk is tied to the level of *Arundo* invasion. Greater *Arundo* biomass in a system is more likely to cause flood, fire, and infrastructure damage.

While different weightings could be used for each impact class, this analysis will weigh all impact classes as equal with a score ranging from 0 to a maximum of 5. Impact rankings by watershed are shown in Table 9.1 below. Scores are derived using the following methodology. (The table also includes capacity scores the likely lead organization; this is further described below.)

Impact on water use: Watershed units are scored from 0 to 5 based on acreage of *Arundo* because we use a standard water-use rate per acre of *Arundo*, as described in Chapter 4. The cumulative score totaled across all 25 watershed units was 64.

Impact on geomorphology: Watershed units are scored from 0 to 5 based on acreage of *Arundo,* acres per river mile, and portion of *Arundo* found in large stands, as described in Chapter 5. Wide portions of the Sacramento River score lower because *Arundo* would not have significant impacts/alterations on the deep single-channel river. The cumulative score totaled across all 25 watershed units was 64.

Impact on fire: Watershed units are scored from 0 to 5 based on acreage of *Arundo*, number of stands larger than 0.5 acre, and number of fires from 1970 to 2008 that overlapped with *Arundo* stands, as described in Chapter 6. The cumulative score totaled across all 25 watershed units was 46.

Impact on Sensitive species: Watershed units are scored from 0 to 5 based on 24 sensitive species in six taxonomic groups as described in Chapter 7 (with additional information in Appendices B and C). The scores are based on combining a score for *Arundo* impact on each species and a score for spatial overlap between the sensitive species and *Arundo* stands in the watershed unit.

See Table 9-1 for scores for all watersheds. Overall, impacts on sensitive species are scored the highest (74), followed by water and geomorphology (64) and fire (48). Water, geomorphology and fire are highly correlated to *Arundo* acreage, listed species is less so. Totaling scores from the four impacts yields a final impact score for each watershed unit. The maximum possible score is 20. The highest was 18 and the lowest was 1. Figure 9-2 shows total impacts by watershed unit.

Along with impacts, the capacity of groups in each watershed program area to build a long-term control program is critical. This factor is also rated in Table 9-1 and described in more detail in Table 9-2 (Appendix D lists more detailed notes on capacity in each watershed unit). This rating is based on two factors: (1) having an experienced lead entity with capacity to implement large complex projects and (2) having permits in place and the capacity to obtain permits for large complex projects. To rate how experienced the likely lead entity is we made a subjective judgment based on factors including: how large their staff is, how extensive their programs are, how many programs they have with partners, how extensively they work with landowners, how much experience they have managed other large programs and executing large grant-funded projects successfully. For permitting we looked at how much (if any) *Arundo*-specific permitting is already in place and the ability of the group to obtain needed permits. Each of these two factors is rated from 0 to 5. The two scores are added for a total of up 10 points maximum. The capacity score for each watershed unit is then added to the impact score for that unit to generate an overall priority score by watershed unit.

Table 9-1. *Arundo* treatment priority ranking by watershed (north to south). Based on *Arundo* impacts and program capacity. "Active" status indicates that the organization is already an active lead.

Watershed units	**Acres *Arundo***	**Portion treated already**	**Potential lead entities**	**Impact**					**Capacity**			
				Water	**Geo.**	**Fire**	**Sens. Spp.**	**Sub-total**	**Exp'd lead**	**Per-mits**	**Sub-total**	**Total**
Sac. River Headwaters: Castle-Stillwater Creeks	24	30%	Western Shasta RCD	2	1	1	4	8	2	3	5	**13**
Cottonwood Creek	5	0%	W. Shasta & Tehama RCDs	0	0	0	1	1	3	3	6	**7**
Elder Creek	85	11%	Tehama RCD	3	4	3	2	12	3	2	5	**17**
Sac. River Upper: Cottonwood to Thomes Creeks	154	0%	Tehama RCD	4	4	3	4	15	3	2	5	**20**
Antelope-Mill Creek	14	0%	Tehama RCD	1	2	0	2	5	3	2	5	**10**
Thomes Creek	75	6%	Tehama RCD	3	4	2	3	12	3	2	5	**17**
Stony Creek	562	1%	Glenn RCD	5	5	5	3	18	3	2	5	**23**
Feather River-Chico-Butte Creeks	70	11%	Butte RCD	3	3	3	5	14	3	2	5	**19**
Sac River Middle: Stony to Cache Creek	153	1%	Glenn & Butte RCDs	4	4	3	4	15	2	2	4	**19**
Colusa Trough-Stone Corral-Freshwater Creeks	115	18%	Colusa RCD	4	4	3	3	14	2	1	3	**17**
Bear-Yuba River	44	0%	Yuba RCD	2	2	1	4	9	0	1	1	**10**
Cache-Putah Creeks	254	6%	Yolo RCD (active)	5	5	4	4	18	5	5	10	**28**
Sac. River Lower: Cache to Putah Creeks	1	0%	Yolo RCD (active)	0	0	0	1	1	5	5	10	11

Table 9-1. (cont.)

Watershed units	**Acres *Arundo***	**Portion treated already**	**Potential lead entities**	**Impact**					**Capacity**			
				Water	**Geo.**	**Fire**	**Sens. Spp.**	**Sub-total**	**Exp'd lead**	**Per-mits**	**Sub-total**	**Total**
American-Mokelumne Rivers-Deer Creek	29	4%	Placer RCD	2	3	1	5	11	3	2	5	**16**
Ulatis Creek	80	3%	Solano RCD	3	2	2	5	12	4	2	6	**18**
Los Banos-Panoche-Salado Creeks-San Joaquin River	65	15%	Westside RCD	3	3	2	5	13	0	0	0	**13**
Calaveras River	28	1%	San Joaquin RCD	2	2	1	4	9	1	0	1	**10**
Stanislaus-Tuolumne Rivers	36	0%	East Stanislaus RCD	2	3	1	3	9	2	2	4	**13**
Bear Creek-Merced River	39	1%	East Merced RCD	2	1	1	2	6	1	5	6	**12**
Chowchilla-Fresno Rivers	230	74%	River Partners	5	5	4	1	15	4	3	7	**22**
San Joaquin River	57	0%	Madera/ Chowchilla RCD	3	3	2	2	10	0	0	0	**10**
Tulare Lake-Los Gatos Creek	8	0%	Westside RCD	1	0	0	1	2	0	0	0	**2**
Kings River	91	5%	Sierra RCD & Kings Riv. Con'y	3	3	3	2	11	2	2	4	**15**
Kaweah-Tule River	34	7%	Tulare RCD	2	1	1	3	7	0	0	0	**7**
Kern River	4	25%	NW Kern RCD	0	0	0	1	1	0	0	0	**1**
Total:	**2,256**	**12%**		**64**	**64**	**46**	**74**	**248**	**54**	**48**	**102**	**350**

Table 9-2. Lead organization capacity and permitting status for watershed units (north to south).

Watershed Unit	Potential Lead Group	Capacity, Interest	Landscape-level Permitting* Status	Notes
Sac. River Headwaters: Castle-Stillwater Creeks	Western Shasta RCD	High	CEQA MND adopted	Applied unsuccessfully to WCB in 2018. New District Manager in 2019. Likely to re-apply in 2020.
Cottonwood Creek	Western Shasta & Tehama RCDs	High	CEQA MND adopted (W. Shasta). Tehama has CEQA, CDFW for portions.	Applied unsuccessfully to WCB in 2018. New District Manager in 2019. Likely to re-apply in 2020.
Elder Creek	Tehama RCD	Medium	none known	Prefer small pilot project as first step.
Sac. River Upper: Cottonwood to Thomes	Tehama RCD	Low	none known	Potential partner with Sacramento River Watershed Forum.
Antelope-Mill Creek	Tehama RCD	Medium	none known	Prefer small pilot project as first step.
Thomes Creek	Tehama RCD	Medium	none known	Prefer small pilot project as first step.
Stony Creek	Glenn RCD	Medium	Old CEQA MND, uses NRCS practices that do not cover *Arundo* control methods very well. Part of multi-agency permit program that is no longer active.	Prefer large pilot project as first step.
Feather River-Chico-Butte Creeks	Butte RCD	Medium	none know, but past projects by partners	RCD rebuilding, very interested. Prefer small pilot project as first step.
Sac River Middle: Stony to Cache Creek	Glenn & Colusa RCDs	Low	none known	Potential partner with Sacramento River Watershed Forum.
Colusa Trough-Stone Corral-Freshwater Creeks	Colusa RCD	Low	none known	
Bear-Yuba River	Yuba RCD	Inactive	none known	
Cache-Putah Creeks	Yolo RCD (active lead)	High	CEQA MND posted, other permits in process	Applied for WCB SFC grant 2019. RCD manages restoration projects, has large staff including some GIS and regulatory experience.

Table 9-2. (cont.)

Watershed Unit	Potential Lead Group	Capacity, Interest	Landscape-level Permitting* Status	Notes
Sac. River Lower: Cache to Putah Creeks	Yolo RCD (active current lead)	High	CEQA MND posted, other permits in process	Small amount of *Arundo*, could be treated out of phase to stop from establishing.
American-Mokelumne Rivers-Deer Creek	Placer RCD	Medium	none known	Placer County Ag. Dept. as potential partner.
Ulatis Creek	Solano RCD	Medium	unknown	Solano RCD staff have experience with *Arundo* removal projects.
Los Banos-Panoche-Salado Creeks-San Joaquin River	Westside RCD	Inactive	none known	Watershed crosses many RCD boundaries.
Calaveras River	San Joaquin RCD	Low	none known	
Stanislaus-Tuolumne Rivers	East Stanislaus RCD	Low	none known	East Stanislaus RCD works with River Partners.
Bear Creek-Merced River	East Merced RCD	Medium	CEQA and CDFW 1600 for 55 miles of Merced River.	E. Merced RCD (with E. Stanislaus RCD and River Partners) submitted 2019 CDFA app, not funded.
Chowchilla-Fresno Rivers	River Partners	Medium	unknown	Projects pursued are on public land only, not full watershed approach.
San Joaquin River	Tranquility RCD	Inactive	none known	South of where River Partners currently works.
Tulare Lake-Los Gatos Creek	Westside RCD	Inactive	none known	
Kings River	Sierra RCD & Kings River Conservancy	Medium	CEQA NOE for spots along 7-mile reach.	Kings River Conservancy actively managing several spots along a 7-mile reach.
Kaweah-Tule River	Tulare RCD	Low	none known	
Kern River	North West Kern RCD	Inactive	none known	

*Including CEQA, State Water Board (SWB), CDFW 1600 Streambed Alteration Agreement, Army Corps of Engineers (USACOE), National Oceanic & Atmospheric Association (NOAA), U.S. Fish & Wildlife Service (FWS).

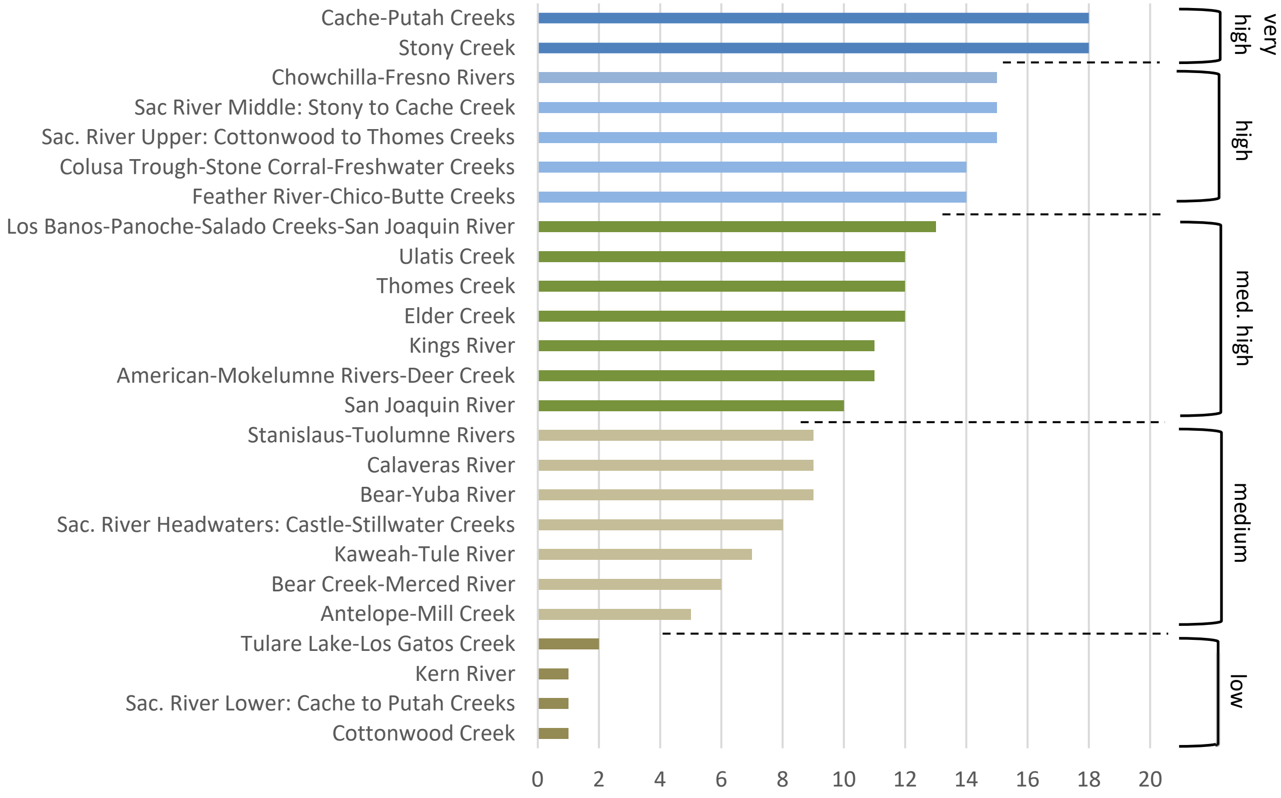


Figure 9-2. Overall *Arundo* impact score by watershed unit, arranged by total impact score. Colors represent different levels of priority rankings.

9.2.2 Control Priority

Overall there are three priority actions for implementing *Arundo* control projects:

1. Implement new *Arundo* control on invaded systems, with prioritization of areas where watershed-based programs/approaches are being used and where the benefit is greatest.
2. Implement new *Arundo* control on watersheds with low levels of invasion, protect these areas from future invasion and degradation caused by *Arundo* invasion. It is more cost efficient to control *Arundo* before it becomes abundant.
3. Implement *Arundo* re-treatments of project areas that have already implemented watershed-based control. This protects the initial investment and moves the program toward the goal of eradication.

Funding new *Arundo* control on watersheds should target watersheds experiencing the most severe impacts coupled with highest available capacity (and associated likelihood of achieving success), as described in the ranking section above and shown in Figures 9-3 and 9-4. A given watershed with high levels of *Arundo* invasion will have the greatest benefit from systematic 'top-down' *Arundo* control. These systems will see the greatest water savings, the greatest 'normalization' of geomorphic modification, and the greatest reduction of fire risk. Many of the more invaded systems would also see substantial benefits to sensitive species, but this enhancement is more complicated as it is dependent on co-occurrence of *Arundo* and sensitive species (see Chapter 6). The overall impact ranking selects for watersheds that have higher levels of *Arundo* invasion (due to a correlation of invasion level with the impact level for water use, geomorphology and fire).

Sensitive species impacts, however, are not so highly correlated with level of *Arundo* invasion (Chapter 6). Watershed units with high impacts to sensitive species could be selected based on this one impact alone, if benefit to sensitive species habitat is considered the priority for selection.

Position in the valley-wide watershed should also be considered, with the Castle-Stillwater-Sacramento River headwaters watershed unit being the highest priority in the Sacramento Valley by virtue of being farthest upstream. It would start a 'top-down' valley-wide control trajectory. In the San Joaquin Valley three units: Kings River, Kaweah-Tule River, and Kern River watershed units would be the top priorities from a 'top-down' perspective.

Control of *Arundo* on watersheds with low levels of invasion is the second priority. Some watersheds have low levels of *Arundo*, most likely due to more recent introductions, but also often tied to a lower suitability of the system. Control of invasive plants early in the invasion process is always more cost effective than responding to a larger, more widespread invasion. Programs should be able to control *Arundo* on many of these less invaded watersheds with less complicated permitting and far lower project implementation costs. Treated *Arundo* biomass can often be left standing if it is scattered, also greatly reducing treatment costs. Foliar application of uncut stands is the most effective treatment methodology rather than cut-stump treatment. All of these factors make control of *Arundo* on less invaded systems very attractive, especially if the *Arundo* is impacting sensitive species.

Re-treatment of *Arundo* within established program areas is of the highest importance; without it, eradication cannot be achieved. It is the part of the control program that is the hardest to execute. It is critical to select project leads with the organizational capacity to execute over the long term. Most program leads use a wide range of mechanisms to carry out re-treatments. The role of the lead is to track all project areas and ensure that the re-treatment work is being done. This requires typically requires the use of GIS system to track *Arundo* populations and ROEs.

Though it is relatively low-cost, established programs typically must solicit funding from a range of funding sources to carry out long-term re-treatments. Successful re-treatment programs solicit funding and re-treatment work from locally appropriate sources including: local agencies with a vested interest in the area remaining *Arundo*-free (municipalities, counties, water agencies, flood control districts); land owners (private, conservancies, public); the U.S. Department of Agriculture's

Natural Resource Conservation Service (NRCS); County Ag Departments (directly or through CDFA or the local Weed Management Area); HCPs (Habitat Community Plans) or NCCPs (Natural Community Conservation Plans); and NPOs and volunteer groups.

Programs and projects that do not fit into a watershed-based 'top-down' control program should be evaluated carefully. There are situations where control of *Arundo* at a downstream site can make sense. For instance, control may help protect important structures and/or restore important habitat. It may capitalize on a landowner with the resources to commit to long-term re-treatments. Or it may a site that will serve well as a high-visibility demonstration project where small-scale success can leverage greater buy-in from local landowners. These sites are, however, at significant long-term risk of re-invasion. Funds should be set aside to respond to re-invasion, which is expected to be periodic and varying in intensity.

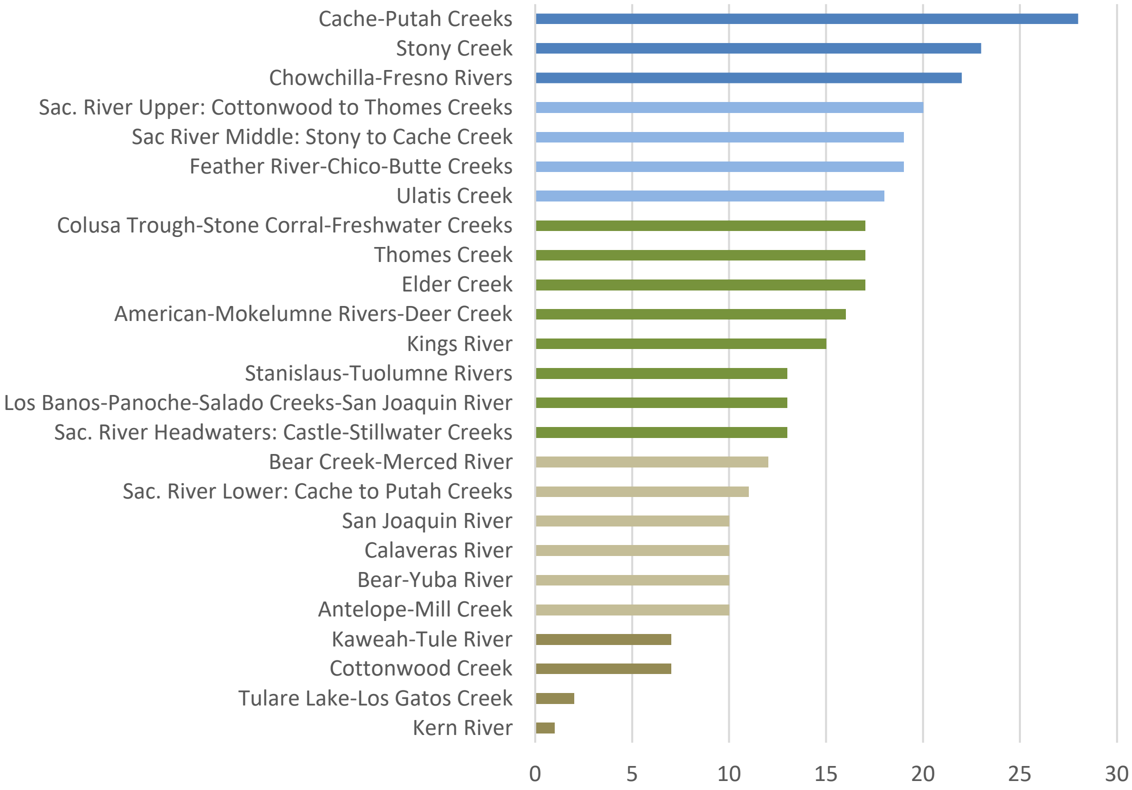
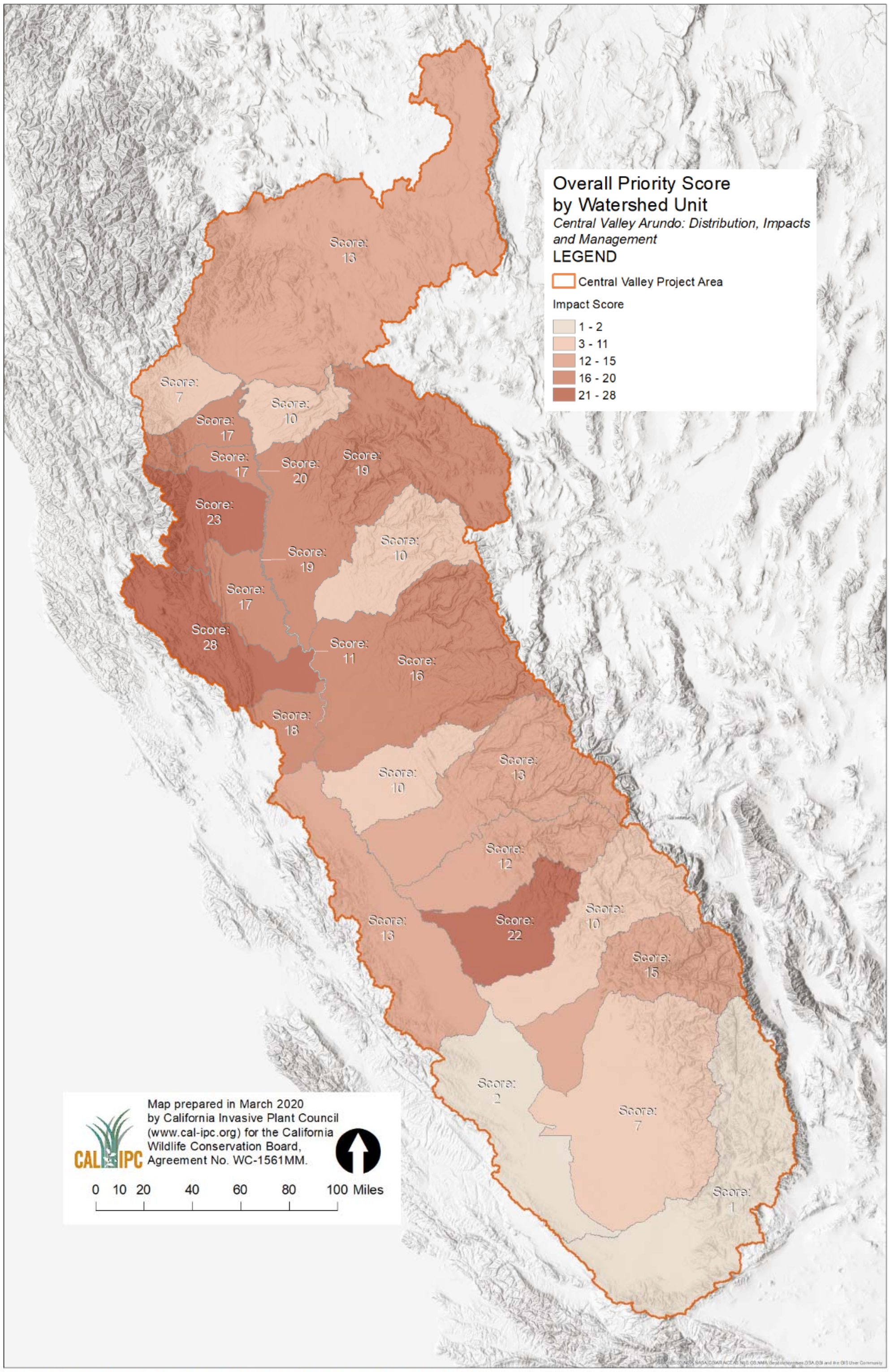


Figure 9-3. Overall priority for *Arundo* control by watershed, based on both impact and capacity. Colors represent different priority rankings.



Map prepared in March 2020 by California Invasive Plant Council (www.cal-ipc.org) for the California Wildlife Conservation Board, Agreement No. WC-1561MM.

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Figure 9-4. Overall priority for *Arundo* control by watershed, based on both impact and capacity. Darker shades indicate higher priority.

Mitigation projects may also initiate *Arundo* control in the middle of an invaded system. These types of projects are tied to ownership and habitat restoration objectives, and hopefully set aside long-term management funds to keep *Arundo* out of the preserved/restored habitat. Projects that merely reduce *Arundo* biomass or only carry out one treatment are not effective long-term control projects and should not be presented as such.

9.2.3 Watershed Summaries and Future Opportunities

Each watershed unit has its own unique situation in terms of *Arundo* infestation level, impacts, and the capacity of the most likely local lead entity. The scores from Table 1 are used to show results graphically. Figures 9-2 and 9-3 shows watershed units ranked by *Arundo* impact, which can be used to gauge where *Arundo* is causing the most damage. Figure 9-4 shows watershed units ranked by overall priority which incorporates the capacity of local organizations to build a successful program to address the *Arundo* in each watershed unit. (By virtue of the scoring system—impact has four categories each with a maximum of 5 points and capacity has two categories each with a maximum of 5 points—capacity is weighted half as heavily as is impact.)

Across the Central Valley region there are currently only a few local entities with sufficient capacity to undertake a watershed-scale project for eradicating *Arundo*, and most of these are in the Sacramento Valley. (See discussion in Appendix D for details in each watershed unit.) The capacity to build and manage resource management projects needs to be built, both at the local level but maybe also at a broader regional level. Some of this capacity used to exist at both RCDs and County Ag Departments. Unfortunately, much of this capacity was lost in 2008 when state programs reduced their budgets in response to the recession. Currently, however, some of this capacity is returning.

At the local level, the renewal of funding for the state's Weed Management Area (WMA) program provides an opportunity to build local capacity via grants from CDFA, particularly if those grants are allowed to be used for planning purposes (such as project permitting) as well as implementation, especially long-term re-treatments. One advantage of these funds is that they do not mandate that grantees get ROEs signed by landowners, unless the individual County Ag Department requires this.

Other grant opportunities may help support projects at the local level. Environmental Quality Incentive Program (EQIP) from the Natural Resources Conservation Service (NRCS) provides funding for conservation work on working lands. CDFW's Environmental Enhancement Fund can be used to restore habitat for fish and wildlife in waters of the state. Calfire is making funding available for fuels reduction, which may be appropriate for some settings. But overall the amount of funding through these type of grant programs is relatively small relative to the cost of *Arundo* removal. They may, however, be useful for long-term re-treatment.

Opportunities for larger grants are available through state bond-funded programs like those at WCB, the State Water Resources Control Board (which funded the 2011 distribution and impacts study for coastal watersheds from Monterey to Mexico), and regional Integrated Water Management plans through the California Department of Water Resources. These are a good fit for well-designed *Arundo* eradication projects because such projects are designed to be durable over the long-term which is required for such funding sources. The scale of a watershed-wide *Arundo* eradication program presents obvious challenges through the magnitude and time commitment of the effort, and being able to access and treat all *Arundo* populations is also difficult given some landowners' reticence to participate. This can be addressed over time if funding is available over an extended period, since some landowners are swayed once others have preceded them. Requirements for signed ROEs from landowners present an additional challenge. Beyond the logistical difficulties, it is an extra psychological hurdle for landowners to sign a legal document allowing the state to access their land for a decade or more.

Collaboration at a regional level may help boost each area's efforts. It may offer some economy of scale if entities are able to follow a common template. One existing effort with potential is the Sacramento Valley Durable Collaborative, which seeks to more efficiently address regional conservation issues, rather than to administer a number of regional contracts to address the same issue across district boundaries. It engages the leaders of the region's RCDs, the same individuals with whom we discussed *Arundo* removal, and *Arundo* is on the agenda. Whatever solutions are successful will be shared. And it's possible that working regionally to market the importance of *Arundo* control could build greater awareness and increase landowner participation. This collaboration works over the same region spanned by the Sacramento River Watershed Forum, another nexus for groups that should be interested in finding ways to implement *Arundo* control across the region. We will explore the potential for holding a joint conference on *Arundo* control in the Central Valley. A San Joaquin Valley regional effort would be particularly useful, as the valley has few potential watershed unit leads.

State and local entities have an opportunity to work together to address the impacts of *Arundo* on the Central Valley. Completed projects and projects underway provide test cases demonstrating what is required for success. The information and recommendations in this report provide a foundation for designing and implementing watershed-wide removal projects needed to protect the region's resources.

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