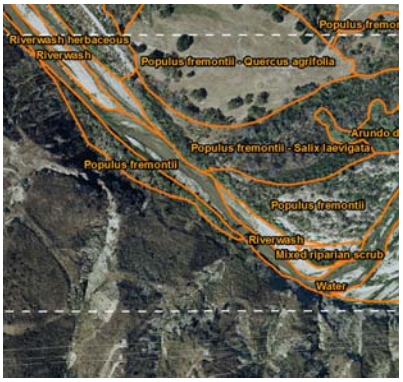
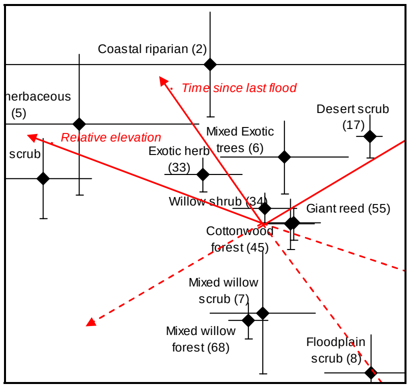
Santa Clara River Parkway
Floodplain Restoration Feasibility Study





Analysis of Riparian Vegetation Dynamics for the Lower Santa Clara River and Major Tributaries
Ventura County, California

FINAL REPORT
October 2007

Prepared for
The California Coastal Conservancy
1330 Broadway, 11th Floor
Oakland, California 94612-2530

Prepared by
Stillwater Sciences
2855 Telegraph Avenue, Suite 400
Berkeley, California 94705

Stillwater Sciences

Acknowledgements

Our sincere thanks go to Peter Brand and the California State Coastal Conservancy for enthusiastically supporting our efforts to develop the background information necessary to understand and document how the Santa Clara River system functions, and conservation planning and river management efforts in the watershed that build from that understanding.

The project team included Zooey Diggory as the project manager and Amy Merrill as the principal investigator, with project direction and technical input from Bill Sears and Bruce Orr. Gretchen Coffman, Casey Stewman, Sarah Lewis, Johanna LaClaire, and David Kisner (all from URS); Todd Lemein and Keegan Kennedy (both from UCSB); and Gilda Barboza (CNPS) collected the vegetation data upon which this analysis is based. Scott Dusterhoff and Sebastian Araya were instrumental in pulling together physical data sets for the analysis. Data analysis was conducted by Amy Merrill. Background research and written synthesis were provided by Amy Merrill and Zooey Diggory. Tami Cosio and Sebastian Araya performed GIS analyses and produced report maps. Bruce Orr provided technical review of earlier drafts of this document.

Contact:

Zooey Diggory
Ecologist/Project Manager
Stillwater Sciences
2855 Telegraph Avenue, Suite 400
Berkeley, CA 94705
(510) 848-8098
zooey@stillwatersci.com
www.santaclaraparkway.com

Cover photographs:

Left - Example of vegetation conditions in the lower Santa Clara River corridor (photograph by Stillwater Sciences)
Center – Excerpt from vegetation mapping report (Tile 32) (Stillwater Sciences and URS Corporation 2007).
Right – Excerpt from Figure 3-3 produced for this report.

Preferred citation:

Stillwater Sciences. 2007. Analysis of Riparian Vegetation Dynamics for the Lower Santa Clara River and Major Tributaries, Ventura County, California. Santa Clara River Parkway Floodplain Restoration Feasibility Study. Prepared by Stillwater Sciences for the California State Coastal Conservancy and the Santa Clara River Trustee Council.

Table of Contents

List of Tables

List of Figures

List of Appendices

1 INTRODUCTION

The 116-mile long Santa Clara River flows in a westerly direction from headwaters on the northern slopes of the San Gabriel Mountains in Los Angeles County through the Santa Clara River Valley and the Oxnard Plain in Ventura County, and finally empties into the Pacific Ocean near the City of Ventura. Many large coastal southern California rivers (*i.e.*, the Los Angeles, Santa Ana, and San Gabriel rivers) have been confined to concrete channels in their lower reaches to provide flood protection for surrounding urban areas, dramatically reducing (or eliminating) riparian vegetation and the fluvial geomorphic processes that maintains a functioning river corridor ecological system. While flood protection infrastructure, diversions, roads, agriculture, and urbanization have constrained or disrupted natural geomorphic and hydrologic processes causing riparian and aquatic habitat degradation in the lower Santa Clara River, the loss of wetland and riparian habitat in the Santa Clara River floodplain has likely been much less than that observed in other major rivers in Southern California (*e.g.*, the San Gabriel River, as reported by Stein *et al.* 2007). As a result, the lower Santa Clara River has retained a significant amount of high quality aquatic and riparian habitat supporting threatened and endangered species including *Bufo microscaphus californicus* (arroyo toad), *Empidonax traillii extimus* (southwestern willow flycatcher), *Vireo bellii pusillus (*least Bell's vireo), and *Dodecahema leptoceras* (slender-horned spineflower).

The present-day Santa Clara River is a dynamic semi-arid ecological system driven primarily by periodic short duration, high intensity flood events (Stillwater Sciences 2007). The channel is functionally on the boundary between meandering and braided river forms in terms of the relationship between gradient, discharge, and bed material grain size. The result (where natural processes prevail) is an unusual compound channel morphology that is essentially braided at lower flows but more akin to a low sinuosity meandering channel during large flood discharges. The channel morphology is affected primarily by large flood flows rather than by moderate discharges that are frequently used to characterize channel form response in temperate climate river channels. These factors result in a shifting mosaic of riparian vegetation throughout the corridor.

A number of studies and planning efforts have begun on the river to address the impacts to the lower Santa Clara River riparian ecosystem. Understanding the physical drivers for riparian vegetation distribution, composition, and health is a crucial part of river management and restoration planning, particularly because riparian vegetation serves as an indicator for important environmental variables, including habitat quality and quantity, but also because this understanding allows restoration planners to better predict vegetation response to restoration actions. A variety of physical factors are known to influence the recruitment, growth, persistence, distribution, and composition of riparian vegetation, including relative depth to groundwater, frequency of disturbance, substrate composition, and salinity. The relative roles these factors play in determining the pattern and composition of riparian vegetation within the lower Santa Clara River system, however, is not well understood.

1.1 Objectives

1.1.1 Understand primary physical drivers of riparian vegetation dynamics

The primary objective of the riparian vegetation dynamics analysis is to characterize the relationship between selected physical processes and the distribution of riparian plant species within the study area. Results from this analysis will provide a basis for developing restoration strategies and plans for the lower Santa Clara riparian-floodplain corridor. The California State Coastal Conservancy (SCC), along with partner organizations The Nature Conservancy (TNC) and Friends of the Santa Clara River (FSCR), has initiated the Santa Clara River Parkway project, which is an effort to acquire and restore a 20 mile-long corridor along the mainstem Santa Clara River that extends from the river mouth to the Sespe Creek confluence. In support of Parkway planning, the SCC is currently funding a Floodplain Restoration Feasibility Study; the study is designed to assist the SCC and its partners in the identification of opportunities and constraints associated with the acquisition, management, and eventual restoration of the Parkway area. The study will assess the hydrologic, geomorphic, and biological attributes of the Parkway area, and develop a set of recommended restoration strategies. The results of this analysis will elucidate linkages between physical processes and the establishment and maintenance of riparian vegetation and assist in predicting how riparian vegetation may establish and persist on restored floodplains within the study area.

1.1.2 Characterize, and assess changes to, historical vegetation conditions

Another objective of this report is to characterize the likely historical (pre-1900) extent and form of riparian vegetation within the lower Santa Clara River to provide a potential reference condition for restoration planning. In their analysis of historical steelhead populations, Boughten *et al.* (2006) synthesized an extensive amount of historical information for southern California steelhead-bearing rivers, including the Santa Clara River. Their report provides insight into the likely conditions of historical riparian corridors along southern California rivers prior to widespread European ranching and colonization, and their findings that relate to the Santa Clara River are summarized here. Another source of information received regarding historical change in the Santa Clara River watershed was Schwartzberg and Moore (1995). In addition, historical aerial and ground-based photography, historical maps, and digitized Geographic Information System (GIS) maps of past flood events were utilized to document changes in the extent of riparian vegetation in the lower Santa Clara River. Current understanding of historical vegetation conditions in the Santa Clara River will likely be substantially enhanced by the results of the San Francisco Estuary Institute’s Ventura County Historical Ecology Study, which is scheduled to be completed in early 2009 and will synthesize historical data resources to create a practical understanding of fluvial, riparian, and wetland resources prior to significant Euro-American modification.

1.2 Study Area

The analysis area (Figure 1-1) encompasses the extent of riparian vegetation within the 500-year floodplain along the lower mainstem Santa Clara River in Ventura County, a reach of approximately 38 mi.

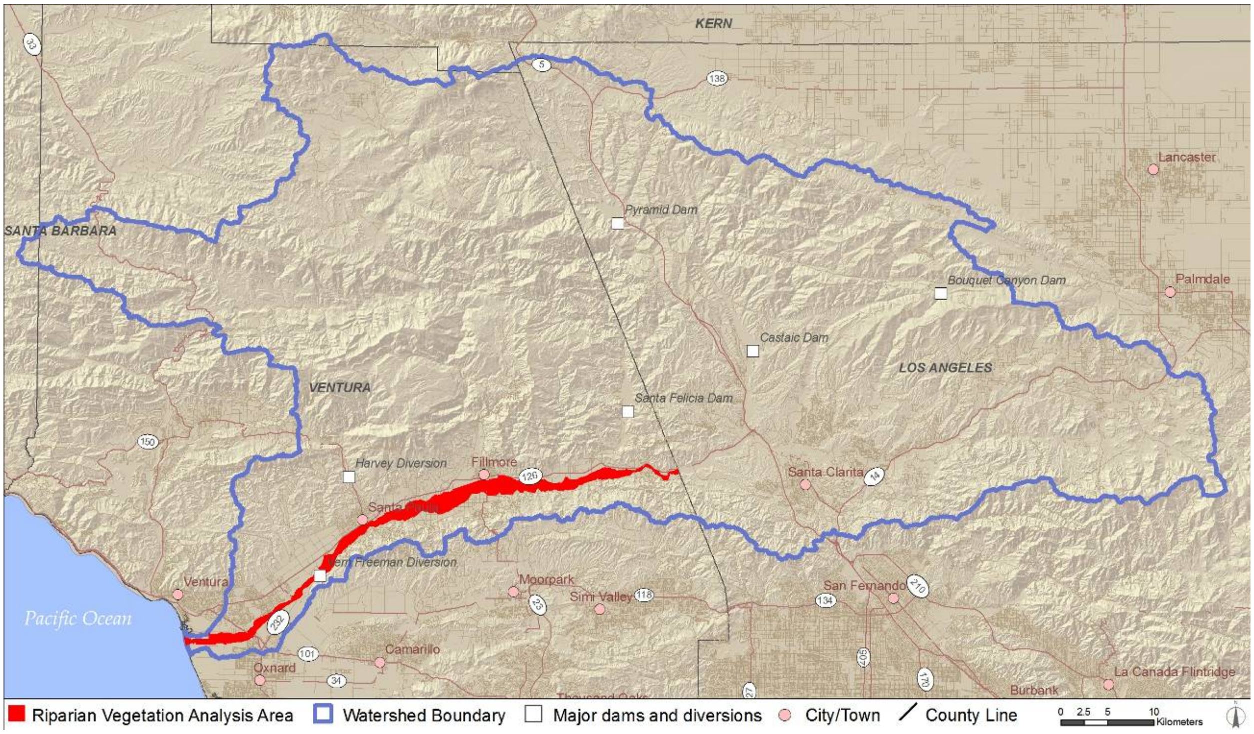


Figure 1-1. The Santa Clara River watershed and riparian vegetation dynamics analysis area.

2 CHANGES IN RIPARIAN VEGETATION CONDITIONS

2.1 Conceptual Model of Historical Riparian Vegetation Conditions

The lower Santa Clara River experiences high annual and inter-year flow variability as a consequence of its semi-arid, Mediterranean-type climate. During the rainy season (November and March), river flows increase, peak and subside rapidly in response to high intensity rainfall, whereas in summer months flows may be intermittent or non-existent in many tributaries and, in the mainstem, depend upon geological controls on groundwater-surface water interactions (Stillwater Sciences 2007). The episodic and extreme nature of discharge in the Santa Clara River watershed results in the majority of total sediment transport occurring in very short periods of time (Stillwater Sciences 2007). The implication is that the morphology of the Santa Clara River does not change progressively in response to small floods, but instead will experience significant episodic changes associated with much larger floods. These dynamic flood and sediment transport patterns are essential to describing and understanding current and historical vegetation patterns in the lower river.

While historical flow conditions are hypothesized to have been less “flashy” than experienced today (Schwartzberg and Moore 1995, Boughten *et al.* 2006, Stillwater Sciences 2007), it can be safely assumed that riparian vegetation composition and distribution have always been strongly influenced by the dynamic patterns of flooding, scour, and sediment deposition exhibited by the lower Santa Clara River. Figure 2-1 illustrates the dramatic response of riparian vegetation to annual flood events. Prior to high-flow events, flow is conveyed primarily in a single low-flow channel and vegetation heavily encroaches into the active channel (Figure 2-1). During a high-flow event, the channel widens and forms a primarily single meandering channel that scours away nearly all vegetation in the active channel (Figure 2-1). Following the high-flow event, flows recede into a braided channel and vegetation re-established in the active channel, although the active channel may now have a dramatically different plan-form than before (Figure 2-1).

In the period prior to widespread European ranching and colonization (approximately prior to 1820, following establishment of the first mission in 1782), the Santa Clara River likely had perennial stream flow, a higher channel elevation, and supported a more-or-less continuous and broad riparian forest. It is likely that, prior to water diversion and groundwater pumping, all reaches of the Santa Clara River experienced perennial stream flow, except in the driest years. There are historical reports that describe perennial stream flow for several southern California rivers, including the Santa Ana, Santa Margarita, and San Luis Rey, that are now intermittent largely as a result of water impoundment, diversion, and groundwater pumping (Boughten *et al.* 2006).

Prior to removal of riparian vegetation for ranching and other land uses, the Santa Clara River likely flowed at elevations closer to the floodplain surface. Boughton *et al.* (2006) suggest that prior to the development of USGS maps in the late 1800’s and early 1900’s, many southern California river channels had already experienced significant incision as a result of vegetation clearing, ranching, and other land uses, as well as climatic events. These land uses and climatic events resulted in decreased stream bank stability and increased stream power allowing high flows to entrench the channel. Prior to incision, the Santa Clara River channel would have supported higher groundwater elevations and more frequent floodplain inundation under lower flows. These channel conditions would have facilitated the recruitment and establishment of large tracts of riparian vegetation.

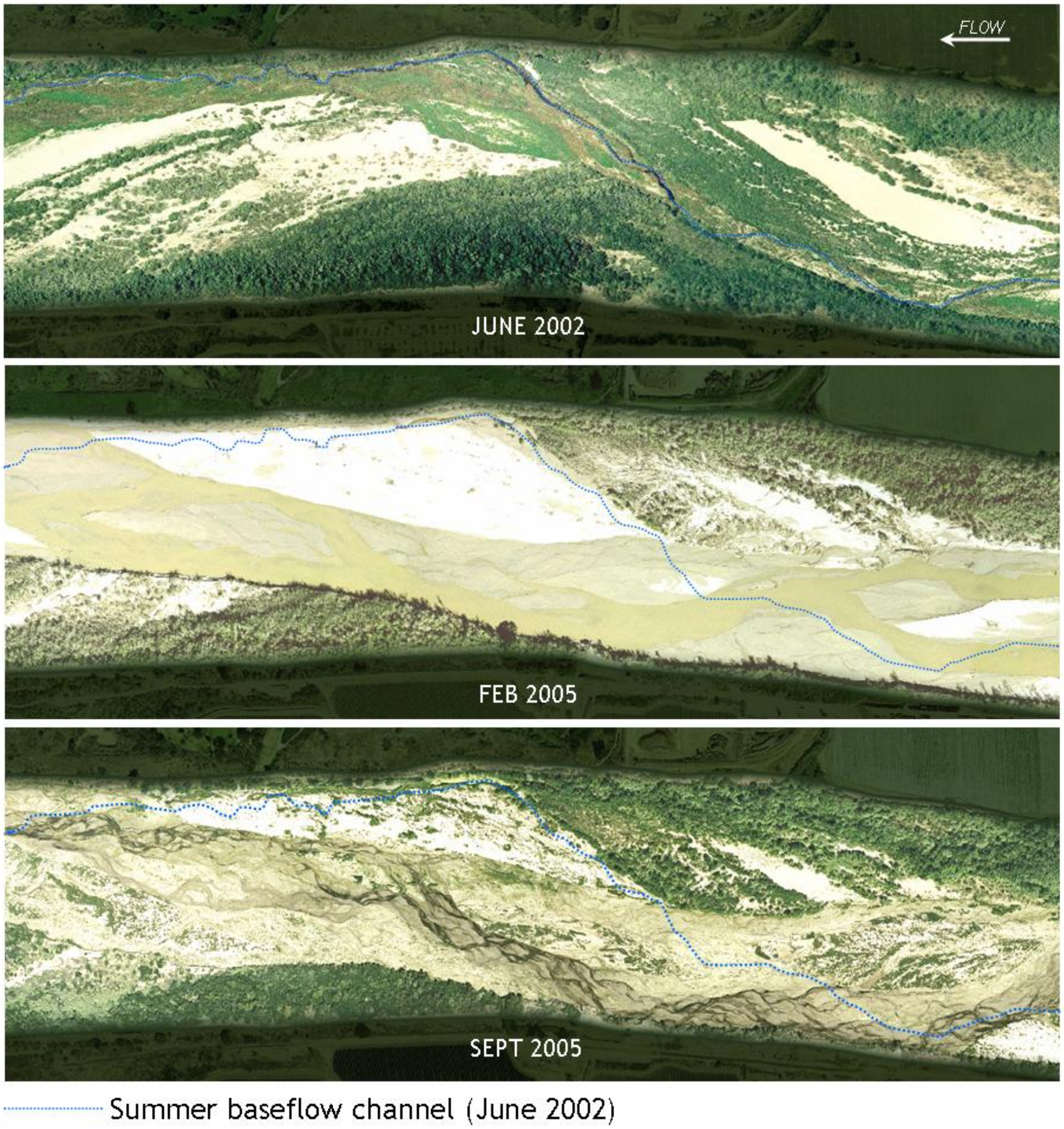


Figure 2-1. Riparian vegetation response before (June 2002), immediately after (February 2005), and following (September 2005) the 2005 high-flow event.

Perennial stream flow, higher channel and groundwater elevations, and an unconfined floodplain likely supported a diverse mosaic of woodland, scrub, herbaceous and seasonal wetland habitats. Simons, Li & Associates (1983) report that the Santa Clara River floodplain was, historically, as much as 2 mi (3.2 km) wide in its lowermost reaches. The riparian area likely supported dense, multi-stored stands of broadleaf trees, including *Populus* (cottonwood), *Platanus* (sycamore), and *Salix* spp. (willows), that extended from a few to several miles wide (Roberts *et al.* 1980, Holland and Keil 1995, Boughton *et al.* 2006). In contrast, vegetation within the 500-year floodplain of the lower river is now dominated by herbaceous communities and non-native, invasive *Arundo donax* (giant reed), with only small, isolate patches of

Quercus (oak) and *Platanus* vegetation communities (Stillwater Sciences and URS Corporation 2007). Prior to any vegetation removal, the extent and composition of riparian vegetation in the Santa Clara River watershed would have supported a diversity of native animal species (Knopf *et al.* 1988, RHJV 2000). In addition, the greater extent of riparian vegetation would have provided a higher degree of ecosystem services such as filtering run-off, shading the river, and providing energy from leaf litter and woody debris that serves as habitat for in-stream organisms (Gregory *et al.* 1991, Malanson 1993, Naiman and Decamps 1997).

2.2 Methods

Changes in the extent of riparian vegetation along the lower Santa Clara River were examined using overlays of aerial photographs taken after recent floods (Table 2-1).

Table 2-1. Flood events with corresponding aerial photographs used to examine changes in the extent of riparian vegetation in the lower Santa Clara River.

Year	Flow (cfs)	Flood Recurrence Interval
1938	120,000	14 year
1969	165,000	24 year
1978	102,200	11 year
1992	104,000	12 year
1995	110,000	13 year
2005	136,000	16 year

Aerial photographs were typically taken one to two months following the flood, although the 1992 aerial photographs were taken nine months following the February flood. The active channel width was designated using a textural analysis of large-scale aerial photography in ESRI ArcGIS, using similar methods to studies in dryland rivers by Graf (1984, 2000), Tiegs and Pohl (2005), and Tiegs *et al.* (2005). A technical account of the methods is found in Appendix E of Stillwater Sciences (2007). Discrete polygons were digitized on the channel bed to define (1) clear-scoured channel bed without vegetation, and so clearly subject to significant flow; (2) partially-vegetated areas showing evidence of having been subject to flow and erosion and/or deposition, and (3) highly vegetated areas on the channel bed without evidence for scour or deposition in the last flood. The extent of riparian vegetation was designated to include all polygon types (2) and (3).

The analysis was conducted for each set of aerial photographs over the same 34 miles in the lower Santa Clara River: river mile 0 to 7, 9 to 24.5, and 26 to 37.5. The gaps in analysis correspond to gaps or poor-quality coverage in the 1938 aerial photography set. To equalize the area of analysis, all years were clipped to the same longitudinal extent as the 1938 coverage. The 1946 aerial photography set was excluded from the analysis because its extent was half that of the other years.

2.3 Results

The riparian corridor of the lower Santa Clara River is currently much narrower, on average, compared to historical accounts, although the area of riparian vegetation has been dynamic over time (Table 2-2). The 1938 flood was the third largest flood analyzed, but inundated the greatest amount of floodplain (over 12,000 ac) (Table 2-2). The 1938 flood occurred before the construction of major dams and levees, so this year likely provides the most accurate example of historical flood extent (Stillwater Sciences 2007). By 1969, when the largest flood analyzed occurred, dams, levees, and development in the floodplain were already beginning to limit the extent of floodplain inundation (approximately 2,000 ac less than the smaller magnitude 1938 flood) (Table 2-2). The magnitude of the 1969 flood appears to have resulted in significant scour of riparian vegetation, as demonstrated by the small percent of vegetated area (26%). The moderate sized floods of 1978, 1995, and 1995 all inundated similar floodplain extents (7,246 to 7,951 ac) and had similar percentages of vegetated area (43 to 68%) (Table 2-2). The 2005 flood, which was similar in magnitude, although slightly larger than the 1938 flood, inundated nearly half the amount of floodplain as the 1938 flood and had a similar percentage of vegetated area (36%).

Table 2-2. Area of vegetated and unvegetated floodplain affected by selected floods.

Year	Flood Magnitude (cfs)	Area (acres)				Percent Vegetated
		Total Floodplain Area	Scoured Channel Bed	Partially Vegetated Floodplain	Highly Vegetated Floodplain	
1938	120,000	12,364	7,497	3,272	1,595	39
1969	165,000	10,508	7,727	1,616	1,165	26
1978	102,200	7,951	4,501	1,377	2,073	43
1992	104,000	7,246	2,350	2,388	2,508	68
1995	110,000	7,825	3,407	1,040	3,378	56
2005	136,000	7,233	4,664	7,91	1,778	36

The 2005 flood inundated approximately 60% less area than the similarly sized 1938 flood. In addition, the total amount of riparian vegetation mapped in 2005 was approximately 50% less than that found in 1938 (Stillwater Sciences and URS Corporation 2007). These differences further demonstrate the dramatic effect of levees in constraining the floodplain and limiting the extent of riparian vegetation in the lower Santa Clara River. This loss, illustrated in Figure 2-2, is most acute in the lowest reaches of the river (river mile 0 to 7) where levees are most extensive and nearly 70% of the riparian corridor has been lost. An example of how levees and subsequent urban development on the floodplain behind levees constrains the floodplain and extent of riparian vegetation in the lower river is provided in Figure 2-3.

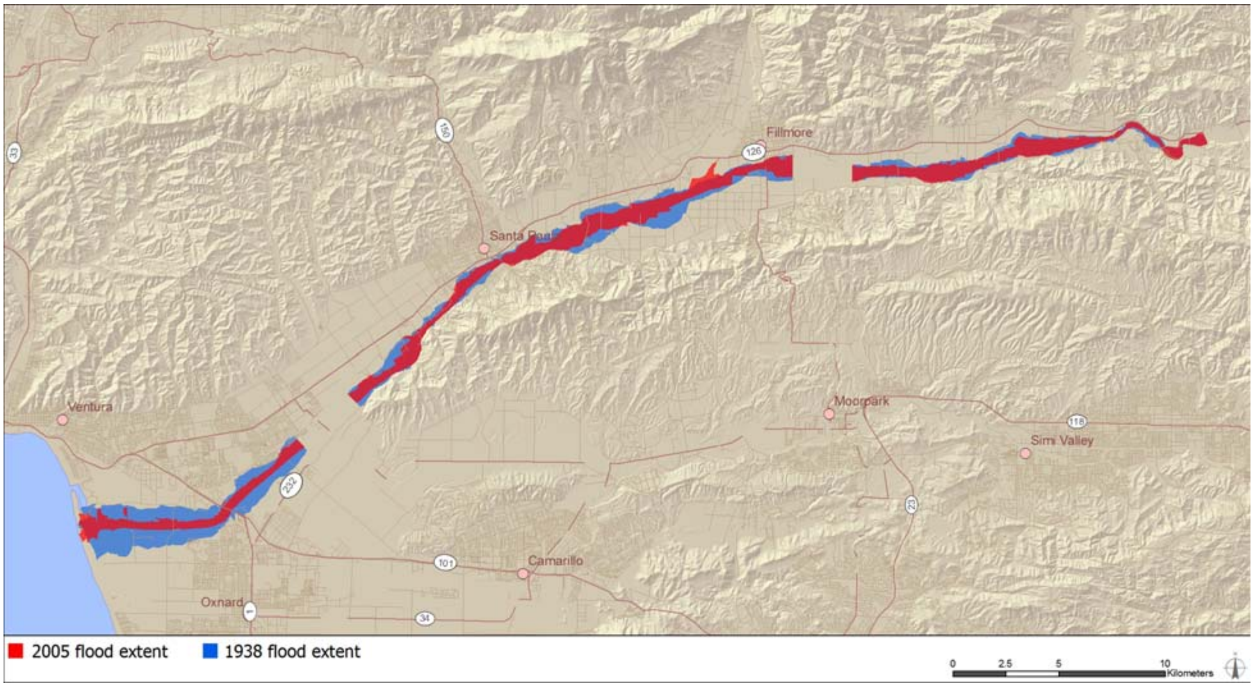


Figure 2-2. Extent of the 1938 and 2005 floods.

Figure 2-3. Riparian corridor conditions at river mile 11 in 1938 and 2005.

2.4 Discussion of Existing Riparian Vegetation Conditions

Levees and other channel constrictions limit the lateral extent of flooding and reduce the area where riparian vegetation can become established and maintained (Figure 2-2 and Figure 2-3). Beyond the dramatic reduction in floodplain and riparian vegetation extent from levees and floodplain development, several other factors affect riparian forest extent, structure, and species composition on the lower Santa Clara River. Historical accounts of central and southern California coastal rivers describe extensive efforts to clear the "monte" – the *Populus* and *Salix* forests that covered the lower reaches of the large rivers (Boughton *et al.* 2006). Vegetation clearing occurred primarily to prepare the land for ranching and farming and for fuel. More recently, urban development has begun replacing the farm land that replaced riparian forests. Major changes in land use and hydrology in the Santa Clara watershed, along with increasing demands on ground and surface water for agricultural and urban uses, have lowered the groundwater table, beyond the reach of tree roots in many areas, and have contributed to increased flood intensity (Stillwater Sciences 2007). Without groundwater to sustain them through the summer, the historical distribution of riparian forest cannot be sustained (Boughton *et al.* 2006). Increasing flood intensity results in more catastrophic scouring of sediment and riparian vegetation during high flow events. In addition, numerous non-native, invasive plant species have colonized the riparian corridor.

As a result of these impacts, the density and extent of vegetation dominated by species that rely on shallow groundwater, such as *Salix*, *Baccharis salicifolia* (mulefat) and *populus*, and the extent of vegetation dominated by later seral species, such as *Platanus*, coast live oak and valley oak, has diminished compared with historical accounts. At the same time, vegetation dominated by species capable of growing in areas with little access to the groundwater and/or colonizing quickly after high intensity flood events, such as the riverwash herbaceous alliance and *Arundo donax*, have likely increased in relative extent (Stillwater Sciences and URS Corporation 2007). Four vegetation alliances cover nearly 50 percent of the existing riparian zone, including: Riverwash Herbaceous, *Arundo donax*, Non-native Grasses and Forbs, and Floodplain Wetland. Although the Riverwash Herbaceous and Floodplain Wetland alliances have a mix of native and non-native species, they are, like the *Arundo donax* and Non-native Grasses and Forbs Alliances, generally dominated by non-native species (Stillwater Sciences and URS Corporation 2007).

The significant loss of riparian vegetation in the lower Santa Clara River equates with a similarly significant loss in habitat quality, quantity and ecosystem functioning. An intact floodplain reduces flood hazard, as flood flows spread out over the floodplain and slow down. This flood attenuation increases groundwater infiltration. Stands of riparian vegetation help filter nutrients from run-off and improve water quality. The extent and diversity of natural communities provide open space and recreational opportunities for the local community. A dramatically smaller and more fragmented riparian corridor means that many of these benefits are compromised or eliminated. Understanding the conditions and processes that maintain riparian vegetation is, therefore, critical to developing restoration strategies that enhance both the ecological and human-use benefits provided by the lower Santa Clara River riparian corridor.

3 ANALYSIS OF RIPARIAN VEGETATION DYNAMICS

3.1 Vegetation Dynamics in Semi-arid River Systems

In the lower Santa Clara River, periodic short duration, high intensity flood events through the meandering and braided river channel result in dynamic patterns of scour, sediment deposition, and floodplain inundation (Stillwater Sciences 2007). These dynamic hydrologic and geomorphic processes have been documented in other semi-arid stream systems, where they have been shown to influence groundwater patterns and riparian vegetation distribution, structure and composition, and result in patches of varying successional stages and species assemblages (*e.g.*, Baker and Walford 1995, Hupp and Osterkamp 1996, Bendix 1997, Shafroth *et al.* 1998, Bagstad *et al.* 2006).

Many researchers have investigated the influence of specific physical processes, such as flood inundation, groundwater levels, stream power, and sedimentation, on riparian vegetation patch distribution and composition. In general, these studies have shown that water availability is the strongest driver of vegetation patterns in semi-arid systems, but results have varied on the particular source (stream flow or groundwater) and mechanism (*e.g.*, scour, inundation, or water supply) of water, and other influential physical and biological variables. Studies to identify the strongest influences on vegetation patterns in semi-arid streams have revealed the importance of the frequency and magnitude of flood disturbance (Bendix 1994, Bendix 1997, Harris 1999, Bendix and Hupp 2000), distance to groundwater (Stromberg *et al.* 1996, Shafroth *et al.* 1998), and a combination of the two (Hupp and Osterkamp 1996, Lite 2003, Bagstad *et al.* 2006, Leenhouts *et al.* 2006). Other physical variables, such as sedimentation (Baker and Walford 1995), fire regime (Bendix 1994), and flood timing (Shafroth *et al.* 1998) have also been found to affect vegetation patterns, as have post-establishment successional and competitive processes (Baker and Walford 1995, Shafroth *et al.* 1998, Bagstad *et al.* 2006).

These results have allowed many of these researchers to develop river-tailored or quantitative management and restoration recommendations to increase the distribution and/or richness of native riparian plant species by specifically addressing those variables having the strongest influence on vegetation distribution and composition (*e.g.*, Shafroth 1998, Harris 1999, Baird *et al.* 2005, Bagstad *et al.* 2006). This ability and the desire to better predict vegetation response to management and restoration actions that are implemented to meet other objectives, such as flood control, were the primary motives for conducting this analysis of riparian vegetation dynamics on the lower Santa Clara River.

3.2 Methods

3.2.1 Vegetation data

Two sets of vegetation data were used to explore relationships between plant species composition and physical processes along the lower Santa Clara River riparian corridor. One set of data includes species-specific information on occurrence and percent cover, but covers a smaller part of the analysis area. This dataset is referred to as the species-specific dataset. The second set of data is a map of the vegetation alliances that occur in the analysis area, but that includes no species specific information. This dataset is referred to as the alliance dataset. Both sets of data were integrated with physical site data to assess the relationship between the physical site variables and the distribution of either particular plant species or vegetation alliances.

The species-specific dataset was developed from field-based mapping using a modified version of the California Native Plant Society (CNPS) vegetation rapid assessment field data form and a modified version of the CNPS vegetation reconnaissance field data form. For these field methodologies, the percent cover of each species that is characteristic of, or dominant in, the vegetation type that the plot represents was collected (for a more detailed description of the data collection methods, see Stillwater Sciences and URS Corporation [2007]). Through this effort, percent cover data for plant species in 340 plots in the analysis area was collected. The position of each data collection plot was mapped and integrated into the project GIS. Two of the 340 vegetation plots were excluded from further analysis since one included a large amount of cover of an unidentified species, and the other included a species with a unique occurrence in the watershed. As a result, 338 plots were included in the species-specific analyses.

The alliance dataset is based on delineation and classification of riparian vegetation alliances through photo interpretation of September 2005 orthophotographs, conducted at on-screen scales between 1:1,200 and 1:10,000 by a field-experienced photo interpreter (Stillwater Sciences and URS Corporation 2007). Through this second process, land in the entire riparian corridor in the analysis area was assigned as agricultural, disturbed, developed, unvegetated land, or assigned a vegetation alliance, according to the classification presented in Stillwater Sciences and URS Corporation (2007). Since this photo-interpretation used the field-based species-specific dataset to provide 'ground truthing', these two data sets cannot be considered independent. Sample points (n=2,000) were randomly selected in ESRI ArcGIS within the analysis area. Of the 2,000 original random vegetation alliance sampling points, 1,516 points fell within riparian vegetation polygons. The remainder fell in areas classified as Agricultural, Urban or Unvegetated Riverwash and were removed from the dataset. Of the 58 vegetation alliances mapped within the analysis area (Stillwater Sciences and URS Corporation 2007), 36 are represented in the 1,516 points. Ten of these alliances were, however, represented by less than four sample points and, as a result of this low sample size, were excluded from further analysis. The remaining 26 vegetation alliances are represented by four or more sample points, for a total sample size of 1,490. The distribution of sample points in each of the 26 vegetation alliances is presented in Table 3-1.

Table 3-1. Vegetation alliance sample sizes.

Vegetation Alliance	Sample Size
Artemisia californica- Eriogonum fasciculatum	4
Artemisia californica	10
Artemisia tridentata	30
Arundo donax	251
Baccharis pilularis	28
Baccharis salicifolia	13
Eucalytus spp.	4
Floodplain wetland	139
Lepidospartum squatmatum	14
Mixed riparian forest	5
Mixed riparian scrub	27
Mixed scrub	5
Mixed willow forest	52
Mixed willow scrub	21
Non-native grasses and forbs	91
Populus balsamifera	65

Vegetation Alliance	Sample Size
Populus fremontii	40
Riverwash herbaceous	398
Riverwash scrub	74
Salix exigua	29
Salix exigua – Arundo donax	28
Salix exigua – Baccharis salicifolia	12
Salix laevigata	60
Salix lasiolepis	67
Salix lucida	19
Tamarix spp.	4
Total	**1,490**

3.2.2 Physical site variables

Site variables that reflect key physical processes that are known to control the riparian environment were developed for the analysis area using a combination of spatially explicit data, process models, and interpretation of historical aerial photographs. The following independent, physical variables were selected for inclusion in this analysis:

1. flood recurrence interval;
2. relative elevation;
3. stream power;
4. stream gradient;
5. time since last flood;
6. wetted width; and
7. longitudinal station (distance from river mouth).

Other physical site variables were considered but excluded because of lack of adequate data (*e.g.*, substrate texture, sedimentation, soil salinity), lack of variability within the analysis area (*e.g.*, percent insolation and flood timing), high correlation with another independent variables (distance from channel), or inability to extract the data without introducing uncertainty (*e.g.*, geomorphic surface type, upstream extent of vegetation type, and levee confinement).

Zones of both rising groundwater and surface water loses to the subsurface occur throughout the lower Santa Clara River due to interactions between tributary basin inputs and geologic constraints (Stillwater Sciences 2007). However, groundwater withdrawals and recharge strongly influence these gaining and losing reaches, especially during dry years when there can be significant lowering of the groundwater table. The availability of groundwater within the upper 9 to 10 ft of soil (Stromberg *et al.* 1996), in addition to the intermittent availability of surface water along the stream, is expected to be an important variable controlling the distribution of plant species and vegetation alliances along the lower Santa Clara River (Shafroth *et al.* 2000). The distribution of gaining vs. losing reaches was included as a descriptive variable in the analysis but, because delineation of gaining vs. losing reaches was based in part on the vegetation density and distribution, was not incorporated into multivariate tests for significant correlations between physical site variables and plant species distribution (see below).

Using ESRI ArcGIS layers of recent vegetation mapping (Stillwater Sciences and URS Corporation 2007), LiDAR-derived digital elevation models, HEC-RAS hydraulic modeling (URS Corporation 2005), flood inundation mapping (Stillwater Sciences 2007), and other physical data sets, spatially explicit data for the seven selected physical site variables were developed for the analysis area and are described below.

Flood recurrence interval (categorical variable). The flood recurrence interval at each sample point was determined using the GIS coverage of predicted flood recurrence interval zones within the 500-year floodplain according to the HEC-RAS hydraulic model of the lower Santa Clara River (URS Corporation 2005). HEC-RAS categorizes flood recurrence intervals into the following groups:

- < 2 year = active channel zone
- 2 to 5 year
- 5 to 10 year
- 10 to 25 year
- 25 to 50 year
- 50 to 100 year
- 100 to 500 year
- > 500 year

Flood recurrence interval was chosen to serve as a proxy for a variety of other physical variables, including patterns of scour and deposition. Flood recurrence interval is expected to correlate with relative elevation and stream power.

Relative elevation (continuous variable). The elevation of each sample point was determined from the LIDAR-based digital elevation model of the lower river and calculated relative to the channel thalweg. Relative elevation is expected to serve as a proxy for flood frequency and duration as well as patterns of scour and deposition and flood recurrence interval. Relative elevation is given in feet.

Stream power (continuous variable). The stream power of the 2-year and 50-year recurrence interval floods was derived from the HEC-RAS channel cross-section closest to each sample point. Stream power will be used as an index of flood disturbance and other fluvial geomorphic factors (*e.g.*, associated effects of scour, deposition, inundation, substrate texture). Stream power may be correlated with flood recurrence interval and wetted width. Units are given in lb ft^{-2}.

Time since last flood (categorical variable). The age (or time since last major resetting disturbance) of each sample point was determined from the GIS-based assessment of plan form channel dynamics (see Appendix E of Stillwater Sciences [2007]). Sample point age will provide some indication of how long vegetation has had to become established and grow (*i.e.*, successional stage). Age categories were developed relative to 2005 (the year of the aerial photographs upon which vegetation mapping was conducted) and determined by the floods that were mapped for the GIS assessment. Discharge records for the lower Santa Clara River indicate nine flood events in excess of 2,800 m^3s^{-1} (100,000 cfs) since 1930, with a maximum recorded flood event of 4,670 m^3s^{-1} (165,000 cfs) in January 1969, and a larger but ungauged event associated with the collapse of the St. Francis Dam in March 1928. The largest natural flood events correspond very clearly to the high intensity rainfall years associated with the El Niño Southern Oscillation, and correlate strongly with events every three to seven years as part of the recent wet period of the ENSO cycle since 1969 (Stillwater Sciences 2007). Fewer floods occurred in the dry period of 1944–1968. Time since last flood was associated with these major events and includes:

- <1 year (January 10, 2005 flood)
- 10 years (January 10, 1995 flood)
- 13 years (February 12, 1992 flood)
- 27 years (March 3, 1978 flood)
- 36 years (January 25, 1969 flood)
- 62 years (January 23, 1943 flood)
- 67 years (March 2, 1938 flood)
- >67 years

Wetted width (continuous variable). The wetted width of the 2-year and 50-year recurrence interval floods under current topographic conditions (*i.e.*, 2005) at each sample point was determined from the nearest HEC-RAS cross-section. Wetted width will serve as a proxy for floodplain width (which is difficult to ascertain in the threaded channel portions of the river) and is expected to give some indication of the effect of levee confinement. The wetted width variable could be correlated with stream power and flood recurrence interval. Units are given in feet.

Channel gradient (continuous variable). The channel gradient at each sample point will be determined from the closest HEC-RAS cross-section. Channel gradient was chosen as a variable to provide an indication of how longitudinal position along the channel effects vegetation composition. Channel gradient was calculated based on the HEC-RAS run for the 2-year and 50-year recurrence interval floods.

Longitudinal station (continuous variable). The longitudinal station of each sample point was determined from the closest HEC-RAS cross-section. Longitudinal station was chosen as a variable to provide an indication of how longitudinal position along the channel effects vegetation composition. Units are in feet, beginning at the mouth (0 feet) and extending up river 200,000 feet, or 37.9 mi (61 km) to the Ventura - LA County line.

Gaining vs. losing reaches (categorical variable). Whether a sample point was in a gaining vs. losing reach (*i.e.*, where groundwater levels are higher vs. lower than the stream channel) was determined based on the GIS coverage prepared for the Santa Clara River Enhancement and Management Plan (AMEC 2004 for "rising water" and the extent of green vegetation in the September 2005 orthophotography.

3.2.3 Linking vegetation data to physical site variables

Based on the vegetation and physical site data, two paired vegetation – physical variable datasets were developed. For the species specific data, physical site variables associated with the center of each mapped plot were queried from the Project Area GIS and stored in a database which was linked to the plant species cover information.

Alliance level vegetation maps were overlaid with the GIS layers of physical site data; all of these layers cover the entire analysis area (Figure 1-1). For each sample point (n=1,490; see discussion in Section 3.2.1), data on all of the physical site variables and vegetation alliance type were extracted from each GIS layers for that point or, in the case of data derived from the HEC-RAS hydraulic model, from the nearest channel cross-section.

3.2.4 Analysis methods

Plant species composition and physical site variables

Correlation between plant species distribution and physical site variables were assessed in the species-specific dataset assessed using multivariate techniques and simple regression between continuous variables. Comparisons between the distributions of two species our two vegetation alliances were made using two-tailed t-tests, assuming unequal variance due to differences in sample size and associated variation in the data. Correlations among species occurrences and between the species and physical site variables were assessed together using canonical correspondence analysis (CCA, see McCune and Grace 2002), a direct gradient analysis technique that has been useful in other riparian studies (*e.g.*, Fernández-Aláez *et al.* 2004, Baker and Walford 1995, Aguiar and Ferreira 2005, Goebela *et al.* 2006). Plant species occurring less than two times have been shown to result in instability in correspondence analysis (Tausch *et al.* 1995) and were excluded from the CCA. Prior to running CCA, correlations among physical site variables were checked and one of each pair of variables with a Pearson correlation coefficient greater than 0.70 were removed.

Vegetation alliance and physical site variables

Descriptive statistics of the seven physical site variables are presented as bar graphs by vegetation alliance (with one standard error). No species specific data is associated with these points; instead the areas have been classified to the alliance level using a combination of photo-interpretation and ground-truthing (see Stillwater Sciences and URS Corporation [2007] for more information). Sample sizes and variance differ among vegetation alliances; in some cases descriptive statistics for some vegetation alliances are discounted due to very high standard deviations and small sample sizes (*e.g.* < 10). Frequency distribution curves were used to explore hypothesis regarding the distribution of five common alliances in relation to key physical site variables: 1) Black Cottonwood (*Populus balsamifera*) Alliance, 2) Fremont Cottonwood (*P. fremontii*) Alliance, 3) Mixed Willow Forest Alliance, 4) Big Sagebrush (*Artemisia tridentata ssp. Parishii*) Alliance, and 5) Giant Reed (*Arundo donax*) Alliance.

Relationship between key species and physical site variables

Frequency distribution curves, simple regression analysis, non-parametric chi-square tests, and the two-tailed t-tests were used to test hypotheses that the distributions of several key species are related to some or all of the seven selected physical site variables. The key species examined are *Populus balsamifera* and *P. fremontii* (black and Fremont cottonwood), *Salix exigua*, *S. laevigata*, *S. lasiolepis*, and *S. lucida* (narrowleaf/sandbar willow, red willow, arroyo willow, and shining willow), *Baccharis salicifolia* , *Artemisia tridentata ssp. Parishii* (big sagebrush), and *Arundo donax*.

3.3 Results and Discussion

3.3.1 Relationships between plant species composition and physical site variables

Prior to the multivariate CCA of the species-specific dataset of 338 plots, one from each pair of highly correlated variables was removed. Pearson correlation coefficients exceeded 0.70 for several pairs of physical site variables, including channel gradient for the 2-year and 50-year recurrence interval flood (r = 0.84; 50-year channel gradient was removed), and between the 2-year channel gradient and station (r = 0.83; 2-year channel gradient was removed). The final CCA included 338 polygons (rows) and 88 species (columns) in the main matrix and 338 polygons with nine physical variables (columns) in the second matrix. All data were centered and standardized to unit variance, and ordination axes were scaled to optimize representation of the vegetation plots (rows; McCune and Grace 2002; McCune and Mefford 1999).

Eigenvalues indicate the amount of variation in the vegetation data that is captured in a particular ordination axis. In this case, 2.6 percent of the variation within the species data is represented by the first two ordination axes generated from the CCA (Table 3-2). This very low percent of species variation explained is a common outcome of CCA and not fully understood (Palmer 2007, Økland and Eilertsen 1994). Several experienced authors suggest it is not a reliable indicator of the veracity of the CCA analysis and should be largely ignored (Økland 1999). The Monte Carlo test is considered a more reliable indicator of statistical power of a CCA analysis (McCune and Grace 2002). This tests whether the eigenvalue for a particular axis is significantly different than if derived from a randomly distributed dataset. The eigenvalues for CCA axes 1 and 2 indicate that patterns seen in species distribution is significantly different from random (p = 0.012; Table 3-3). Although 2.6 percent is clearly a small proportion of the overall variation, the relationship among species and between the species distribution and physical site data is significant (p = 0.01) based on Monte Carlo tests (Table 3-3).

Table 3-2. Summary statistics for the first two canonical correspondence (CCA) axes.

Statistic[1]		Axis 1	Axis 2
Eigenvalue[2]		0.257	0.209
Variance in species data	% of variance explained	1.4	1.2
	cumulative % explained	1.4	2.6
Pearson Correlation, Species-Environment[2]		0.654	0.616
Kendall (Rank) Correlation, Species-Environment		0.468	0.467

[1] Total variance ("inertia") in the species data 17.7396.

[2] Eigenvalues indicate significance of correlations among physical variables and species distributions, and the percent of variation in species distribution explained by the physical site variables is presented as "% of variance explained".

[3] Correlation between sample scores for an axis derived from the species data and sample scores that are linear combinations of the environmental variables.

Table 3-3. The Monte Carlo test results for axis eigenvalues.

Real Data		Randomized Data (989 runs)			
Axis	Eigenvalue	Mean	Minimum	Maximum	P[1]
1	0.255	0.127	0.069	0.529	0.0120
2	0.205	0.091	0.060	0.185	--[2]

[1] P= proportion of randomized runs with species-environment correlation greater than or equal to the observed species-environment correlation (*i.e.*, p= (1+no. permutations>= observed)/(1+no. permutations)).

[2] P is not reported for axis 2 because using a simple randomization test for these axes may bias the values (McCune and Mefford 1999). However, the range of eigenvalues derived from randomly distributed data do not include the values calculated based on the real field data, indicating that correlations among species and environmental values represented in axis 2 is significantly different from random.

Through CCA, each of the 338 plots is assigned an axis score, or position related to how well plant species composition and physical site data are correlated to each axis. A biplot of vegetation plot distribution in relation to the three most strongly correlated physical site variables is presented in Figure 3-1. In this case, the 338 plots are broadly distributed along axes 1 and 2, based on the CCA scores derived for each plot.

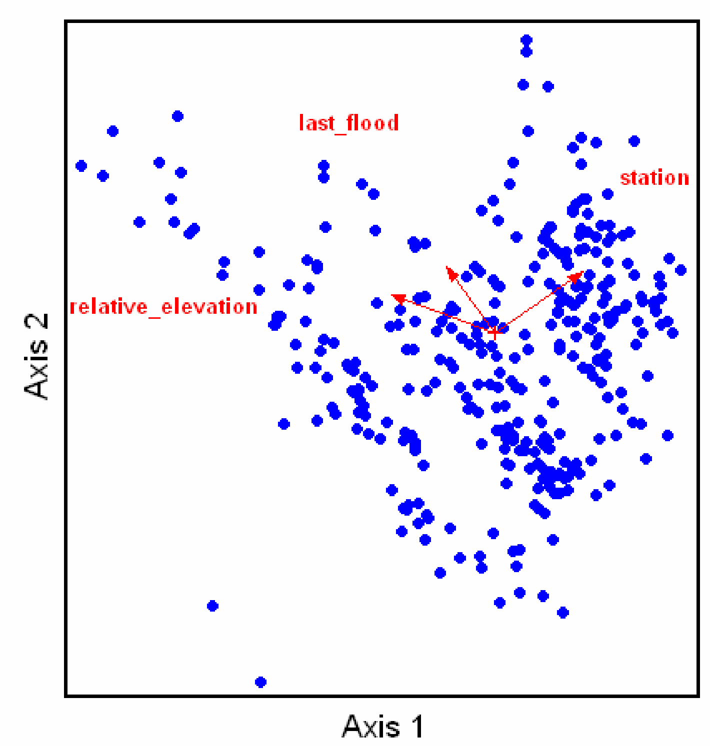


Figure 3-1. Biplot of 338 vegetation plots distributed along ordination axes 1 and 2. (Arrows represent environmental variables with the greatest correlation to the axes; arrow direction indicates the maximum correlation; arrow length is related to the strength of the correlation.)

Correlations among the CCA axes and the nine physical site variables are presented in Table 3-4. Axis 1 is strongly correlated to sample point elevation and station (longitudinal position along the river); axis 2 is most highly correlated to time since last flood and, to a lesser degree, station (Table 3-4).

Table 3-4. CCA correlations and biplot scores for physical site variables in relation to species composition (n=338).

Variable[1]			Biplot Scores	
	Axis 1	Axis 2	Axis 1	Axis 2
Relative Elevation	**-0.866**	0.58	-0.437	0.162
Time Since Last Flood	-0.400	**0.629**	-0.202	0.285
Recurrence Interval	-0.265	0.400	-0.134	0.182
Groundwater Reach	0.092	-0.044	0.047	-0.020
Stream Power (50-year flood)	0.063	0.171	0.032	0.077
Wetted Width (2-year flood)	0.089	-0.363	0.045	-0.165
Stream Power (2-year flood)	-0.169	0.092	-0.085	0.042
Wetted Width (2-year flood)	0.065	-0.381	0.033	-0.173
Station	**0.740**	**0.57**	0.374	0.261

[1] **Bold** indicates physical site variables most strongly correlated with axes 1 and 2.

From these test results, we can conclude that there is a significant relationship between riparian species composition and the physical variables measured. The physical variables most highly correlated to plant species composition include:

- Relative elevation above the channel thalweg;
- Distance from the river mouth (station); and
- Time since last flood.

To understand the distribution of the plant associations in the 338 plots, correspondence axes scores were averaged by super-alliance. The relationship between the fourteen super-alliances and the 56 vegetation alliances described in Stillwater Sciences and URS Corporation (2007) is presented in Appendix A. Biplot scores for all plots in each of the fourteen super-alliances were averaged and are presented, along with sample size (in parentheses) in Figure 3-2.

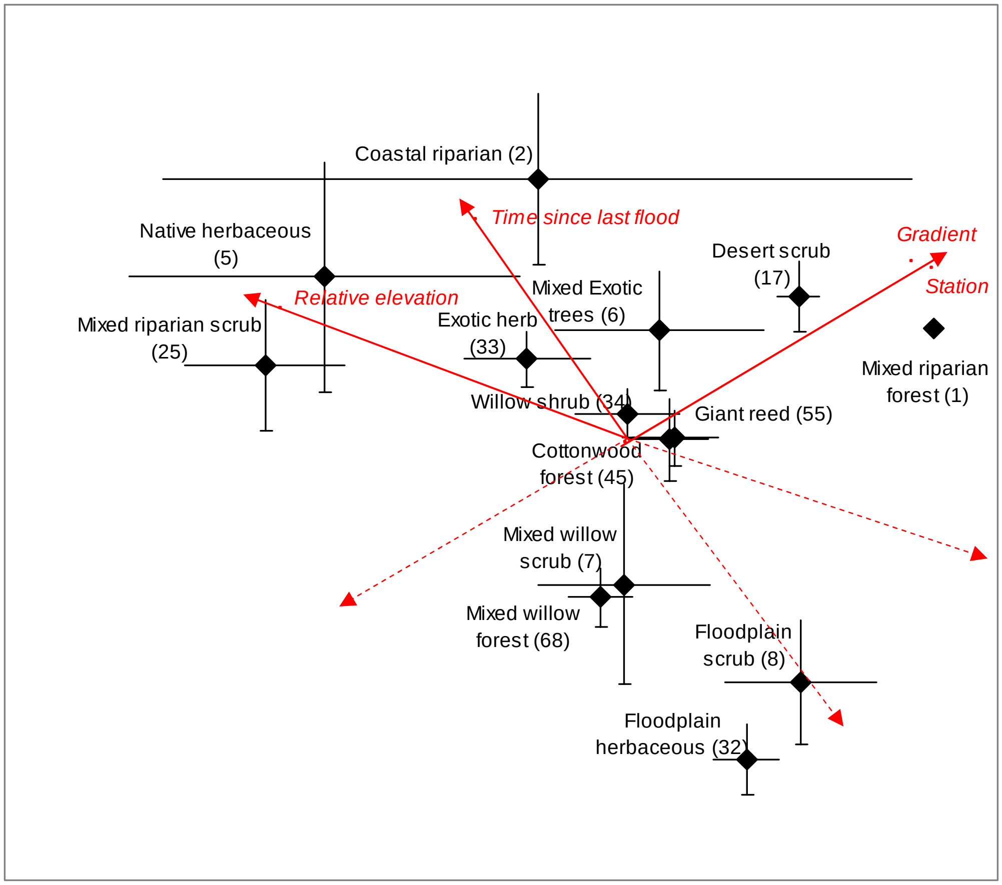


Figure 3-2. CCA plot scores on axes 1 and 2, averaged by super-alliance (n) (± 1 SE). The three physical variables most significantly correlated with the axes are shown in red.

Axis 1, the horizontal axis, reflects differences in relative elevation and distance from river mouth (station), whereas Axis 2, the vertical axis, reflects time since last flood, and to a lesser degree, distance from river mouth (station). Along the relative elevation vector, the Native Herbaceous and Mixed Riparian Scrub alliances occur at the highest relative elevations (farthest above the channel thalweg), whereas the Floodplain Herbaceous and Floodplain Scrub Alliances occur at the lowest (closest to the channel thalweg). Both Floodplain Scrub and Floodplain Herbaceous super-alliances occur in areas that have been flooded most recently (time since last flood), whereas the Exotic Herbaceous and Mixed Exotic Trees occur in areas that have been flood-free for the longest periods of time. Desert Scrub occurs farthest from the river mouth (station), while Willow Forest and Willow Scrub super-alliances tend to occur closer to the river mouth. The centroids of some of the most common super-alliances, including P*opulus*, *A. donax*, and *Salix* Shrub are close to the origin, indicating that they are well distributed along the major physical gradients.

Relative elevation can reflect one, some, or all of the following physical variables that have been found previously to be important in predicting riparian vegetation distribution in semi-arid streams: (1) differences in ground water availability during the dry season; (2) differences in stream power at different geofluvial surfaces (Bendix 1999); and/or (3) differences in flood frequency and duration at geofluvial surfaces (Bendix and Hupp 2000). However, differences in depth to ground water associated with gaining vs. losing reaches are not incorporated in this variable, reducing its predictive ability. By including time since last flood, differences between the effects of groundwater and stream power can be separated, to some degree, from the effects of flood frequency. As seen in Figure 3-2, the vectors for relative elevation and times since last flood are similarly oriented in the biplot. However, more species and plots fall along the low end of the time since last flood axis (*i.e.*, they occur in areas that were more recently flooded) than along the low end of the relative elevation axis (Figure 3-2). This suggests that the distribution of vegetation alliances is more strongly affected by how recently an area was flooded than by its relative elevation (*i.e.*, stream power and/or access to ground water). Vegetation alliances in this group include: Floodplain Scrub, Floodplain Herbaceous, to a lesser extent, Mixed Willow Forest and Mixed Willow Scrub (Figure 3-2).

In addition to the three variables presented in Figure 3-1 and Figure 3-2, wetted width and flood interval were also important correlates, particularly to the second axis (Table 3-4). Unlike several other studies of southern California riparian areas (*e.g.* Bendix 1994 and 1999), results from this study did not implicate stream power (*i.e.*, the ability of stream flow to do work such as scour and transport sediment) as a primary correlate to plant species distribution. Other researchers have aptly argued that since stream power is a measure of a stream's ability to erode and deposit sediment, or scour riparian vegetation, it could be an important factor controlling the establishment (via germination substrate creation) and survival (ability to survive scouring floods) of riparian species (Bendix 1994, Bendix 1999, Bendix and Hupp 2000). Stream power is primarily a function of discharge, channel gradient, and channel width and, under typical conditions, is expected to decrease towards the river mouth as the channel gradient decreases and the channel width increases. This does not occur in the lower Santa Clara River, however, due to local variations in channel gradient, increases in water and sediment input from Sespe Creek and other tributaries, flow diversion, and narrowing of the channel in the lowest reaches due to levees (Stillwater Sciences 2007). As a result of these factors, reach-scale estimates of stream power do not demonstrate a predictable longitudinal (upstream to downstream) pattern, with the highest stream power occurring below Sespe Creek and lowest above Sespe Creek (Stillwater Sciences 2007). As a result, reach-scale differences in stream power and longitudinal position (station) are separated in this system and longitudinal position comes out to be a stronger correlate to plant species distribution than differences in stream power (Table 3-4). Further, as Bendix (1999) points out, stream power varies across the channel cross-section as much as it does longitudinally. It is likely that the more generalized, cross-section averaged measure of stream power used in this study does not resolve the large and important variation in stream power that occurs across the cross-section, and therefore this measure did not come out as an important controller of plant species distribution.

3.3.2 Differences in distribution among vegetation alliances

In the following sections, the distribution of vegetation alliance sample points (n=1,490) in relation to physical site variables is discussed and graphs of alliance averages for each physical site variable are presented. Site variable averages by alliance, standard errors, maximums, and minimums are presented in Appendix B.

Distance from river mouth (Station)

The average distance from the river mouth of each vegetation alliance is presented in Figure 3-3. The *Tamarix* spp. Alliance is represented by only four sample points, and these all occur in the upper extent of the analysis area, close to the Ventura-L.A. County line. Since tamarisk seeds are known to effectively disperse via air and water (Bossard *et al.* 2000), this currently small population of tamarisk is well positioned to spread to downstream reaches of the lower Santa Clara River.

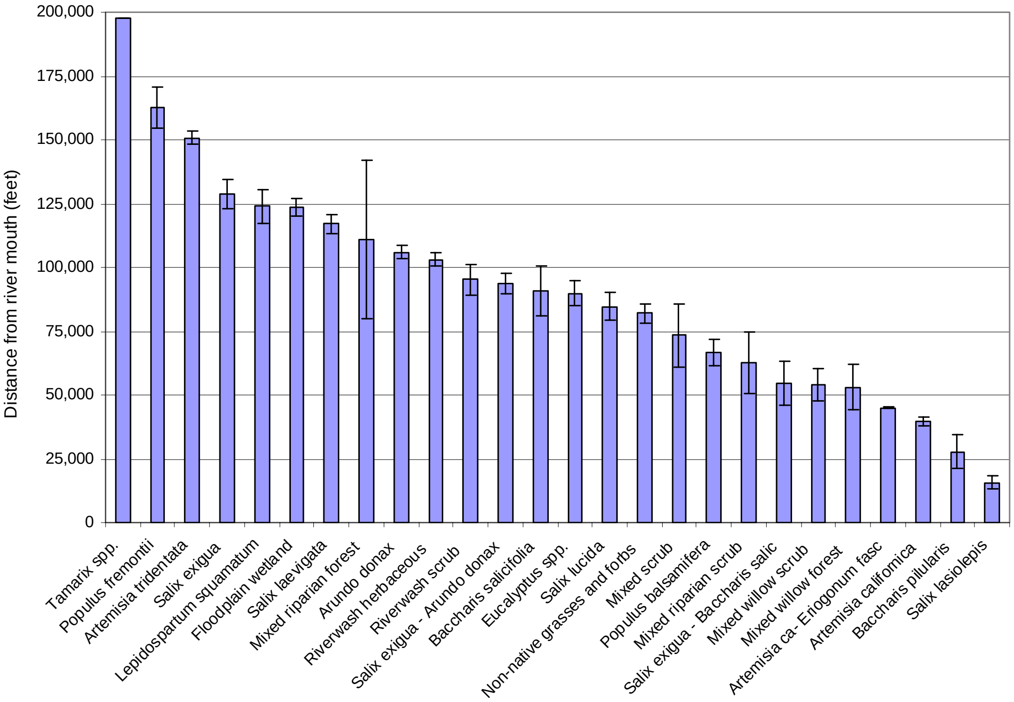


Figure 3-3. Average longitudinal position (± 1 SE) of vegetation alliances in the analysis area.

The average longitudinal position of the *Populus fremontii* Alliance is much farther upstream than that of the *P. balsamifera* Alliance (both are represented by 40 or more sample points), although there is substantial overlap between to two: the *P. fremontii* Alliance extends down to 45,000 ft (8.5 mi) from the river mouth, and the *P. balsamifera* Alliance extends up to approximately 100,000 ft (18.9 mi) (see Appendix B). The *Salix exigua*, *S. laevigata*, and *S. lucida* Alliances tend to occur farther inland than the *S. lasiolepis* Alliance; and the *S. lucida* Alliance generally occurs at distances over 100,000 ft (18.9 mi) from the river mouth. As expected, the distribution of drier site alliances, such as *Artemisia tridentata* ssp. *parishii* and *Lepidospartum squamatum* (scalebroom) are located in the upper reaches of the analysis area.

The Floodplain Wetland Alliance is generally located toward the inland part of the analysis area: the average distance from the river mouth is 123,550 ft (23.4 mi) (Appendix B). The large number of samples of this alliance (n=139) results in small standard errors, when in fact, the alliance ranges from 20,000 to 186,000 ft (3.8 to 35.2 mi) from the river mouth. The infrequent occurrence of this alliance in the lower 10 miles of the river could be a result of the narrow floodplain in this highly confined reach of the river (Stillwater Sciences 2007).

Relative elevation

The average elevation above the channel thalweg (relative elevation) of each vegetation alliance is presented in Figure 3-4. As expected, the Floodplain Wetland and Riverwash Herbaceous alliances occur at the lowest relative elevations, while *Eucalyptus*, *Baccharis pilularis* (coyote bush), and *Artemisia californica* (coastal sagebrush) alliances occur at the highest relative elevations (Figure 3-4). Interestingly, the *Artemisia tridentata* Alliance occurs, on average, at low relative elevations (approximately 5 ft). Several alliances, such as *Salix exigua-Baccharis salicifolia* (narrowleaf willow-mulefat) and *Artemisia californica* (California sagebrush), Mixed Willow Scrub, and *Baccharis salicifolia*, have both large sample sizes and large standard errors, suggesting that these alliances occur across a wide range of relative elevations (Figure 3-4). Alliances dominated by *S.lucida*, *S. exigua*, and *S. laevigata* tend to occur at lower relative elevations (within 6 ft), whereas *S.lasiolepis* dominated areas tend to occur higher above the channel (approximately 12 ft).

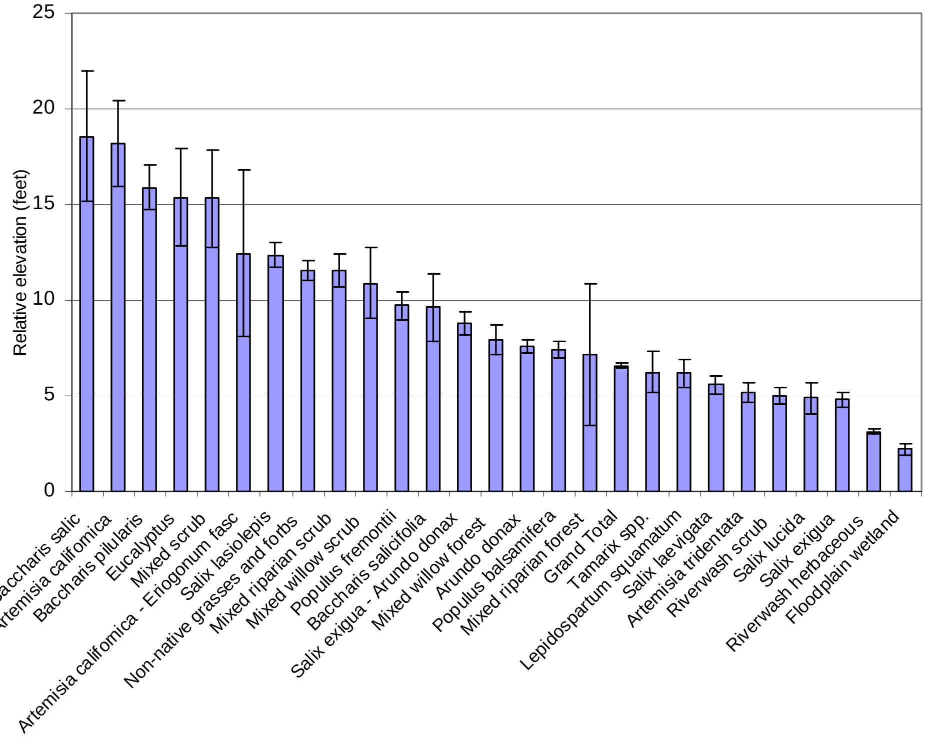


Figure 3-4. Average relative elevation (± 1 SE) of vegetation alliances in the analysis area.

Flood recurrence interval and time since last flood

Because time since last flood was more strongly correlated than recurrence interval to species distribution among the vegetation plots in the CCA analysis (Figure 3-4), the vegetation alliances are presented in order of time since last flood in Figure 3-5, along with the associated average flood recurrence interval.

The time scales differ between these two variables, as well as the degree of variation among alliances. As expected, the Riverwash and Floodplain Wetland alliances occur in the most recently flooded areas with the shortest estimated flood recurrence interval, whereas *Eucalyptus*, *Baccharis pilularis*, and *Artemisia* alliances tend to occur in areas that have been flood-free for longer periods of time (Figure 3-5). Similar to the pattern observed in relative elevation, all of the willow dominated alliances except *S. lasiolepis* tend to occur in recently flooded areas. The average time since last flood of the *Arundo donax* Alliance is short, similar to that of the *Salix* and *Populus* alliances.

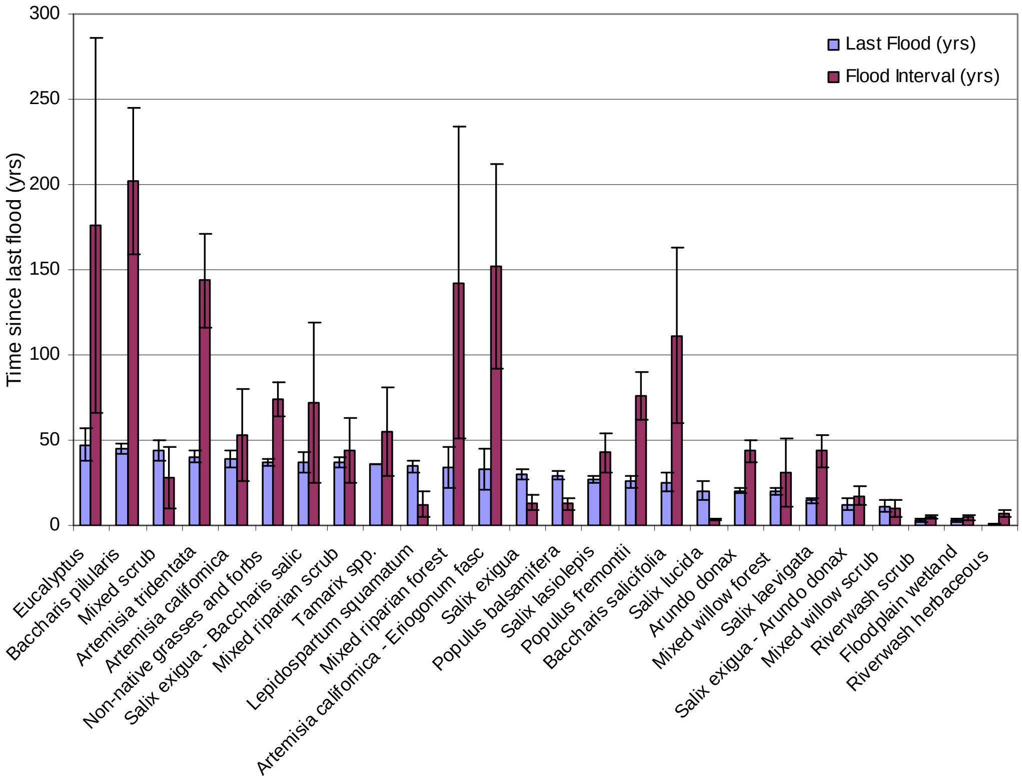


Figure 3-5. Average time since last flood and flood recurrence interval (± 1 SE) of vegetation alliances in the analysis area.

Stream power

The average stream power of the 2- and 50-year recurrence interval flood of vegetation alliances is presented in Figure 3-6. In Figure 3-6, vegetation alliances are sorted in order of the power at the 50-year recurrence interval because this is believed to be the more important discharge event geomorphically (Figure 3-6). It is interesting to notice the lack of agreement between the 50-year and 2-year recurrence interval data sets, and recognize the difficulty of determining the most important flow in terms of plant species distribution. Results from the CCA indicate that the two measures of stream power are similarly and weakly correlated with plant species composition (see Table 3-4), but weakly correlated with each other ($R^2 = 0.143$; $p < 0.001$, $n = 338$). As discussed above in Section 3.3.1, this is likely due to the similar lack of influence of these reach-averaged variables on plant species distribution. Measures of stream power that are specific to geofluvial surface (*e.g.*, floodplain terrace or channel thalweg) are more likely to reflect differences in plant species distribution (Bendix 1999, Bendix and Hupp 2000).

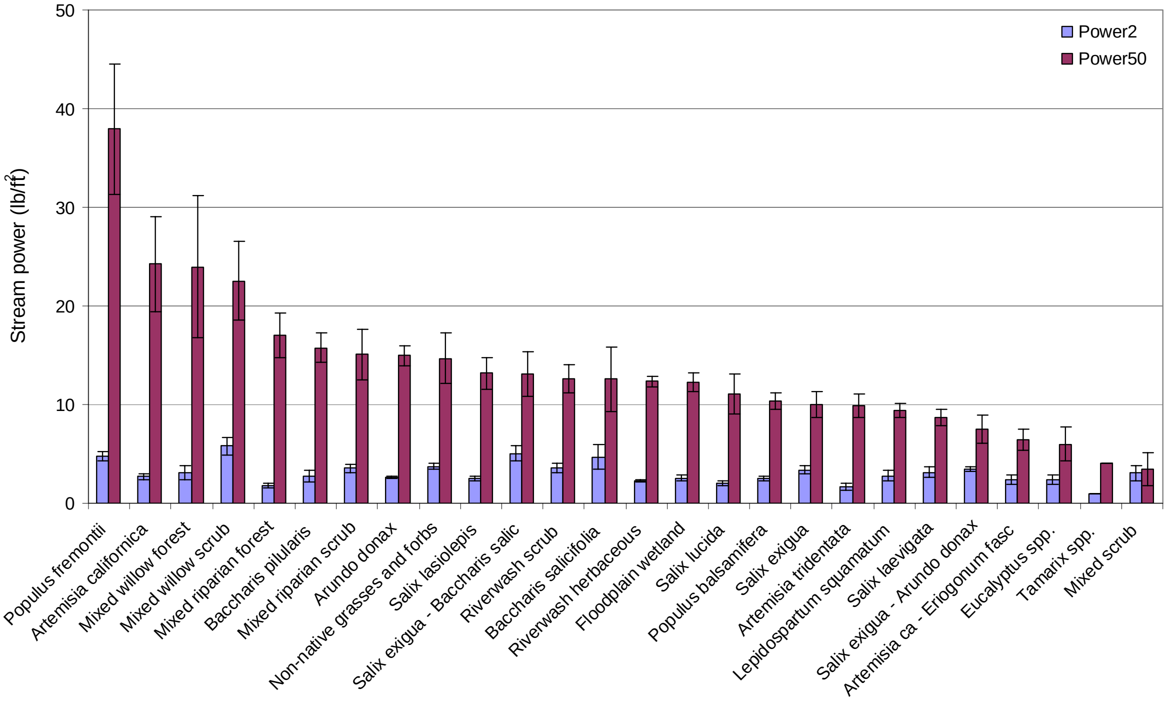


Figure 3-6. Average stream power at the 2- and 50-year recurrence interval flood (± 1 SE) of vegetation alliances in the analysis area.

Channel gradient

Channel gradient at the 2- and 50-year recurrence intervals are highly correlated ($R^2 = 0.73$) and channel gradient is strongly and positively correlated to longitudinal position ($R^2 = 0.68$). Thus, differences in average channel gradient among vegetation alliances are likely to reflect the effects of one or both of these co-varying characteristics. Average channel gradient for each vegetation alliance is presented in Figure 3-7.

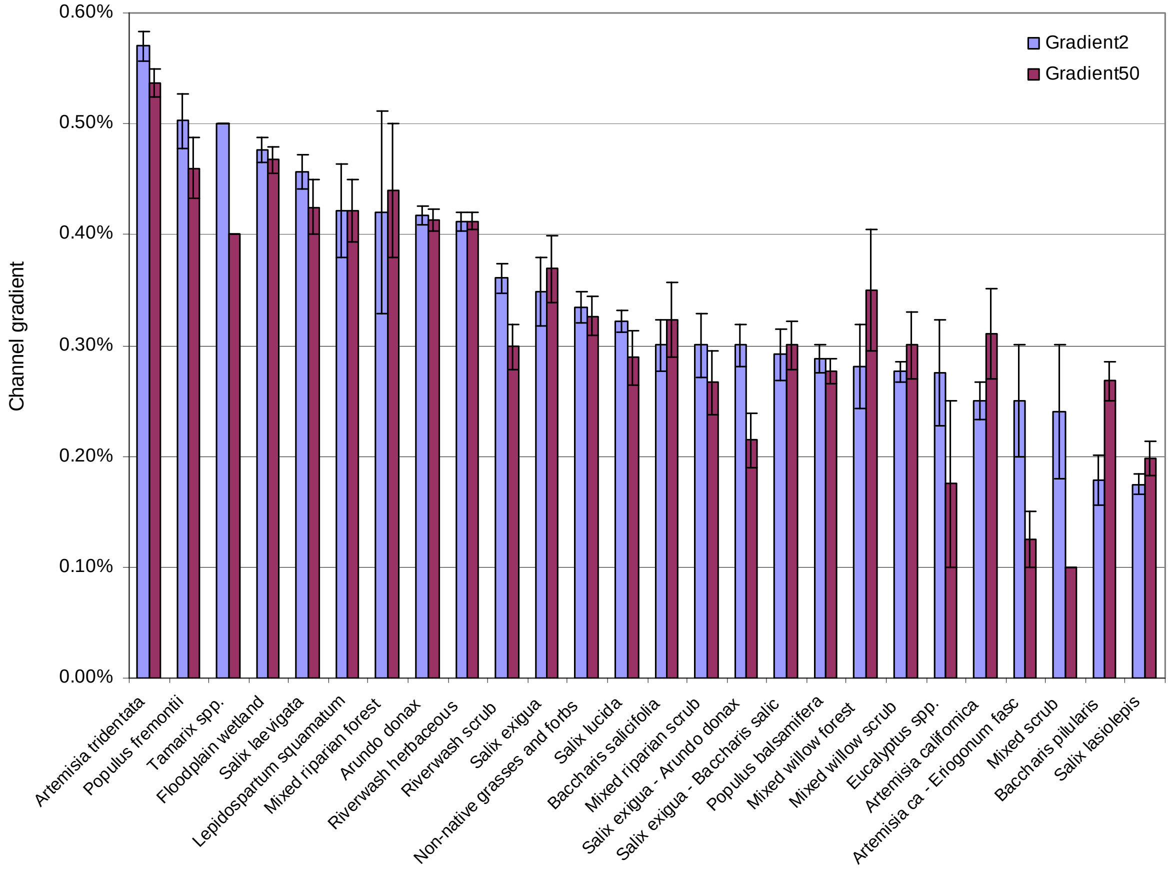


Figure 3-7. Average channel gradient at the 2- and 50-year recurrence interval flood (± 1 SE) of vegetation alliances in the analysis area.

Wetted width

The wetted width of the channel during the 50-year recurrence interval flood at the 1,490 vegetation alliance sample points is plotted against distance from the river mouth in Figure 3-8. Theoretically, one would expect the 50-year floodplain width to increase consistently from the headwaters to the river mouth as the channel experiences increased stream flow and becomes more alluvial in nature. As illustrated in Figure 3-8, the lower Santa Clara River follows this expected pattern from 200,000 ft downstream to approximately 100,000 ft (20 mi) from the river mouth. Downstream of 100,000 ft, however, the 50-year floodplain narrows as a result of natural geologic constraints placed along the southern valley wall by South Mountain (Stillwater Sciences 2007). Below approximately 50,000 ft (10 mi), levees and bank revetments constrain the 50-year floodplain until it broadens out again near the river mouth (Stillwater Sciences 2007).

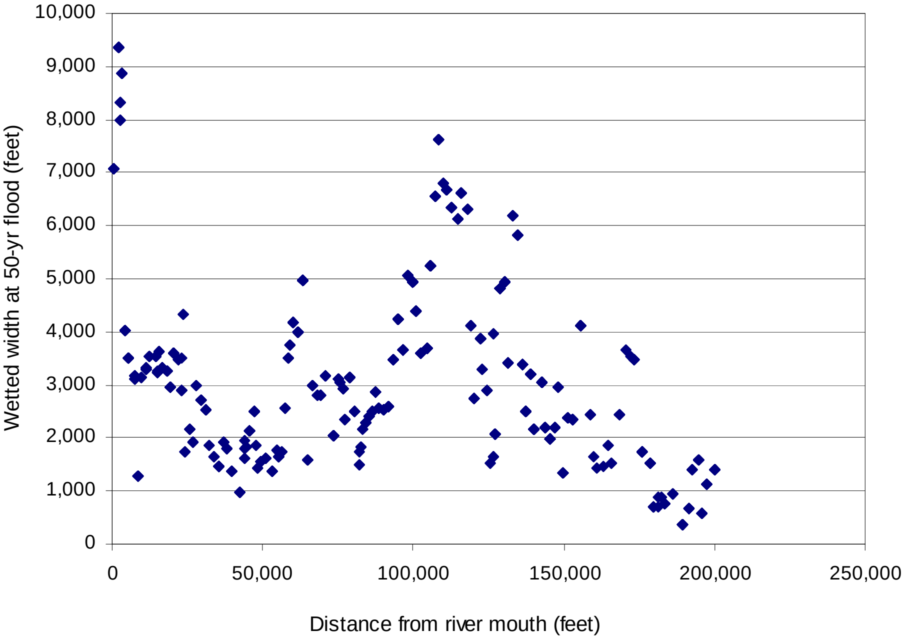


Figure 3-8. Wetted width during the 50-year recurrence interval flood as a function of distance from river mouth at each of the 1,490 vegetation alliance sample points.

Several common vegetation alliances, such as *Lepidospartum squamatum*, *Baccharis pilularis*, and those with *S. exigua* as a dominant or co-dominant species (*S. exigua* and *Salix exigua-Baccharis salicifolia*) occur primarily in broad reaches, where the width of the 50-year floodplain exceeds 2,000 ft (Figure 3-9; Appendix B). *Lepidospatum squamatum* and most of the *S. exigua* dominated alliances occur over 1,000 ft from the river mouth, in less confined reaches of the lower Santa Clara River. The *Baccharis pilularis* Alliance, meanwhile, ranges from the confluence of Sespe Creek to the coast, the most highly constrained part of the lower river. The *B. pilularis* Alliance, however, only occurs in areas where the 50-year floodplain exceeds 3,000 ft in width, indicating a preference for less confined reaches (Figure 3-9; Appendix B). While the *Arundo donax* Alliance occurs throughout the range of 50-year floodplain widths, the *S. exigua-Arundo donax* Alliance only occurs in relatively narrow reaches (approximately 2,300 to 3,100 ft wide), in contrast to the other S. *exigua* alliances described above. This corroborates the earlier observation that the *S. exigua-Arundo donax* Alliance occurs on surfaces subject to more frequent flooding, since this alliance was, on average, flooded more recently than the other S. *exigua* dominated or co-dominated alliances (Figure 3-5; Appendix B).

Other vegetation alliances, such as *Artemisia californica*, Mixed Riparian Scrub, and Mixed Scrub, occur more often in naturally narrow or levee confined reaches that are less than 2,500 ft wide (Figure 3-9; Appendix B). The Mixed Scrub and Mixed Riparian Scrub alliances occur throughout the length of the lower Santa Clara River, while the *Artemisia californica* Alliance only occurs in the lower 50,000 ft of the river.

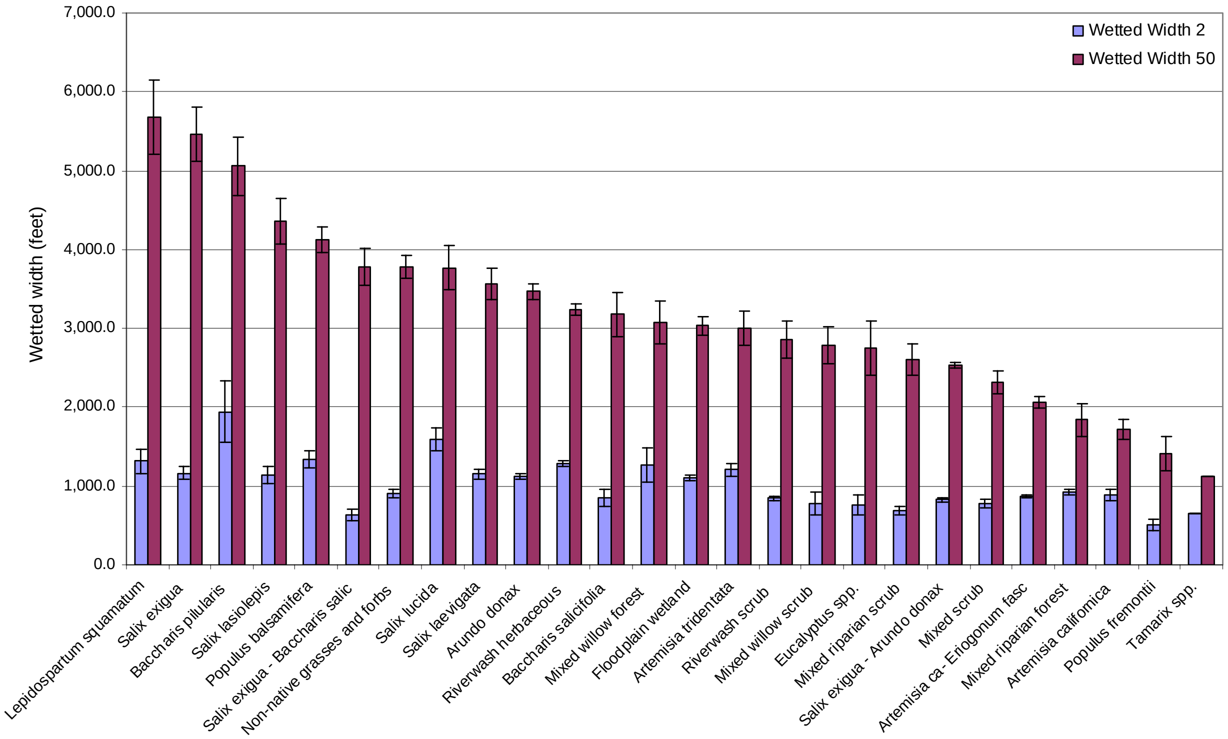


Figure 3-9. Average wetted width at the 2- and 50-year recurrence interval flood (± 1 SE) of vegetation alliances in the analysis area.

Gaining vs. losing reaches

We examined the frequency with which vegetation alliances occur in gaining vs. losing reaches of the river and compared them with the ‘expected’ unbiased frequency, 54 percent, of gaining reaches in the full 1,490 dataset (red line in Figure 3-10). Alliances that occur in gaining reaches well above the unbiased frequency of 54 percent are expected to prefer higher groundwater conditions, while alliances found in gaining reaches much less than 55 percent of the time are expected to tolerate lower and/or less reliable groundwater conditions. Several alliances at the highest range of occurrences in gaining reaches have very with small sample sizes and and therefore average data for these alliances should not be used to reliably interpret ecological preferences (Figure 3-10). Other alliances represented by over 10 sample points show clear biases for gaining or losing reaches. The two *Populus* alliances, as well as several willow-dominated alliances (*e.g.*, Mixed Willow Scrub, *Salix laevigata*, and *Salix lasiolepis*) occur much more frequently in gaining reaches than would be expected were they randomly distributed. Similarly, *S.exigua*, *Artemisia tridentat*a and *Lepidospartum squamatum* alliances occur predominantly in losing reaches.

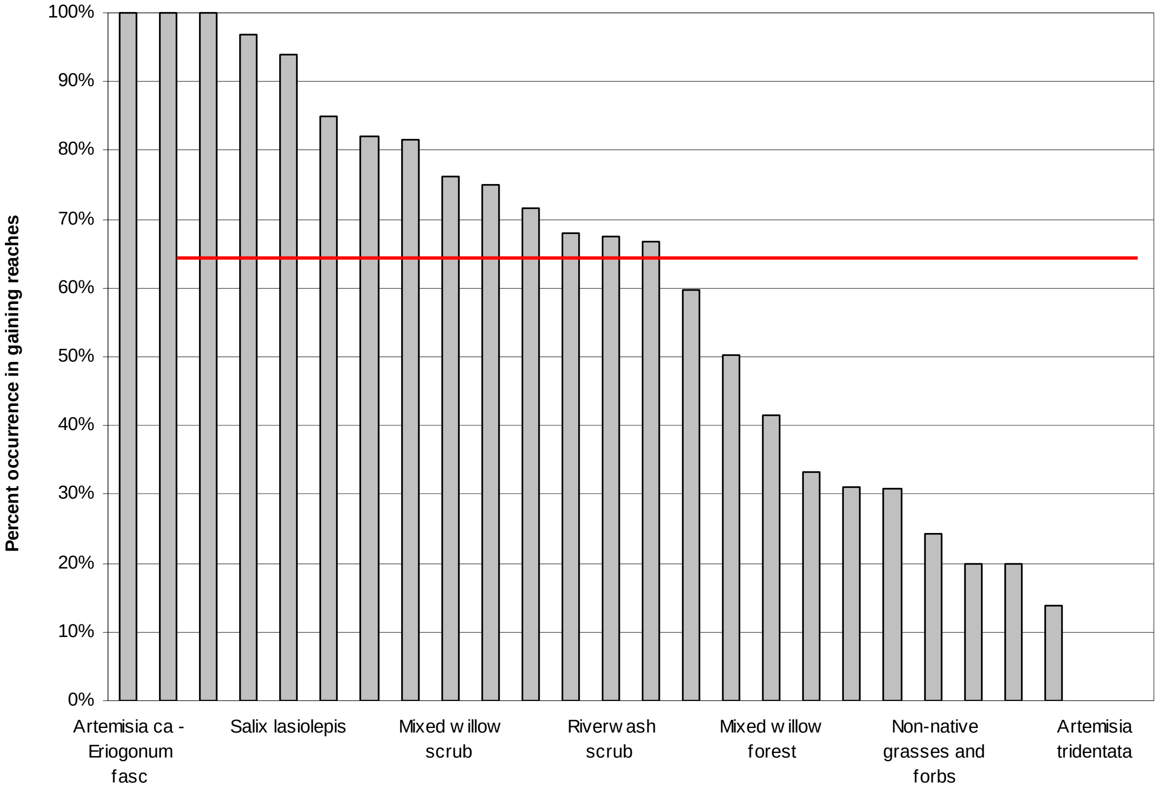


Figure 3-10. The percent occurrence of vegetation alliances (n) in gaining reaches. The percent of gaining reaches in the analysis area (54%) is represented by a red line to indicate the expected unbiased frequency of vegetation alliances in gaining reaches.

3.3.3 Distribution of key vegetation alliances and dominant species in relation to physical site variables

Using the alliance dataset of 1,490 points, we examined the distribution of five ecologically significant native and non-native vegetation alliances in relation to the three principle physical correlates identified in the CCA: relative elevation; distance from river mouth; and time since last flood. The five vegetation alliances examined were:

- *Populus balsamifera* (black cottonwood);
- *Populus fremontii* (Fremont cottonwood);
- *Artemisia tridentata* (Califonia sagebrush);
- Mixed Willow Forest; and
- *Arundo donax* (giant reed).

In addition, we investigated the relationship between eight dominant species in these five vegetation alliances and the three key physical site variables using the species-specific dataset (see Section 3.2.4). Since the photo-interpretation used to develop the alliance dataset used the species-specific dataset to provide 'ground truthing', these two datasets cannot be considered independent. However, they do include two different sets of sample sites within the lower Santa Clara River.

Populus alliances and species distribution

Relative elevation. The frequency of *Populus balsamifera* Alliance sample points (n=65) and *P. fremontii* Alliance sample points (n=40) in relation to relative elevation is presented in Figure 3-11. Differences in frequency distribution between these alliances are not statistically significant (p>0.10; two-tailed t-test, assuming unequal variance), but both alliances are clustered below 12 ft (Figure 3-11).

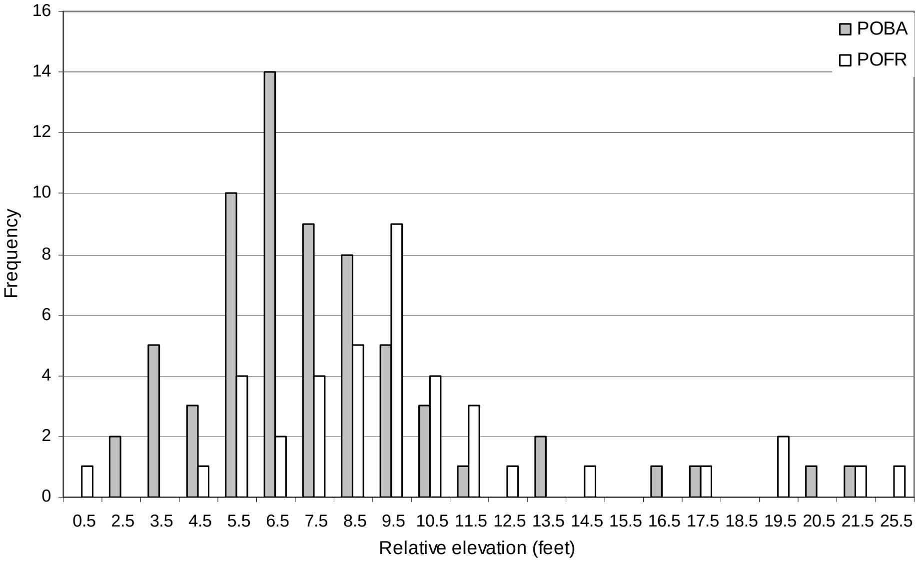


Figure 3-11. Frequency of *Populus balsamifera* (POBA) and *Populus fremontii* (POFR) alliance sites in relation to relative elevation.

The distributions of *P. fremontii* (n=64) and *P. balsamifera* (n=73) percent cover from the species-specific dataset versus relative elevation are presented in Figure 3-12. This dataset reflects a similar pattern to the alliance dataset, with both species occurring more frequently and at higher percent covers below 12 ft, relative elevation. *Populus fremontii* occurs at statistically lower relative elevations than the rest of the sites in the species-specific database (5.8 ft vs. 7.7 ft; p=0.003; two-tailed t-test, assuming unequal variance). There is no statistical difference in the elevation distributions of the *P. fremontii* and *P. balsamifera* by percent cover (p>0.10; two-tailed t-test, assuming unequal variance).

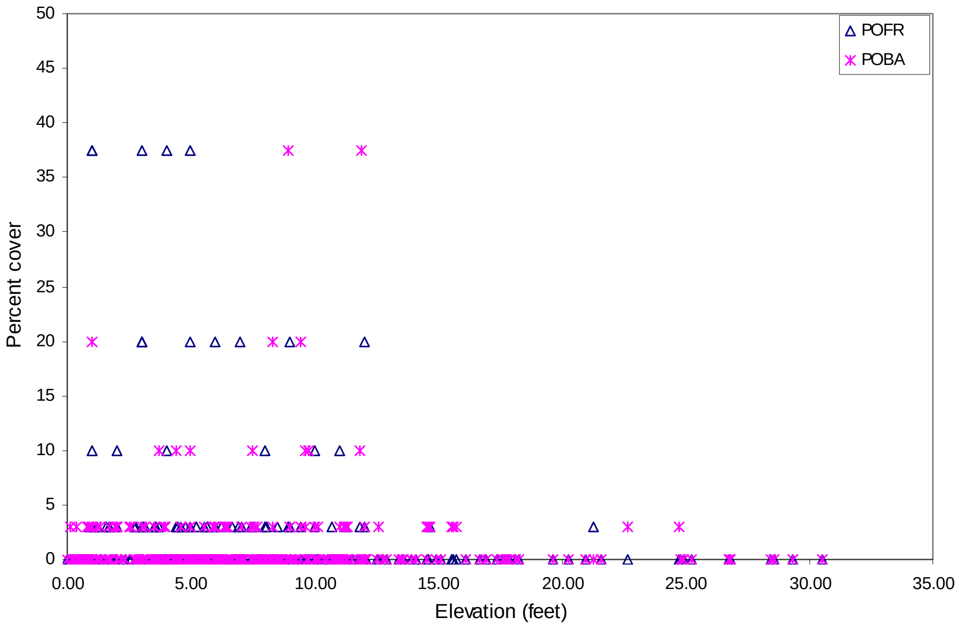


Figure 3-12. Distribution of *Populus balsamifera* (POBA) and *Populus fremontii* (POFR) percent cover in relation to relative elevation.

Distance from river mouth. The frequency of *P. fremontii* and *P. balsamifera* alliances in relation to distance from the river mouth is presented in Figure 3-13. There is some overlap of these alliances in the middle reaches (approximately 95,000 ft), particularly just below the Sespe Creek confluence. The *Populus balsamifera* Alliance, however, also occurs downstream of 25,000 ft, while the *P. fremontii* Alliance occurs in the upper reaches of the analysis area (Figure 3-13).

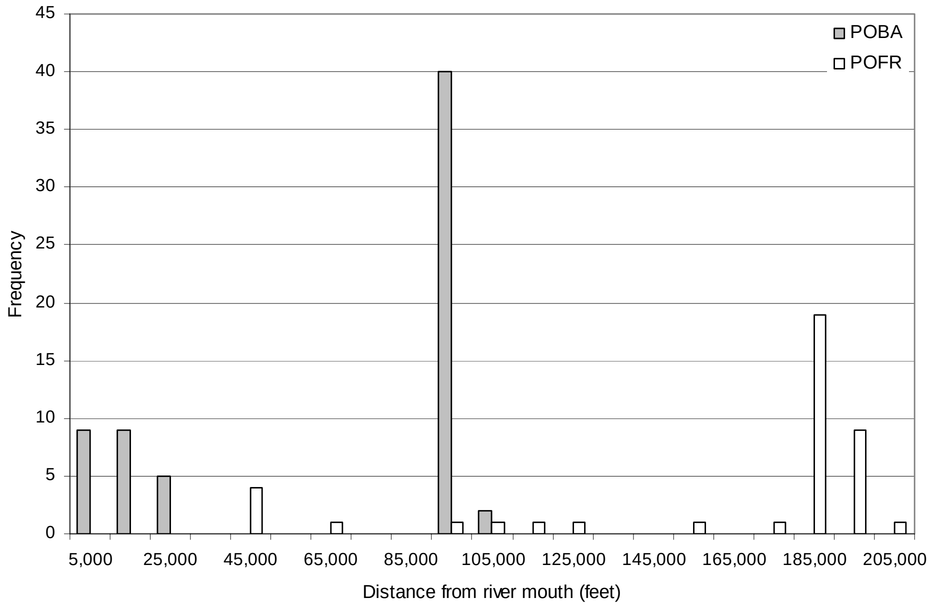


Figure 3-13. Frequency of *Populus balsamifera* (POBA) and *Populus fremontii* (POFR) alliances in relation to distance from the river mouth.

The longitudinal distribution of *Populus fremontii* and *P. balsamifera* in the species-specific database is presented in Figure 3-14. This graph presents a broader distribution for both species than the alliance dataset (Figure 3-13) since the species-specific dataset includes all sites where the species occur, rather than only those where they are dominant. Many miles of overlap at the three percent cover level occur below 100,000 ft (18 mi), or the Sespe Creek confluence. *Populus fremontii* occurs throughout the analysis area, while *P. balsamifera* is confined to reaches below approximately 100,000 feet (Figure 3-13). In the area of distributional overlap, *P. fremontii* does not occur over five percent cover, while *P. balsamifera* cover ranges from three to 37.5 percent in the same area, suggesting that *P. balsamifera* is more successful in these intermediate areas than *P. fremontii*. In spite of the overlap, the difference in longitudinal position between the species is significant ($p < 0.001$; two-tailed t-test). *Populus fremontii* also occurs in areas with narrower 50-year wetted widths than *P. balsamifera* ($p < 0.01$; two-tailed t-tests assuming unequal variance). This is likely a reflection of *P. fremontii*'s general distribution in the upper, narrower reaches of the analysis area (see Figure 3-8).

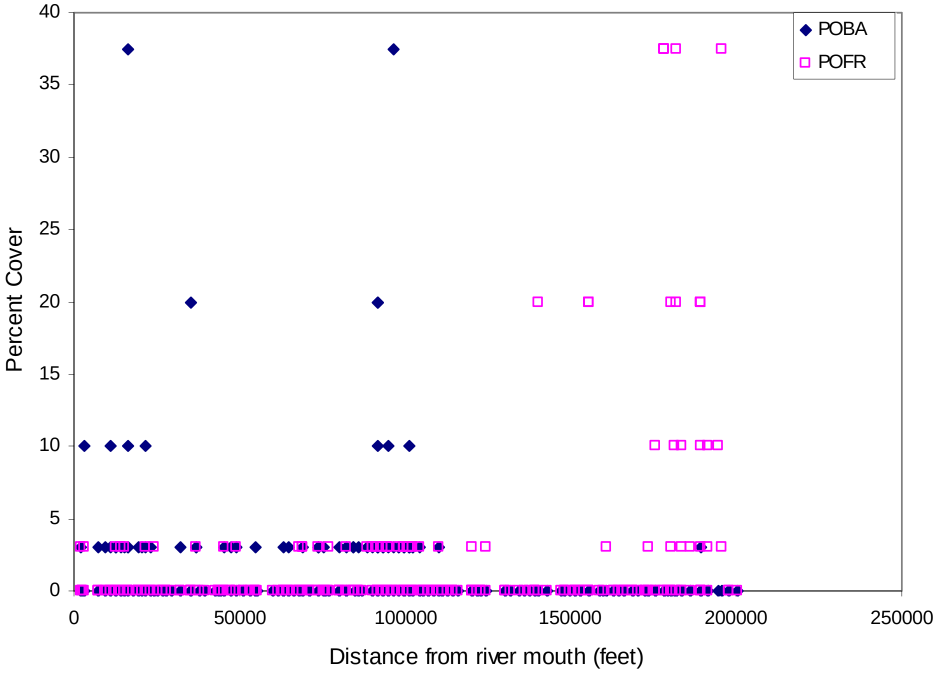


Figure 3-14. Distribution of *Populus balsamifera* (POBA) and *Populus fremontii* (POFR) percent cover in relation to distance from river mouth.

Time since last flood. Figure 3-15 presents the frequency of *P. fremontii* and *P. balsamifera* alliances in relation to time since last flood and shows no clear trend towards more or less recently flooded sites for either alliance. The greatest frequency of *Populus* alliances, however, occur at relative elevations associated with floods that typically exceed the 15-year recurrence interval, with the exception of the most recent flood event in 2005 (Stillwater Sciences 2007). Other, smaller floods occurred 13, 19, 22, 25, 29, 39, and 40 years ago, but do not correlate to surfaces supporting either of the *Populus* alliances. These findings suggest that many of the *P. fremontii* and *P. balsamifera* stands are cohorts established following the largest floods over the past half-century. There was not sufficient time between the 2005 flood event, which was among the largest on record (Stillwater Sciences 2007), and the 2005 mapping of vegetation alliances (Stillwater Sciences and URS Corporation 2007) for the development of *Populus* forests, although *Populus* seedlings were abundant and widespread during the mapping (B. Orr, *pers. obs.*).

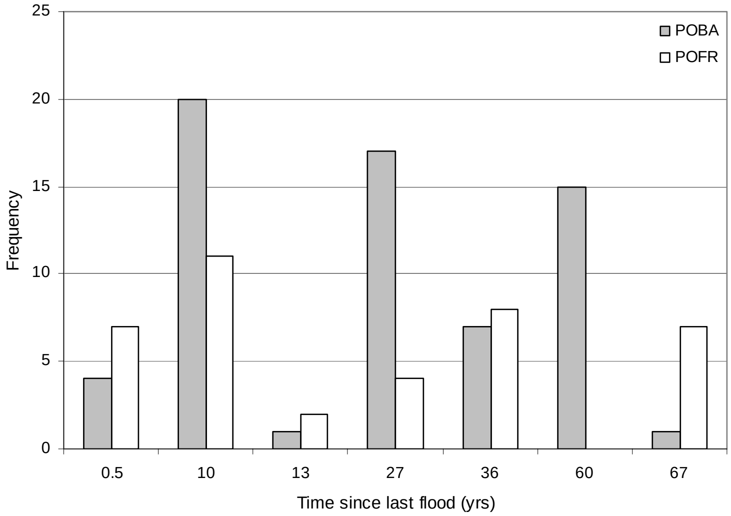


Figure 3-15. Frequency of *Populus balsamifera* (POBA) and *Populus fremontii* (POFR) alliances in relation to time since last flood.

The frequency of *P. fremontii* and *P. balsamifera* from the species-specific dataset by time since last flood is presented in Figure 3-15. The same major flood events (1995, 1978, and 1969) are evident in this analysis as with the alliance dataset (Figure 3-14), but using the species-specific data reveals the abundance of *Populus* seedlings that occurred in many plots following the 2005 flood. The high frequency of *Populus* following the 2005 flood is primarily a function of *Populus* presence, rather than percent cover (which was relatively low). This suggests that new cohorts of *P. fremontii* and *P. balsamifera* are establishing on recently flooded area and could contribute to the extent of the *P. fremontii* and *P. balsamifera* alliances in the future.

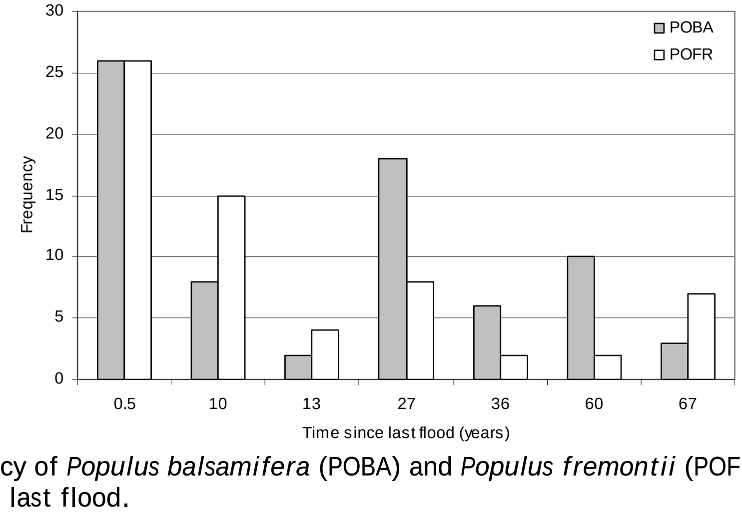


Figure 3-16. Frequency of *Populus balsamifera* (POBA) and *Populus fremontii* (POFR) percent cover in relation to time since last flood.

Gaining vs. losing reaches. The unbiased frequency of plant species in gaining reaches is approximately 17 percent (60 out of 338 plots occur in gaining reaches). Therefore, species that occur in gaining reaches over 17 percent of the time are expected to prefer higher groundwater conditions, while species found in gaining reaches less than 15 percent are expected to tolerate lower and/or less reliable groundwater conditions. *Populus fremontii* and *P. balsamifera* occur in gaining reaches approximately 68 percent of the time, demonstrating a clear preference for higher groundwater conditions and agreement with the alliance dataset results (Section 3.3.2).

Summary. *Populus fremontii* and *P. balsamifera* are both common riparian forest species along the lower Santa Clara River. *Populus fremontii* has a wider geographic range and is the only *Populus* species found above the confluence with Sespe Creek (105,000 ft [19 mi] from the river mouth) to the upstream extent of the analysis area. Large flood events (*i.e.*, with recurrence intervals exceeding 15 years) appear to encourage the development of *Populus* forests, although these same flood events also encourage *Salix* spp. and *Arundo donax* establishment (see below).

The only measured differences between *P. fremontii* and *P. balsamifera* other than distance from river mouth were covariates to that variable, including stream gradient and floodplain width; *P. fremontii* tends to occur along steeper gradients and narrower areas, both of which are characteristic of the upper reaches of the lower Santa Clara River where *P. fremontii* dominates. *Populus balsamifera* is known to be the more drought-intolerant of the two species, which is probably what restricts its extent to the moister, coastal areas or, outside of the analysis area, to higher elevation sites (*e.g.*, the upper Sespe Creek watershed). Like other riparian species, both species showed a significant preference for gaining reaches where summer water supply is assumed to be more reliable.

Mixed Willow Forest Alliance and willow species distribution

Several *Salix* species are dominant or co-dominant in the Mixed Willow Forest Alliance. Typically two or more *Salix* species (*Salix laevigata*, *S. lasiolepis*, or *S. lucida* ssp. *lasiandra*) dominate the tree layer, and are co-dominants in the shrub layer, along with *S. exigua* and *Baccharis salicifolia*. The distribution of this alliance, as well as the distributions of the *Salix* species that are common to it, are examined in this section. The Mixed Willow Forest Alliance is represented by 52 sample points from the alliance dataset. Associated willow species are represented by the following sample sizes from the species-specific dataset:

- *S. exigua* (SAEX) n = 154
- *S. laevigata* (SALA) n = 127
- *S. lasiolepis* (SALS) n= 127
- *S. lucida* (SALU) n = 42

Relative elevation. The Mixed Willow Forest Alliance occurs most often below 12 ft in relative elevation (Figure 3-17), with the highest frequency of the alliance occurring at 8 ft.

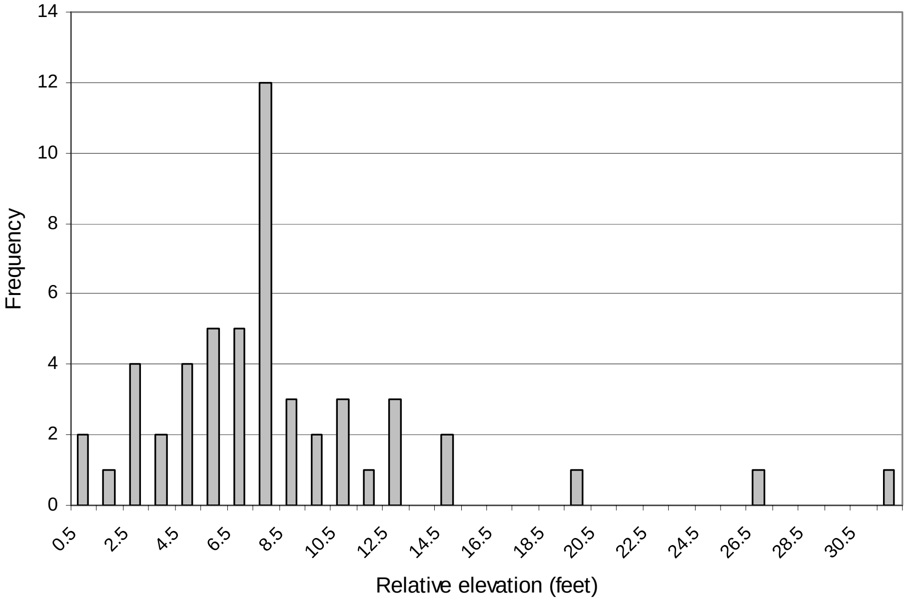


Figure 3-17. Frequency of Mixed Willow Forest Alliance in relation to relative elevation.

The species-specific dataset agrees with the alliance-based analysis, with *Salix* species generally occurring below 12 ft in relative elevation (Figure 3-18). *Salix lucida* is more often found within 8 ft relative elevation (p = 0.18; Chi Square test), whereas the other three willow species show no discernable preference for relative elevations within 12 ft relative elevation.

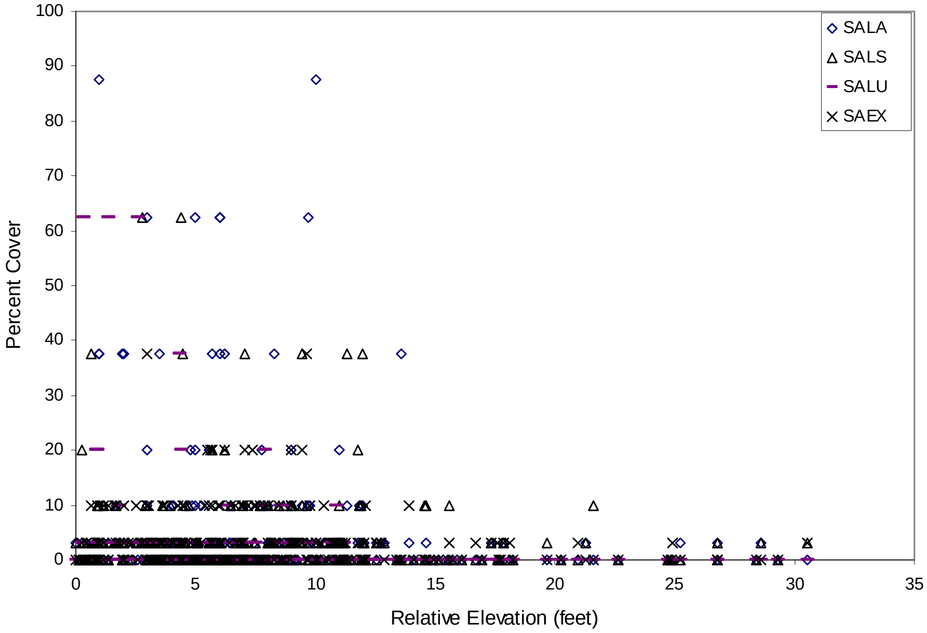


Figure 3-18. Distribution of *Salix laevigata* (SALA), *S. lasiolepis* (SALS), *S. lucida ssp. lasiandra* (SALU), and *S. exigua* (SAEX) percent cover in relation to relative elevation.

Distance from river mouth. Mixed Willow Forest Alliance occurs throughout the analysis area, showing no preference for the upper, mid or lower reaches of the lower Santa Clara River (Figure 3-19).

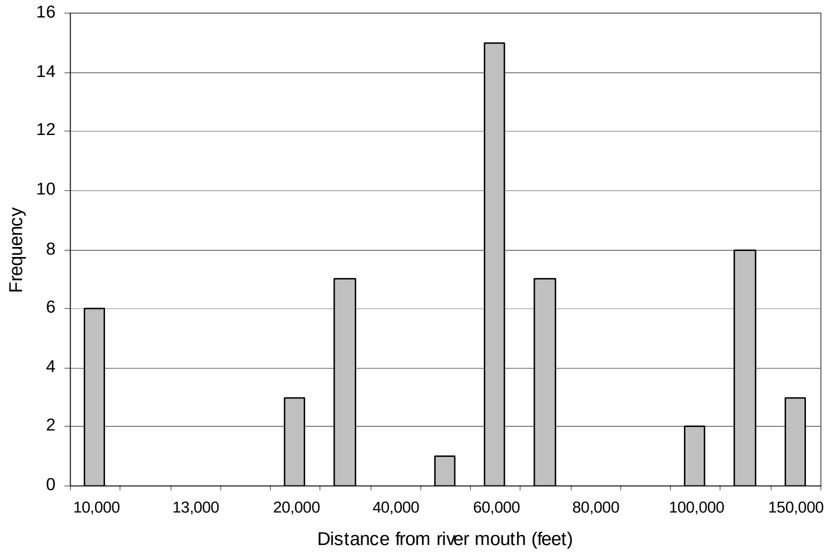


Figure 3-19. Frequency of Mixed Willow Forest Alliance in relation to distance from the river mouth.

Longitudinal distribution of the four *Salix* species varies (Figure 3-20). *Salix lasiolepis* occurs in greatest abundance closer to the river mouth; *S. lucida* occurs most along the mid-reaches; and *S. laevigata* and *S. exigua* occur most often along the mid and upper reaches (Figure 3-20).

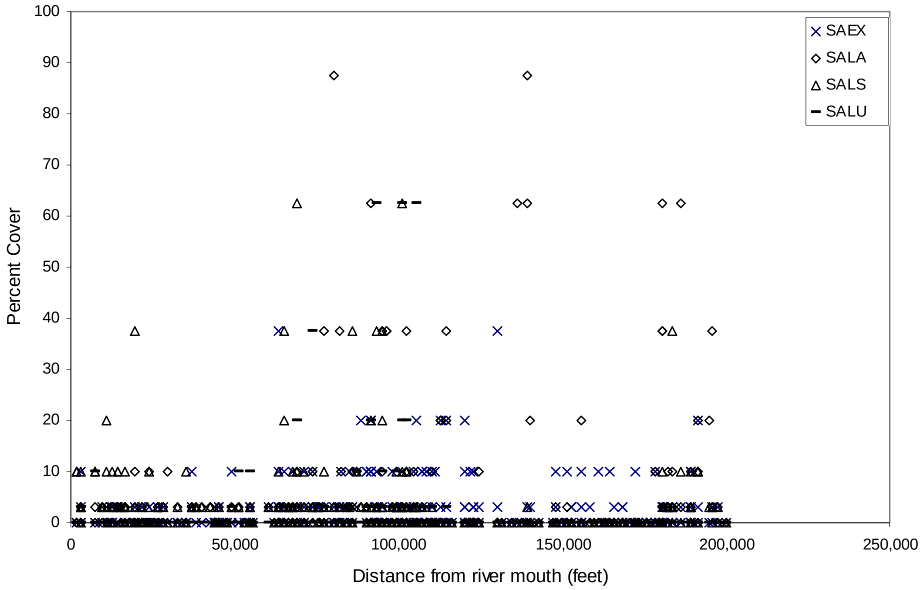


Figure 3-20. Distribution of *Salix laevigata* (SALA), *S. lasiolepis* (SALS), *S. lucida* ssp. *lasiandra* (SALU), and *S. exigua* (SAEX) percent cover in relation to the distance from river mouth.

Time since last flood. As with the *Populus* alliances, the Mixed Willow Forest Alliance occurs primarily on surfaces that were inundated during the largest floods of the last 100 years (Figure 3-21). Perhaps because *Salix* are short lived and a seral species in relation to *Populus*, they are less frequent on surfaces flooded during the 1969 and 1938 events than on more recently flooded surfaces.

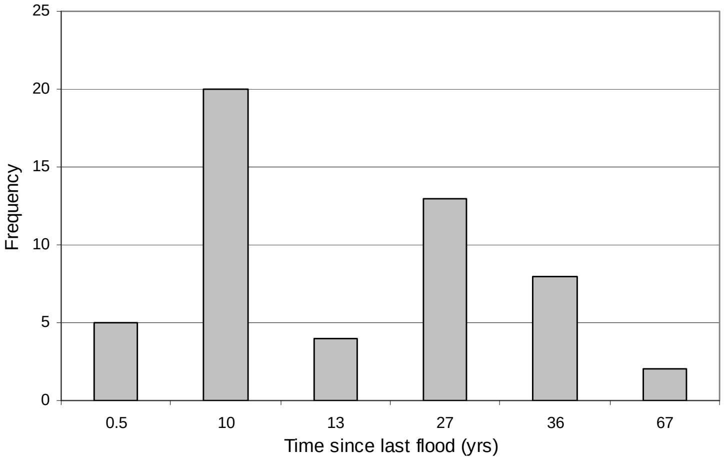


Figure 3-21. Frequency of Mixed Willow Forest Alliance in relation to time since last flood.

The distribution of the four *Salix* species in relation to time since last flood is shown in Figure 3-22. Only those plots with five percent or more cover of a *Salix* species were used in the analysis and, as a result, sample sizes were reduced: *S. exigua* n= 53; *S. laevigata* n=44; *S. lapiolepis* n = 40; and *S. lucida* n = 13). Plots with low percent cover of *Salix* species are most frequent on surfaces inundated during the 2005 flood that are not represented by the Mixed Willow Forest Alliance frequency curve in Figure 3-21. All of the *Salix* species except *S. exigua* show a trend towards more frequent occurrence on the most recently flooded surfaces.

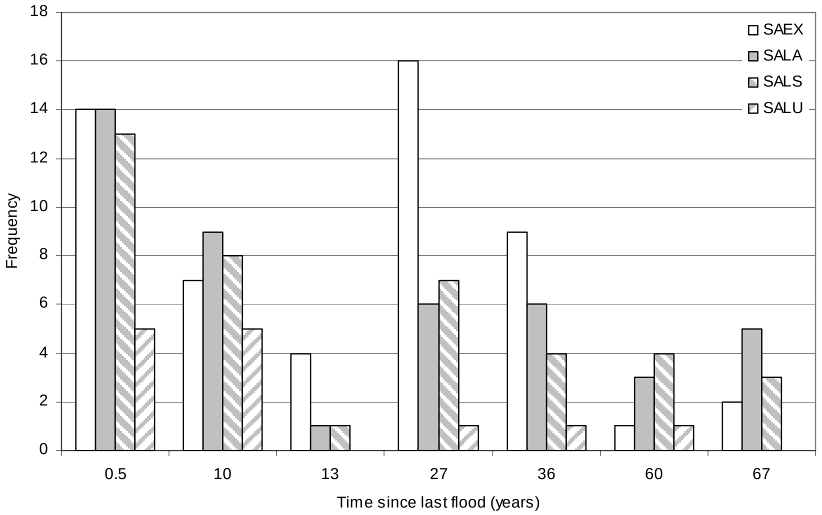


Figure 3-22. Frequency of *Salix laevigata* (SALA), *Salix lasiolepis* (SALS), *Salix lucida ssp. lasiandra* (SALU), and *Salix exigua* (SAEX) in relation to time since last flood.

Gaining vs. losing reaches. The four *Salix* species occurred in gaining reaches well over 17% of the time, indicating a clear bias for the higher groundwater table conditions found in gaining reaches (Table 3-5). These findings are similar to those reported in Section 3.3.2 for *Salix* dominated vegetation alliances.

Table 3-5. Frequency of four willow species in gaining reaches.

Scientific name	Common name	Frequency in gaining reaches
Salix lasiolepis	Arroyo willow	58%
Salix lucida	Shining willow	52%
Salix laevigata	Red willow	61%
Salix exigua	Narrowleaf willow	44%

Summary. The Mixed Willow Forest Alliance occurs throughout the longitudinal extent of the analysis area and occurs most often on surfaces that are between 5 and 8 ft in relative elevation and that have been flooded in the last 30 to 40 years. The alliance is not as common on the most recently flooded surfaces (2005), which are more often covered with Riverwash Herbaceous, Riverwash Scrub, or Floodplain Wetland alliances (Stillwater Sciences and URS Corporation 2007). However, these recently flooded areas also support incipient populations of *Salix* spp., *Populus* spp., and *Arundo donax* (Stillwater Sciences and URS Corporation 2007); given time without flooding and some *A. donax* removal, these areas might succeed to Mixed Willow Forest Alliance.

All four of the most common *Salix* species occur most frequently within 12 ft relative elevation, although *S. lucida* tends to occur on slightly lower surfaces than the rest. *Salix lasiolepis* is most frequent in the lower reaches of the analysis area, while *S. laevigata* and *S. lucida* occur primarily in the middle and upper reaches (75,000–125,000 ft [14–23 mi] from the river mouth), possibly reflecting species differences in water needs. *Salix exigua* occurs more frequently in the upper reaches of the analysis area and was found to favor gaining reaches less than the other three species. *S. laevigata, S. lucida, and S. lasiolepis* occur more often along gaining reaches than not, possibly reflecting a preference for areas with a more reliable summer water supply. *S. laevigata, S. lucida, and S. lasiolepis* are also most common on surfaces flooded within the past 10 years, while *S. exigua* is most common on surfaces that have been flood-free for over 25 years.

Except where co-dominant with *Arundo donax*, *S. exigua* occurs most frequently in reaches where the 50-year floodplain width exceeds 2,300 ft. *Arundo donax* co-dominates with *S. exigua* on surfaces that have been flooded in the last 10 years and in areas with narrow 50-year floodplains, possibly reflecting areas subjected to more intense disturbance. These findings suggest that *S. exigua* communities in areas subject to more frequent flood and/or scour disturbance are vulnerable to invasion by *Arundo donax*.

Artemisia tridentata Alliance and species distribution

The *Artemisia tridentata* Alliance is represented by 30 sample points in the alliance dataset and by 19 of the 338 plots in the species-specific dataset.

Relative elevation. The *Artemisia tridentata* Alliance occurs on surfaces that range from 1 to 11 ft, relative elevation, with the greatest frequency (over 30 percent) occurring between 2 and 4 ft (Figure 3-23).

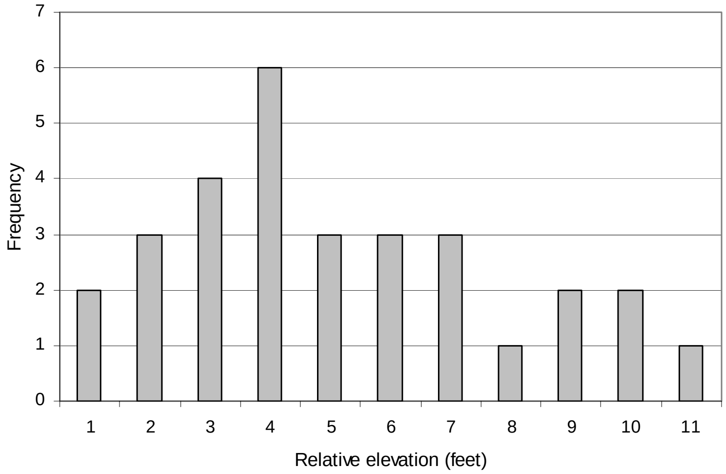


Figure 3-23. Frequency of *Artemisia tridentata* Alliance in relation to relative elevation.

The distribution of *A. tridentata* by percent cover shows a similar pattern to that of the *A. tridentata* Alliance in relation to relative elevation (Figure 3-24). This species tends to occur on lower relative elevation surfaces than the average for the other plots (5.0 ft vs. 7.5 ft relative elevation; $p < 0.001$; two-tailed t-test, assuming unequal variance).

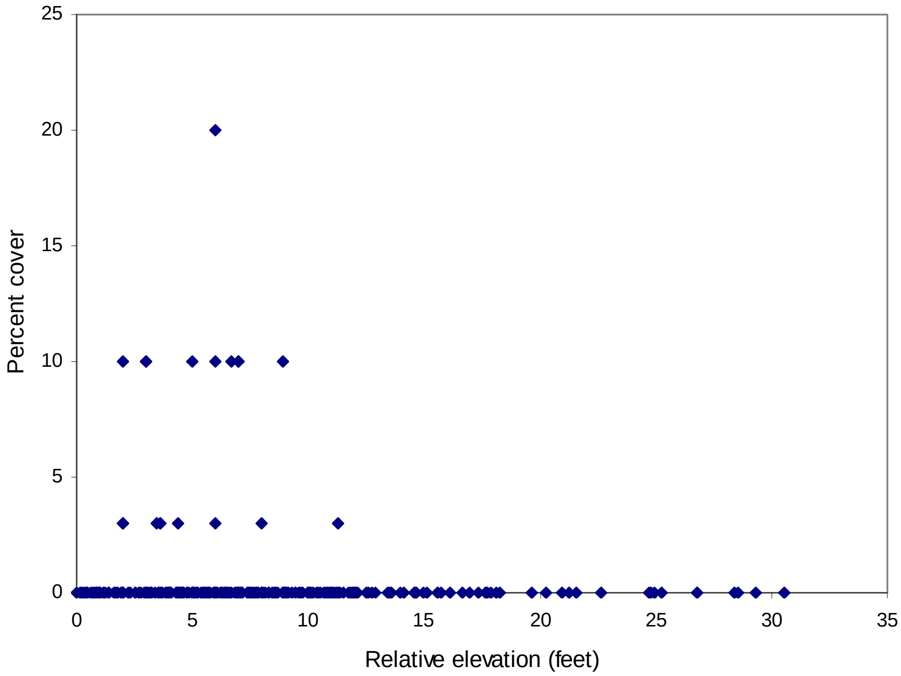


Figure 3-24. *Artemisia tridentata* percent cover in relation to relative elevation.

Distance from river mouth. The *A. tridentata* Alliance occurs only above the Sespe Creek confluence and at greatest frequency approximately 155,000 ft (25 mi) upstream from the river mouth (Figure 3-25).

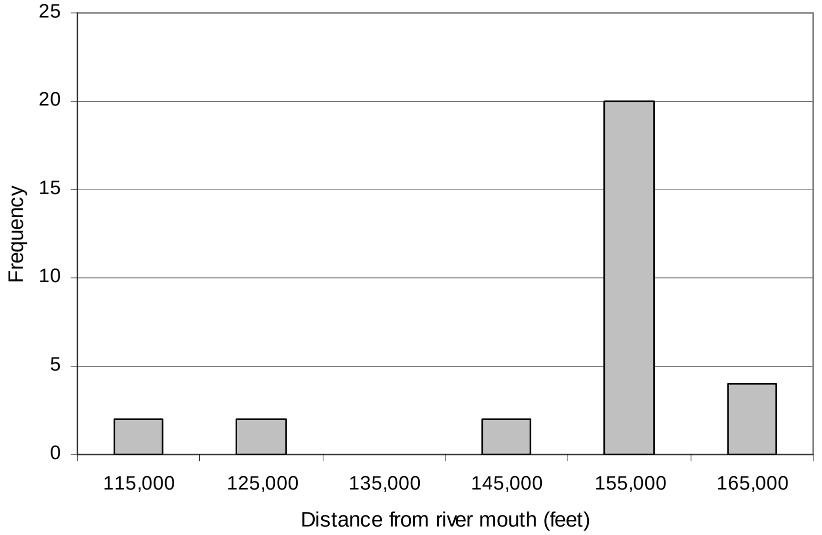


Figure 3-25. Frequency of *Artemisia tridentata* Alliance in relation to distance from the river mouth.

The longitudinal distribution of *A. tridentata* based on the species-specific data is very similar to the *A. tridentata* Alliance (Figure 3-26). Compared to the other plots, plots supporting *A. tridentata* occur farther from the river mouth ($p < 0.001$; two-tailed t-test, assuming unequal variance). Correlates to distance from river mouth, including gradient at the 2-year recurrence interval flow and power at the 50-year recurrence interval, were also significantly different in the *A. tridentata* plots than the rest of the plots (both higher than overall average; $p = 0.050$ and 0.022, respectively; two-tailed t-tests, assuming unequal variances). In addition, this species occurs along reaches where the wetted width of the 50-year recurrence interval flood is significantly less than the rest of the 338 sites (2,270 feet vs. 3,199 feet; $p < 0.001$; two-tailed t-test, assuming unequal variance).

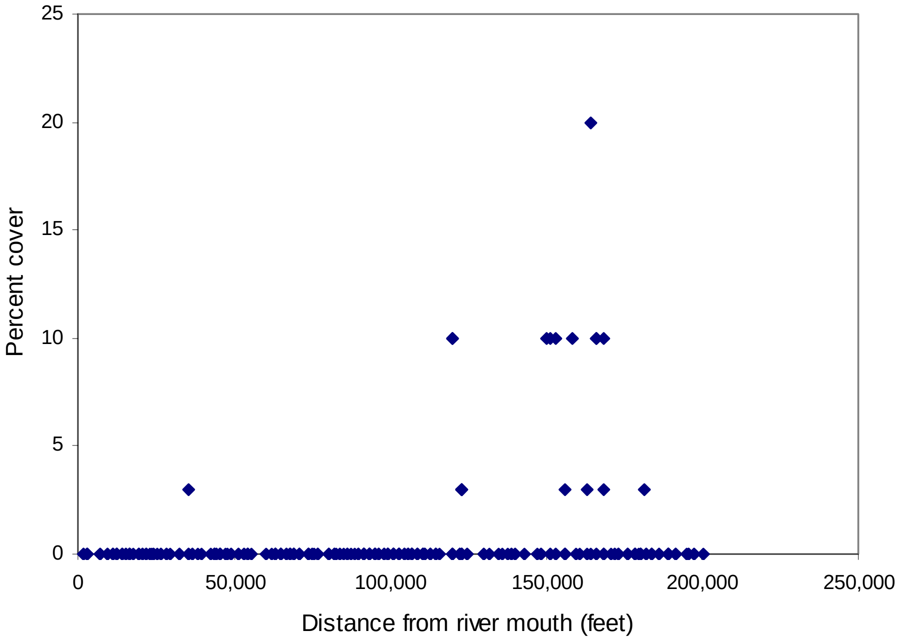


Figure 3-26. Distribution of *Artemisia tridentata* percent cover in relation to distance from the river mouth.

Time since last flood. The *A. tridentata* Alliance occurs most frequently on surfaces flooded over 30 years ago, during the 1969 and 1938 events (Figure 3-27).

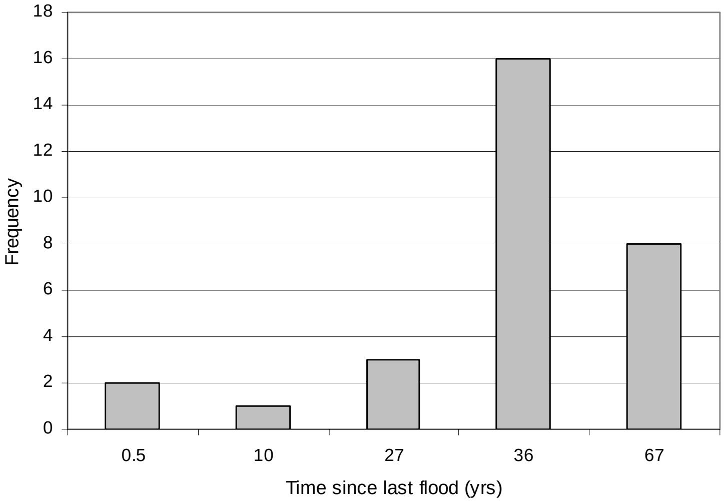


Figure 3-27. Frequency of *Artemisia tridentata* Alliance in relation to time since last flood.

The distribution of *A. tridentata* itself is similar to that of the alliance, although as a species, it occurs somewhat more often on more recently flooded surfaces (Figure 3-28). These results indicate that *A. tridentata* is not a rapid colonizer of recently flooded surfaces but, rather, thrives on surfaces not subject to frequent flooding (Figure 3-27 and Figure 3-28).

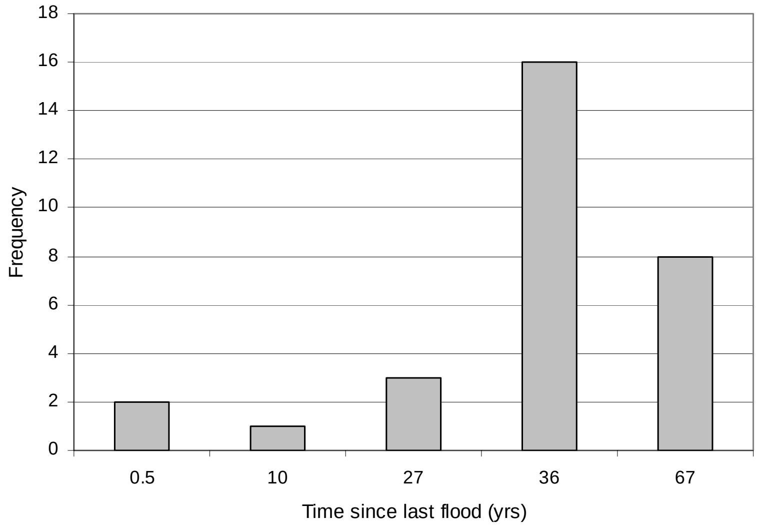


Figure 3-28. Frequency of *Artemisia tridentata* in relation to time since last flood.

Gaining vs. losing reaches. *Artemisia tridentata* occurs in gaining reaches 5% of the time in the species-specific dataset, showing a bias against gaining reaches, since this is far less than the frequency of gaining reaches in the entire dataset. This finding is similar to that reported for the alliance level dataset in which the *A. tridentata* Alliance was never sampled in gaining reaches (Section 3.3.2).

Summary. In summary, *Artemisia tridentata* occurs most often on surfaces that are at low relative elevation but that are not subject to frequent or recent flooding. This situation is most likely to occur in losing reaches, where *A. tridentata* is typically found and a portion of surface flow is lost to the subsurface.

Arundo donax Alliance and species distribution

Arundo donax occurs throughout the analysis area; its prevalence is clearly reflected in both the alliance and species-specific datasets. The *A. donax* Alliance is represented by 250 sample points, out of 1,490, representing 17 percent of the sampling. Several other alliances include *A. donax* as a co-dominant species, but these are not considered here. *Arundo donax* is represented by 84 plots from the species-specific dataset. Thirty two percent of the *A. donax* occurrences are under four percent cover, but five percent of the plots are dominated by *A. donax*, with covers exceeding 80 percent.

Relative elevation. Based on separate regression analyses of the *A. donax* Alliance and vegetation plot data, strong relationships occur between frequency of *A. donax* and relative elevation ($aR^2 = 0.55$; $p < 0.0001$ and $aR^2 = 0.63$; $p < 0.0001$ for the alliance and species-specific datasets, respectively). The distribution and regression of *A. donax* Alliance in relation to relative elevation is shown in Figure 3-29. A nearly identical scatterplot and regression equation were developed from the species-specific dataset, but is not shown here. Both datasets indicate that *A. donax* most often occurs within 12 ft, relative elevation.

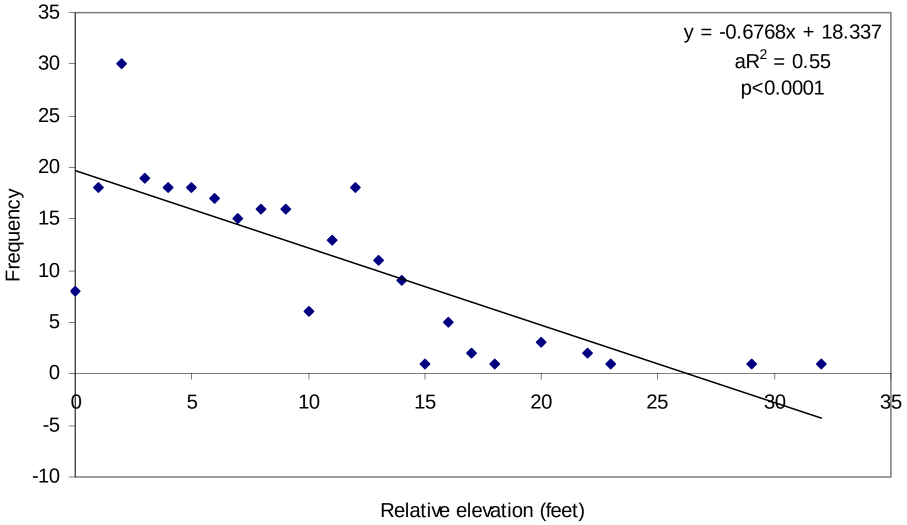


Figure 3-29. Distribution and regression analysis of *Arundo donax* Alliance as a function of relation elevation.

Distance from river mouth. *Arundo donax* Alliance is found along the entire lower Santa Clara River (Figure 3-30). The alliance occurs most frequently between 75,000 and 150,000 ft (15 to 30 mi) from the river mouth. It is likely that *A. donax* is most abundant in these reaches because that is where the floodplain is widest.

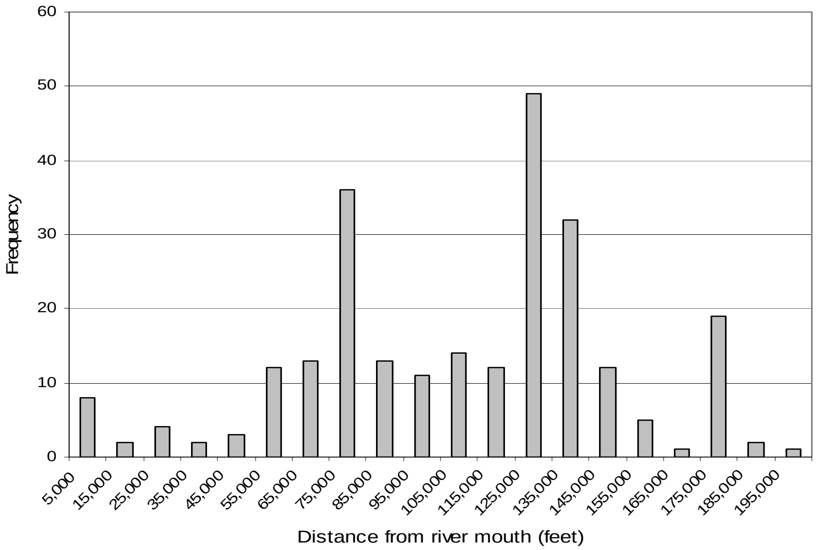


Figure 3-30. Frequency of *Arundo donax* Alliance in relation to distance from the river mouth.

Distribution of *A. donax* by percent cover and distance from river mouth reveals a similar concentration of the species in the middle reaches of the lower Santa Clara River (Figure 3-31). Comparison of plots supporting over 30 percent cover of *A. donax* to all other plots, reveals that moderate to high densities of

A. donax occur more frequently along these middle reaches and along lower gradient reaches than the other plots (Figure 3-32) (p = 0.0008; two tailed t-test, assuming unequal variance). The greater frequency of high density *A. donax* stands along the middle reaches could reflect the abundance of upstream propagule sources and/or the riparian zone width in these areas.

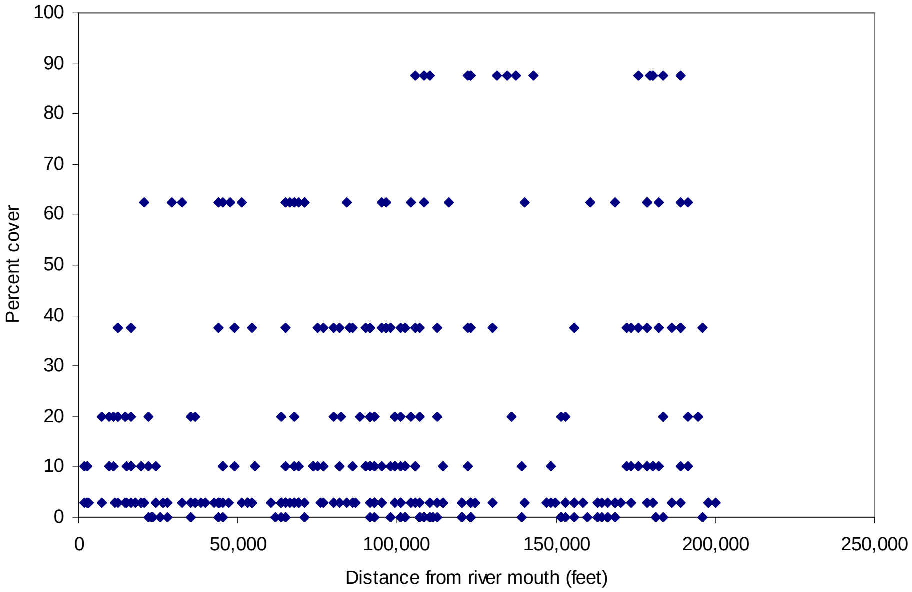


Figure 3-31. Distribution of *Arundo donax* percent cover in relation to distance from the river mouth.

Time since last flood. The *A. donax* Alliance occurs on surfaces flooded during all major flood years, but is most frequent on the most recently flooded surface (2005) (Figure 3-32).

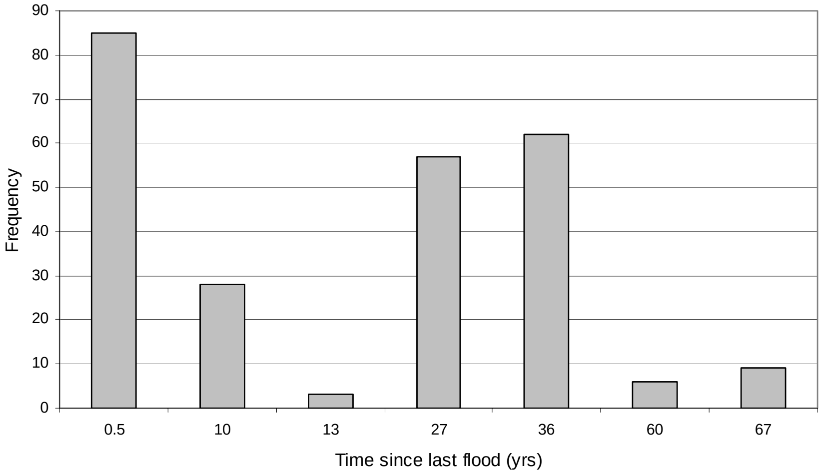


Figure 3-32. Frequency of *Arundo donax* Alliance in relation to time since last flood.

The frequency of vegetation plots supporting over 30 percent cover of *A. donax* is very similar to that of the *A. donax* Alliance, showing greater frequency in the most recently flooded areas (Figure 3-32).

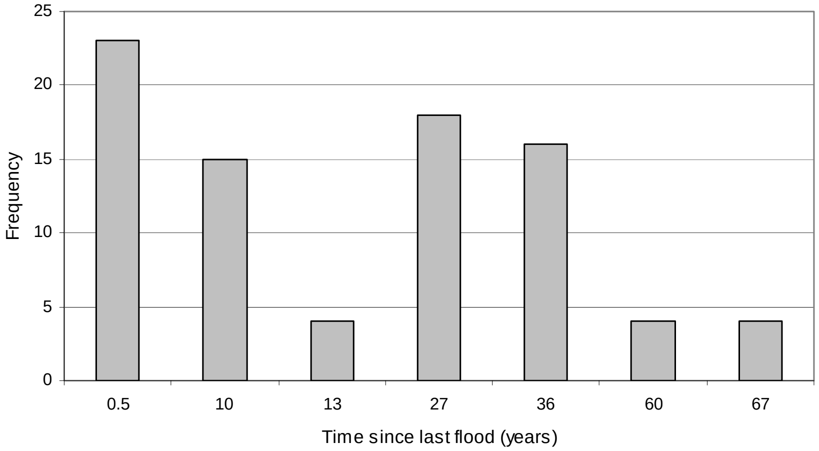


Figure 3-32. Frequency of *A. donax* over 30 percent cover in relation to time since last flood.

Gaining vs. losing reaches. One-third of the sample points classified as *A. donax* Alliance occur in gaining reaches. This is somewhat less than expected by random (54 percent) and suggests a slight bias against gaining reaches. However, in the species-specific dataset, *A. donax* was found to occur along gaining reaches 54 percent of the time, indicating a bias towards gaining reaches since this is much greater than the 17 percent baseline frequency of plots in gaining reaches in the species-specific dataset. The difference between these findings suggests that *A. donax* can become established and survive in a wide range of conditions along the lower Santa Clara, including gaining or losing reaches.

Summary. *A. donax* occurs throughout the lower Santa Clara River, and is recorded in 84 percent of the plots in the species-specific database. *A. donax* shows a strong preference for more recently flooded surfaces, such as those flooded within the past 40 years. *A. donax* occurs more frequently at lower relative elevations, likely reflecting its preference for disturbed areas. The frequency of *A. donax* is greatest from 50,000 to 150,000 ft (9 to 28 mi) from the river mouth, although this could simply be are reflection of the wider floodplain in this portion of the lower Santa Clara River. *A. donax* colonizes post-burn areas rapidly, and it has been shown that fires can actually result in increased *A. donax* cover, thus favoring the invasive species (Coffman 2007). Moreover, *A. donax* provides thick, dry fuel source during the late growing season, thereby increasing the likelihood and intensity of fire. Past and potential future fires along the Santa Clara River, such as the ones that burned approximately 11% of the watershed in 2003, are likely to increase the cover and extent of *A. donax* along the riparian corridor.

Baccharis salicifolia species distribution

Baccharis salicifolia occurs in 45 percent of the 348 species-specific plots. There is essentially no difference between the distribution of *B. salicifolia* in areas of different flood recurrence interval or time since last flood from that of the entire set of plots. This suggests that *B. salicifolia* establishes and survives equally well among surfaces subject to a broad range of flood frequencies. *Baccharis salicifolia* tends to occur at slightly higher relative elevations (7.33 ft) than the overall plot average (8.45 ft; $p = 0.00$; two-tailed t-test, assuming unequal variance). *Baccharis salicifolia* shows a preference for gaining reaches, since it occurs in gaining reaches 48 percent of the time, far more often than the overall frequency of gaining reaches in the species-specific dataset (17 percent).

4 CONCLUSIONS

4.1 Overview

On the lower Santa Clara River, the strongest drivers controlling the distribution of riparian vegetation are flood disturbance and water supply. These factors align well with those found in previous studies, including the magnitude and frequency of flood disturbance (Bendix 1994, Bendix 1997, Harris 1999, Bendix and Hupp 2000), distance to groundwater (as reflected in preference for gaining vs. losing reaches; Stromberg *et al.* 1996, Shafroth *et al.* 1998), and a combination of the two (Hupp and Osterkamp 1996, Lite 2003, Bagstad *et al.* 2006, Leenhouts *et al.* 2006). Relative elevation, associated with flood frequency, and time since last flood, associated with vegetation age, were two of the strongest correlates to the distribution of vegetation. Riparian vegetation along the lower Santa Clara River is subject to infrequent but dramatic resets during large flood events, particularly during wet years associated with the El Niño Southern Oscillation (ENSO; Stillwater Sciences 2007). The largest natural flood events correspond very clearly to the high intensity rainfall years associated with ENSO, and correlate strongly with high rainfall events that have occurred every three to seven years as part of the contemporary ENSO cycle since 1969. The importance of these floods, when many riparian surfaces are either completely scoured, covered with new sediment, or simply flooded, suggests that the extent and distribution of riparian species and vegetation types in the lower Santa Clara River is closely linked to the frequency and timing of major floods associated with ENSO.

In the dry climate of southern California, small variations in water supply (the balance between surface and groundwater availability and evapotranspiration demands) exert important controls on plants species distribution. The variables most closely reflecting water supply in this analysis include distance from the river mouth, relative elevation, and reach type (gaining vs. losing). Distance from the river mouth is strongly correlated to plant species distribution. While the precise mechanism for this correlation is difficult to ascertain, differences in local climatic conditions between the coastal fog belt, where humidity is relatively high and evapotranspiration demand relatively low, and the more arid inland portions of the watershed are probably at least partly responsible for these species distribution trends. Plant species showing particular sensitivity to these local shifts in climate include *Populus* and *Salix* species, *Artemisia tridentata*, and *Lepidospartum squamatum*. Since the distribution of gaining vs. losing reaches was determined in part by vegetation cover, analysis of the independent effects of groundwater reach type in comparison with other physical site variables on plant species and vegetation alliance distribution was not possible. However, the distribution of many key riparian plant species and alliances reveals significant bias for gaining vs. losing reaches. For example, *Salix* and *Populus* dominated alliances occur most frequently in gaining reaches where groundwater levels are closer to the surface, and summer water supply is assumed to be more reliable. In contrast, *A. tridentata* and *L. squamatum* dominated alliances occur more frequently in drier, losing reaches. The distribution of gaining vs. losing reaches is largely controlled by geology: gaining reaches occur where the Piru and Fillmore narrows limit the width of unconsolidated deposits, and subsurface bedrock causes groundwater to rise and discharge to the Santa Clara River (depending on groundwater levels and surface flow conditions; Stillwater Sciences 2007, URS Corporation 2005). Losing reaches occur in areas away from the bedrock controls, where surface flow is lost through the highly permeable bed material to the groundwater table. Thus, predictable differences in groundwater occur with distance from the river mouth. Access to groundwater is likely represented in both the distance from river mouth and relative elevation variables.

4.2 Implications for Restoration and Conservation

The analysis conducted and information developed in this report help inform restoration strategy development in several ways. The information presented here can be used to identify optimal matches between restoration site conditions and apparent species/alliance preferences to improve predictions of what species might recruit naturally or what planted species are likely to be successful in the long-term. If a particular vegetation community is targeted for revegetation because it is rare or provides critical habitat, the physical variables most often associated with that vegetation community can be used to identify optimal revegetation sites (along with other non-ecological constraints, such as land ownership and adjacent land uses). This information can also be used to estimate the potential effects of anticipated changes in physical conditions and processes that might control the distribution of riparian communities. Finally, this information can be used to identify riparian plant communities and particular sites that are most vulnerable to invasion from non-native species, such as *A. donax* and *Tamarisk*.

Our analysis of the controls on the distribution of existing vegetation point to four key variables: time since last flood, relative elevation, longitudinal station (distance from the river mouth), and reach type (gaining vs. losing reaches). The first two variables reinforce the findings from the historical analysis (Section 2) that major floods have a very large effect on riparian vegetation. The event-dominated nature of the lower Santa Clara River validates the use of passive revegetation in the most active (*i.e.*, low relative elevation) areas. This can allow for more concerted, active revegetation efforts on less frequently and less intensely disturbed areas. The pervasiveness of *A. donax* in the riparian corridor makes it clear that control of this weed should be a high priority for any restoration effort in the lower Santa Clara River, particularly in the most frequently flooded areas. The positive feedback between *A. donax* cover and fire suggest that fire influences must be a part of any control effort. Thus, passive restoration in the most frequently and recently flooded areas should be accompanied by intensive *A. donax* control. Impacts to riparian vegetation are most severe from river miles 4.6 to 10.8, where levees severely limit the extent of the riparian corridor and *A. donax* infestation is particularly bad. This area, therefore, should be prioritized for riparian enhancement through active revegetation and *A. donax* removal.

Native *Salix* and *B. salicifolia* dominated alliances cover over 20 percent of the current riparian area while native non-willow tree species dominate nearly 10 percent of the area (Stillwater Sciences and URS Corporation 2007). Thus, well over one-third of existing riparian vegetation is dominated by native plant communities. The location of intact riparian communities should be examined in relation to habitat corridor, sediment and nutrient trapping, and flood dissipation benefits as part of the process of identifying and prioritizing restoration and conservation areas. For example, the riparian area above the confluence with Santa Paula Creek on the mainstem (river miles 17.5 to 38.4) is relatively intact (although still riddled with *A. donax*) and is less constrained by floodplain development and flood control than downstream reaches. This area may be more appropriate for conservation, with active revegetation limited to only the most severely disturbed areas. These existing intact riparian areas can also be used as plant propagule sources and serve as reference sites for restoration projects.

5 LITERATURE CITED

Aguiar FC, Ferreira MT. 2005. Human-disturbed landscapes: effects on composition and integrity of riparian woody vegetation in the Tagus River basin, Portugal. Environmental Conservation, 2005 (Vol. 32) (No. 1) 30-41.

AMEC (AMEC Earth and Environmental). 2004. Santa Clara River Enhancement and Management Plan (SCREMP) – Public Review Document. Prepared for the Ventura County Watershed Protection District, Los Angeles County Department of Public Works, and the SCREMP Project Steering Committee.

Bagstad, K.J., S.J. Lite, and J.C. Stromberg. 2006. Vegetation, soils, and hydrogeomorphology of riparian patch types of a dryland river. Western North American Naturalist 66(1):23-44.

Baird, K.J., J.C. Stromberg, and T. Maddock III. 2005. Linking riparian dynamics and groundwater: an ecohydrologic approach to modeling groundwater and riparian vegetation. Environmental Management 36(4):551-564.

Baker, W.L. and G.M. Walford. 1995. Multiple stable states and models of riparian vegetation succession on the Animas River, Colorado. Annals of the Association of American Geographers 85(2):320-338.

Bendix, J. 1994. Among-site variation in riparian vegetation of the southern California transverse ranges. American Midland Naturalist 132:136-151.

Bendix, J. 1997. Flood disturbance and the distribution of riparian species diversity. Geographical Review 87(4):468-483.

Bendix, J. 1999. Stream power influence on southern Californian riparian vegetation. Journal of Vegetation Science, Vol. 10: 243-252.

Bendix, J. and C.R. Hupp. 2000. Hydrological and geomorphological impacts on riparian plant communities. Hydrological Processes 14: 2977-2990.

Bossard, C.C., J.M. Randall, and M.C. Hoshovsky. 2000. Invasive Plants of California's Wildlands. University of California Press, Berkeley, CA.

Boughten, D.A., P.B. Adams, E. Anderson, C. Fusaro, E. Keller, E. Kelley, L. Lentsch, J. Nielsen, K. Perry, H. Regan, J. Smith, C. Swift, L. Thompson, and F. Watson. 2006. Steelhead of the south-central/southern California coast: population characterization for recovery planning. NOAA Technical Memorandum NMFS-SWFSC-394.

Coffman, G.C. 2007. Factors Influencing Invasion of Giant Reed (Arundo donax) in Riparian Ecosystems of Mediterranean-type Climate Regions. Dissertation, University of California, Los Angeles, CA.

Fernández-Aláez, C., M. Fernández-Aláez, and F. Garcáa-Criado. 2004. Spatial distribution pattern of the riparian vegetation in a basin in the NW Spain. Plant Ecology. 179 (1): 31-42.

Goebel, P.C., K.S. Pregitzer and B.J. Palik. 2006. Landscape hierarchies influence riparian ground-flora communities in Wisconsin, USA. Forest Ecology and Management. 230 (1-3): 43-54.

Graf, W.L. 1984. A probabilistic approach to the spatial assessment of river channel instability. Water Resources Research 20: 953–962.

Graf, W.L. 2000. Locational probability for a dammed, urbanizing stream: Salt River, Arizona, USA. Environmental Management 25: 321–335

Gregory, S. V., F. J. Swanson, W. A. McKee, and K. W. Cummins. 1991. An ecosystem perspective of riparian zones. Bioscience 41: 540-551.

Harris, R.R. 1999. Defining reference conditions for restoration of riparian plant communities: examples from California, USA. Environmental Management 24(1):55-63.

Holland, V. L. and D. J. Keil. 1995. California vegetation. Kendall/Hunt Publishing Company, Dubuque, Iowa.

Hupp, C.R. and W.R. Osterkamp. 1996. Riparian vegetation and fluvial geomorphic processes. Geomorphology 14:277-295.

Knopf, F. L., J. A. Sedgwick, and R. W. Cannon. 1988. Guild structure of a riparian avifauna relative to seasonal cattle grazing. Journal of Wildlife Management 52: 280-290.

Leenhouts, J.M. J.C. Stromberg, and R.L. Scott (editors). 2006. Hydrologic requirements of and consumptive ground-water use by riparian vegetation along the San Pedro River, Arizona. U.S. Geological Survey Scientific Investigations Reports 2005-5163.

Lite, S.J. 2003. San Pedro River riparian vegetation across water availability and flood disturbance gradients. PhD dissertation, Arizona State University, Phoenix, Arizona.

Malanson, G. P. 1993. Riparian landscapes. Cambridge University Press, Cambridge, England.

McCune, B. and J.B. Grace. 2002**.** Analysis of Ecological Communities. MJM Software Design, Gleneden Beach, Oregon.

McCune, B. and M.J. Mefford. 1999. PC-ORD. Multivariate Analysis of Ecological Data, Version 4. MjM Software Design, Glenedon Beach, Oregon.

Naiman, R. J., and H. Decamps. 1997. The ecology of interfaces: riparian zones. Annual Review of Ecology and Systematics 28: 621-658.

Økland. R.H. 1999. On the variation explained by ordination and constrained ordination axes. Journal of Vegetation Science 10:131-136

Økland, R. H., and O. Eilertsen. 1994. Canonical correspondence analysis with variation partitioning: some comments and an application. J. Veg. Sci. 5:117-26

Palmer, M. P. Ordination webpage; accessed on October 26, 2007. http://ordination.okstate.edu/index.html

RHJV (Riparian Habitat Joint Venture). 2000. Version 1.0. The riparian bird conservation plan: a strategy for reversing the decline of riparian associated birds in California. California Partners in Flight, Point Reyes Bird Observatory, Stinson Beach, California. Accessed at: http://www.prbo.org/CPIF/Consplan.html.

Roberts, W. G., J. G. Howe, and J. Major. 1980. A survey of riparian flora and fauna in California. Pages 3-19 in A. Sands, editor. Riparian forests in California: their ecology and conservation. Agricultural Sciences Publications, University of California, Berkeley, California.

Schwartzberg, B. J. and P. A. Moore. 1995. A history of the Santa Clara River. Prepared for the Santa Clara River Enhancement and Management Study.

Shafroth, P.B., G.T. Auble, J.C. Stromberg, and D.T. Patten. 1998. Establishment of woody riparian vegetation in relation to annual patterns in streamflow, Bill Williams River, Arizona. Wetlands 18(4):577-590.

Simons, Li & Associates. 1983. Hydraulic, erosion and sedimentation study of the Santa Clara river Ventura county, California. Ventura, California, Prepared for Ventura County Flood Control District.

Stein, E.D., S. Dark, T. Longcore, N. Hall, M. Beland, R. Grossinger, J. Casanova, and M. Sutula. 2007. Historical and landscape change of the San Gabriel River. SCCWRP Technical Report #499.

Stillwater Sciences. 2007. Santa Clara River Parkway Floodplain Restoration Feasibility Study: assessment of geomorphic processes for the Santa Clara River watershed, Ventura and Los Angeles Counties, California. Prepared by Stillwater Sciences, Berkeley, California for the California State Coastal Conservancy, Oakland, California.

Stillwater Sciences and URS Corporation. 2007. Riparian vegetation mapping and preliminary classification for the lower Santa Clara River and major tributaries (Ventura County, California). Prepared for the California Coastal Conservancy, Oakland, California and Santa Clara River Trustee Council, Ventura, California.

Stromberg, J.C., R. Tiller, and B. Richter. 1996. Effects of groundwater decline on riparian vegetation of semiarid regions: the San Pedro, Arizona. Ecological Applications 6(1):113-131.

Tausch, R.J., D.A. Charlet, D.A. Weixelman and D.C. Zamudio. 1995. Patterns of ordination and classification instability resulting from changes in input data order. *Journal of Vegetation Science.* 6:897-902.

Tiegs S. D. and Pohl M. 2005. Planform channel dynamics of the lower Colorado River: 1976-2000. Geomorphology 69: 14-27.

Tiegs, S.D., J.F. O'Leary and M.M. Pohl. 2005. Flood Disturbance and Riparian Species Diversity on the Colorado River Delta. Biodiversity and Conservation 14:1175-94

URS Corporation. 2005. Santa Clara River Parkway Floodplain Restoration Feasibility Study - Water resources investigation: land use, infrastructure, hydrology, hydraulics, and water quality. Prepared for the California Coastal Conservancy, Oakland, California.

Appendices

APPENDIX A

Habitat Types Cross-Table with Vegetation Alliances

Super Alliance	Alliance
Coastal Riparian	*Abronia* spp. - *Ambrosia chamissonis* *Corethrogyne filaginifolia* *Jaumea carnosa* *Lotus scoparius* *Malosma laurina* *Salicornia virginica*
Desert Scrub	*Artemisia tridentata* *Atriplex lentiformis* *Lepidospartum squamatum* *Pluchea sericea* *Salvia mellifera* *Yucca whipplei*
Exotic Herbaceous	*Carpobrotus* spp. - *Mesembryanthemum crystallinum* Non-native grasses and forbs *Ricinus communis*
Floodplain Scrub	Riverwash scrub
Giant Reed	*Arundo donax*
Mixed Exotic Trees	*Eucalyptus* Mixed exotic trees *Myoporum laetum* *Myoporum laetum - Arundo donax* *Nicotiana glauca* *Nicotiana glauca - Artemisia californica* *Olea europaea* *Schinus molle* *Tamarix* spp.
Mixed Riparian Forest	Mixed riparian forest *Juglans californica* *Platanus racemosa* *Populus balsamifera* *Populus fremontii* *Sambucus mexicana* *Quercus agrifolia*
Mixed Riparian Scrub	*Artemisia californica* *Artemisia californica - Eriogonum fasciculatum* *Baccharis pilularis* Mixed riparian scrub Mixed scrub
Mixed Willow Forest	Mixed willow forest *Salix laevigata* *Salix lasiolepis* *Salix lucida*
Mixed willow scrub	Mixed willow scrub
Native Herbaceous	*Ambrosia psilostachya* *Distichlis spicata* *Eriogonum fasciculatum*

Super Alliance	**Alliance**
	Leymus condensatus *Leymus triticoides* *Potentilla anserina*
Floodplain herbaceous	Floodplain wetland superalliance *Phragmites australis* Riverwash herbaceous *Scirpus* spp.
Willow Shrub	*Baccharis salicifolia* *Salix exigua* *Salix exigua - Arundo donax* *Salix exigua - Baccharis salicifolia*

APPENDIX B

Descriptive Statistics for Physical Site Variables by Vegetation Alliance

Table B-1. Descriptive statistics for physical site variables by vegetation alliance (SE refers to Standard Error).

Alliance	N Rows	Station (feet)				Relative Elevation (ft)				Flood Recurrence Interval (years)				Time Since Last Flood (years)			
		mean	SE	min	max	mean	SE	min	max	mean	SE	min	max	mean	SE	min	max
Artemisia ca- Eriogonum fasc	4	45,085.2	270.1	44,274.9	45,355.3	18.2	2.2	7.7	27.4	53	27	1.5	100	38.8	5.3	10	60
Artemisia californica	10	39,788.4	1,578.0	32,427.2	47,300.8	12.5	4.4	0.3	20.1	152	60	5	500	33.1	12.3	0.5	60
Artemisia tridentata	30	150,738.2	2,500.5	112,776.1	168,601.5	5.2	0.5	1.0	11.0	144	28	1.5	500	40.1	3.5	0.5	67
Arundo donax	251	105,868.6	2,651.6	617.4	194,769.8	7.6	0.3	0.0	32.8	44	6	1.5	500	20.4	1.2	0.5	67
Baccharis pilularis	28	27,746.3	6,701.0	3,020.7	116,120.5	15.9	1.2	2.5	26.7	202	43	1.5	500	45.1	3.0	10	67
Baccharis salicifolia	13	90,804.7	9,533.7	61,875.8	164,516.1	9.6	1.8	2.3	24.6	111	52	1.5	500	25.4	5.5	0.5	60
Eucalyptus spp.	4	89,781.1	4,957.6	83,313.1	104,438.1	15.4	2.6	12.5	23.0	176	110	5	500	47.5	9.5	27	67
Floodplain wetland	139	123,549.2	3,184.9	20,512.8	186,255.7	2.2	0.3	0.0	21.5	5	1	1.5	100	2.7	0.9	0.5	67
Lepidospartum squamatum	14	123,879.3	6,483.0	110,241.7	168,601.5	6.2	0.8	2.7	13.0	12	7	1.5	100	34.6	3.8	27	67
Mixed riparian forest	5	110,963.3	31,224.2	35,344.0	178,465.3	7.2	3.7	2.0	21.8	142	92	2	500	33.9	12.1	0.5	60
Mixed riparian scrub	27	62,568.0	12,025.8	11,280.1	192,656.2	11.5	0.8	6.3	24.8	44	19	5	500	37.0	3.4	10	67
Mixed scrub	5	73,334.5	12,320.3	24,061.3	86,146.5	15.3	2.5	11.8	25.4	28	18	10	100	44.0	6.2	36	60
Mixed willow forest	52	58,609.0	8,903.7	2,934.2	149,938.4	7.9	0.8	0.1	31.5	23	20	1.5	500	19.8	2.1	0.5	67
Mixed willow scrub	21	54,133.5	6,307.0	14,940.0	101,029.8	10.9	1.9	2.1	34.5	10	5	1.5	100	11.5	3.6	0.5	60
Non-native grasses and forbs	91	82,097.1	3,752.7	12,401.5	189,300.4	11.6	0.5	0.0	27.2	74	10	1.5	500	37.2	2.2	0.5	67
Populus balsamifera	65	66,763.2	4,985.7	1,931.0	102,562.3	7.4	0.4	2.1	20.5	13	3	1.5	100	29.1	2.5	0.5	67
Populus fremontii	40	162,586.3	7,887.5	44,274.9	200,242.4	9.7	0.8	0.0	25.0	76	14	1.5	500	25.8	3.7	0.5	67
Riverwash herbaceous	398	103,150.0	2,534.0	2,850.9	200,242.4	3.1	0.1	0.0	26.6	7	2	1.5	500	0.8	0.2	0.5	67
Riverwash scrub	74	95,216.7	5,855.9	12,401.5	197,584.2	5.0	0.4	0.0	14.1	5	1	1.5	100	3.2	0.9	0.5	36
Salix exigua	29	128,949.0	5,783.1	107,125.6	200,242.4	4.8	0.4	1.0	9.4	13	5	1.5	100	30.4	3.0	10	67
Salix exigua - Arundo donax	28	93,532.8	3,929.3	77,115.2	152,831.5	8.8	0.6	2.0	18.9	17	6	5	100	12.3	3.7	0.5	60
Salix exigua - Baccharis salic	12	54,626.8	8,635.6	19,515.8	120,210.1	18.6	3.4	7.9	42.4	72	47	5	500	37.0	5.9	0.5	67
Salix laevigata	60	117,060.1	3,794.7	29,421.1	183,560.0	5.6	0.5	0.0	20.6	44	10	1.5	500	14.7	1.7	0.5	36
Salix lasiolepis	67	15,702.2	2,510.9	617.4	99,539.4	12.4	0.7	0.6	24.8	43	11	1.5	500	27.3	2.0	0.5	67
Salix lucida	19	84,240.0	5,696.8	45,355.3	105,606.7	4.9	0.8	0.2	12.3	4	1	1.5	10	20.5	5.1	0.5	60
Tamarix spp.	4	197,584.2	0.0	197,584.2	197,584.2	6.3	1.1	4.0	9.0	55	26	10	100	36.0	0.0	36	36

Table B-2. Descriptive statistics for physical site variables by vegetation alliance (SE refers to Standard Error).

Alliance	N Rows	Channel Gradient (2-yr flood)				Channel Gradient (50-yr flood)			
		mean	SE	mean	SE	mean	SE	mean	SE
Artemisia ca- Eriogonum fasc	4	0.25%	0.05%	0.25%	0.05%	0.25%	0.05%	0.25%	0.05%
Artemisia californica	10	0.25%	0.02%	0.25%	0.02%	0.25%	0.02%	0.25%	0.02%
Artemisia tridentata	30	0.57%	0.01%	0.57%	0.01%	0.57%	0.01%	0.57%	0.01%
Arundo donax	251	0.42%	0.01%	0.42%	0.01%	0.42%	0.01%	0.42%	0.01%
Baccharis pilularis	28	0.18%	0.02%	0.18%	0.02%	0.18%	0.02%	0.18%	0.02%
Baccharis salicifolia	13	0.30%	0.02%	0.30%	0.02%	0.30%	0.02%	0.30%	0.02%
Eucalyptus spp.	4	0.28%	0.05%	0.28%	0.05%	0.28%	0.05%	0.28%	0.05%
Floodplain wetland	139	0.48%	0.01%	0.48%	0.01%	0.48%	0.01%	0.48%	0.01%
Lepidospartum squamatum	14	0.42%	0.04%	0.42%	0.04%	0.42%	0.04%	0.42%	0.04%
Mixed riparian forest	5	0.42%	0.09%	0.42%	0.09%	0.42%	0.09%	0.42%	0.09%
Mixed riparian scrub	27	0.30%	0.03%	0.30%	0.03%	0.30%	0.03%	0.30%	0.03%
Mixed scrub	5	0.24%	0.06%	0.24%	0.06%	0.24%	0.06%	0.24%	0.06%
Mixed willow forest	52	0.28%	0.04%	0.28%	0.04%	0.28%	0.04%	0.28%	0.04%
Mixed willow scrub	21	0.28%	0.01%	0.28%	0.01%	0.28%	0.01%	0.28%	0.01%
Non-native grasses and forbs	91	0.33%	0.01%	0.33%	0.01%	0.33%	0.01%	0.33%	0.01%
Populus balsamifera	65	0.29%	0.01%	0.29%	0.01%	0.29%	0.01%	0.29%	0.01%
Populus fremontii	40	0.50%	0.02%	0.50%	0.02%	0.50%	0.02%	0.50%	0.02%
Riverwash herbaceous	398	0.41%	0.01%	0.41%	0.01%	0.41%	0.01%	0.41%	0.01%
Riverwash scrub	74	0.36%	0.01%	0.36%	0.01%	0.36%	0.01%	0.36%	0.01%
Salix exigua	29	0.35%	0.03%	0.35%	0.03%	0.35%	0.03%	0.35%	0.03%
Salix exigua - Arundo donax	28	0.30%	0.02%	0.30%	0.02%	0.30%	0.02%	0.30%	0.02%
Salix exigua - Baccharis salic	12	0.29%	0.02%	0.29%	0.02%	0.29%	0.02%	0.29%	0.02%
Salix laevigata	60	0.46%	0.02%	0.46%	0.02%	0.46%	0.02%	0.46%	0.02%
Salix lasiolepis	67	0.17%	0.01%	0.17%	0.01%	0.17%	0.01%	0.17%	0.01%
Salix lucida	19	0.33%	0.01%	0.33%	0.01%	0.33%	0.01%	0.33%	0.01%
Tamarix spp.	4	0.50%	0.00%	0.50%	0.00%	0.50%	0.00%	0.50%	0.00%

Table B-3. Descriptive statistics for physical site variables by vegetation alliance (SE refers to Standard Error).

Alliance	N Rows	Stream Power (2-yr flood)				Stream Power (50-yr flood)			
		mean	SE	mean	SE	mean	SE	mean	SE
Artemisia ca- Eriogonum fasc	4	2	0.5	2	0.5	2	0.5	2	0.5
Artemisia californica	10	3	0.3	3	0.3	3	0.3	3	0.3
Artemisia tridentata	30	2	0.4	2	0.4	2	0.4	2	0.4
Arundo donax	251	3	0.1	3	0.1	3	0.1	3	0.1
Baccharis pilularis	28	3	0.6	3	0.6	3	0.6	3	0.6
Baccharis salicifolia	13	5	1.2	5	1.2	5	1.2	5	1.2
Eucalyptus spp.	4	2	0.5	2	0.5	2	0.5	2	0.5
Floodplain wetland	139	3	0.3	3	0.3	3	0.3	3	0.3
Lepidospartum squamatum	14	3	0.6	3	0.6	3	0.6	3	0.6
Mixed riparian forest	5	2	0.3	2	0.3	2	0.3	2	0.3
Mixed riparian scrub	27	4	0.4	4	0.4	4	0.4	4	0.4
Mixed scrub	5	3	0.8	3	0.8	3	0.8	3	0.8
Mixed willow forest	52	3	0.7	3	0.7	3	0.7	3	0.7
Mixed willow scrub	21	6	0.9	6	0.9	6	0.9	6	0.9
Non-native grasses and forbs	91	4	0.3	4	0.3	4	0.3	4	0.3
Populus balsamifera	65	2	0.2	2	0.2	2	0.2	2	0.2
Populus fremontii	40	5	0.5	5	0.5	5	0.5	5	0.5
Riverwash herbaceous	398	2	0.1	2	0.1	2	0.1	2	0.1
Riverwash scrub	74	4	0.4	4	0.4	4	0.4	4	0.4
Salix exigua	29	3	0.4	3	0.4	3	0.4	3	0.4
Salix exigua - Arundo donax	28	3	0.2	3	0.2	3	0.2	3	0.2
Salix exigua - Baccharis salic	12	5	0.7	5	0.7	5	0.7	5	0.7
Salix laevigata	60	3	0.6	3	0.6	3	0.6	3	0.6
Salix lasiolepis	67	2	0.2	2	0.2	2	0.2	2	0.2
Salix lucida	19	2	0.3	2	0.3	2	0.3	2	0.3
Tamarix spp.	4	1	0.0	1	0.0	1	0.0	1	0.0

Table B-4. Descriptive statistics for physical site variables by vegetation alliance (SE refers to Standard Error).

Alliance	N Rows	Wetted Width (2-yr flood)				Wetted Width (50-yr flood)			
		mean	SE	min	max	mean	SE	min	max
Artemisia ca- Eriogonum fasc	4	874.7	20.3	813.8	895.1	2,057.9	76.4	1,828.8	2,134.3
Artemisia californica	10	888.0	76.1	594.7	1,281.8	1,714.7	125.0	978.4	2,498.3
Artemisia tridentata	30	1,204.5	75.1	511.7	1,745.9	3,004.7	215.0	1,355.6	6,338.0
Arundo donax	251	1,119.9	32.8	220.0	2,742.2	3,467.5	102.2	373.1	9,345.8
Baccharis pilularis	28	1,943.7	391.7	551.6	6,172.4	5,057.0	375.5	3,184.9	8,862.5
Baccharis salicifolia	13	853.0	103.9	551.6	1,613.7	3,175.3	278.0	1,450.1	4,964.0
Eucalyptus spp.	4	759.2	131.9	518.0	1,130.3	2,749.5	345.3	2,158.6	3,674.6
Floodplain wetland	139	1,096.6	36.7	251.2	2,351.9	3,031.4	120.9	764.9	6,691.3
Lepidospartum squamatum	14	1,314.0	149.3	702.1	2,037.4	5,679.3	472.2	2,438.5	6,810.4
Mixed riparian forest	5	917.7	39.4	760.5	964.8	1,837.5	214.1	1,465.8	2,361.1
Mixed riparian scrub	27	681.5	52.9	177.1	1,281.8	2,604.3	191.6	681.6	3,590.1
Mixed scrub	5	780.4	51.5	684.1	966.0	2,314.3	148.5	1,727.6	2,512.2
Mixed willow forest	52	1,102.9	210.4	421.7	6,061.4	3,239.7	279.9	1,355.6	8,319.5
Mixed willow scrub	21	773.9	144.8	251.2	2,287.6	2,789.1	233.5	1,380.6	4,399.6
Non-native grasses and forbs	91	904.4	45.3	220.0	2,037.4	3,775.0	147.4	373.1	7,613.5
Populus balsamifera	65	1,339.1	102.0	380.6	6,061.4	4,118.2	163.5	1,276.5	9,345.8
Populus fremontii	40	511.0	72.9	177.1	2,287.6	1,418.6	216.2	373.1	6,600.7
Riverwash herbaceous	398	1,283.7	30.8	180.6	6,172.4	3,242.0	73.3	580.8	8,862.5
Riverwash scrub	74	842.3	34.5	180.6	2,037.4	2,859.6	234.7	580.8	7,613.5
Salix exigua	29	1,160.6	79.1	410.1	2,037.4	5,465.8	348.3	1,406.7	7,613.5
Salix exigua - Arundo donax	28	824.6	29.7	509.3	1,230.6	2,533.9	38.6	2,291.1	3,130.8
Salix exigua - Baccharis salic	12	637.0	69.8	345.9	1,325.8	3,778.3	238.3	2,728.9	4,964.0
Salix laevigata	60	1,151.0	61.8	357.7	2,351.9	3,567.8	199.5	764.9	6,600.7
Salix lasiolepis	67	1,138.4	111.7	380.6	2,742.2	4,360.6	287.7	1,276.5	9,345.8
Salix lucida	19	1,540.9	146.1	659.9	2,351.9	3,732.8	277.8	1,432.8	5,255.9
Tamarix spp.	4	643.9	0.0	643.9	643.9	1,115.8	0.0	1,115.8	1,115.8