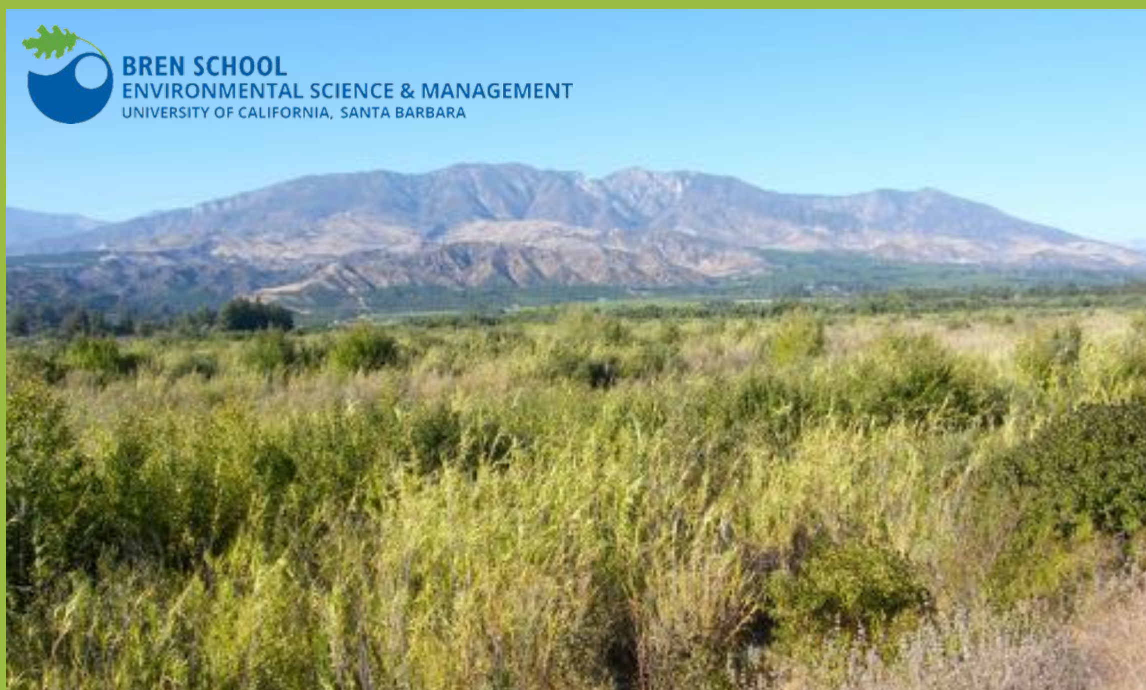
Economic Analysis of Invasive Giant Reed (*Arundo donax*) Control for the Lower Santa Clara River



A Group Project submitted in partial satisfaction of the requirements for the degree of Master of Environmental Science and Management

Project Members
Ian Bell
Eliza Berry
Brooke Prentice-Dekker
Zach McKelvey
Marc Steele

Advisor
Dr. Derek Booth

Bren School of Environmental Science & Management
University of California, Santa Barbara
March 2016

Acknowledgments

We would like to thank everyone who assisted and supported us through the duration of this project. We would especially like to thank our faculty advisor, Dr. Derek Booth, and collaborators at the Riparian InVasion Research Laboratory (RIVRLab) Drs. Adam Lambert and Tom Dudley.

Cover Photo Credits

Top: Dr. Adam Lambert
Bottom left: Marc Steele
Bottom right: William Schlegel

ECONOMIC ANALYSIS OF INVASIVE GIANT REED (*ARUNDO DONAX*) CONTROL FOR THE LOWER SANTA CLARA RIVER

As authors of this Group Project report, we archive this report on the Bren School's website such that the results of our research are available for all to read. Our signatures on the document signify our joint responsibility to fulfill the archiving standards set by the Bren School of Environmental Science & Management.

Ian Bell

Zach McKelvey

Eliza Berry

Marc Steele

Brooke Prentice-Dekker

The mission of the Bren School of Environmental Science & Management is to produce professionals with unrivaled training in environmental science and management who will devote their unique skills to the diagnosis, assessment, mitigation, prevention, and remedy of the environmental problems of today and the future. A guiding principle of the School is that the analysis of environmental problems requires quantitative training in more than one discipline and an awareness of the physical, biological, social, political, and economic consequences that arise from scientific or technological decisions.

The Group Project is required of all students in the Master of Environmental Science and Management (MESM) Program. The project is a year-long activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Group Project Final Report is authored by MESM students and has been reviewed and approved by:

Dr. Derek Booth
March 2016

Abstract

The objectives of this project are to (1) quantify the economic and ecological impacts of the invasive plant *Arundo donax* on the Santa Clara River in Ventura County, California; and (2) explore how *A. donax* control efforts can be cost-effectively expanded within the Santa Clara River catchment and throughout Southern California. This project developed three spatially explicit modeling tools to quantify the impact that *A. donax* has on local economies and natural processes within Southern California: a water-consumption model to quantify evaporative water loss due to *A. donax,* a fire-risk model to assess how *A. donax* alters fire behavior, and a flood model to understand how *A. donax* affects flood damages. Results show that *A. donax* removal projects within the Santa Clara River can result in substantial water-savings benefits as well as generate localized fire- and flood-impact reduction benefits. Results from the water consumption, fire behavior, and flood damage models were compared to the costs of *A. donax* removal and restoration in a cost-benefit analysis. The *A. donax* cost-benefit analysis tool provides a framework to explore the efficiencies of a variety of *A. donax* control and management options, the results of which are the basis for our *A. donax* management recommendations for the Santa Clara River. We recommend strategic restoration that piggybacks on scouring flood events to efficiently treat large areas of *A. donax,* further incorporation of Endangered and Threatened species valuation, and spatially targeted *A. donax* removal that could cost-effectively increase the benefits associated with removal. The broader intended value of this research is twofold: to provide a flexible methodology that can be adapted regionally to assist land managers in planning and prioritizing riparian restoration projects involving *A. donax* removal; and to serve as a tool to better quantify the benefits that can accompany *A. donax* restoration efforts.

Executive Summary

Giant reed (*Arundo donax*) is an invasive perennial reed that grows throughout extensive portions of riparian habitat in southern California. The invasion of *A. donax* in the Santa Clara River (SCR) watershed has degraded essential habitat hosting over 15 Threatened and Endangered species and providing many ecosystem services to the communities in Ventura and Los Angeles Counties. The river and its watershed are a valuable asset for local communities, providing water to a profitable agriculture industry. Programs to remove *A. donax* are underway in the SCR watershed, which follow one of three broad categories of available control/removal methods: mechanical, chemical, and biological. Most recent management plans have incorporated mechanical and chemical methods, while biological controls are still being explored by some agencies for their potential effectiveness in a large-scale program. For long-term program success, removal efforts are often paired with restoration. To better support restoration efforts in the watershed, the true benefits that the people and environment in the region could receive from watershed-scale restoration need to be quantified. The overall goal of this project is to support decision-makers engaging in *A. donax* removal programs in the lower SCR by quantifying the costs of restoring areas of the SCR against the benefits of *A. donax* removal.

The SCR watershed drains a catchment area of 1,626 square miles in Southern California, just north of the greater Los Angeles region. The SCR stretches for over 83 miles across Los Angeles and Ventura Counties, flowing westward to the Pacific Ocean**.** Our area of focus was the entire area contained within the Federal Emergency Management Agency (FEMA) 500-year SCR floodplain from the Los Angeles County line to the Pacific Ocean. This area encompasses approximately the lowermost 50 miles of the SCR.

Arundo donax (A. donax, or giant reed) poses a variety of threats to the riparian ecosystem of the SCR. These threats result from its high evapotranspiration rates, severe fire hazard, and linkage to increased flood damages through erosion, sediment deposition, and interference with the surface flow of water. *A. donax* uses approximately four times as much water as native riparian vegetation, limiting groundwater recharge and instream flow. In many of the watersheds in Southern California, the invasion of *A. donax* has altered fire patterns in riparian ecosystems. Historically, riparian areas have acted as firebreaks that inhibit fire from spreading across the landscape. In addition to high water use and increased fire severity, *A. donax* can increase the severity and extent of flood events. Additionally, *A. donax* has displaced native vegetation throughout Southern California riparian areas, reducing habitat quality for native animal species.

The primary objectives of this project was to use a cost-benefit analysis framework to investigate the costs of *A. donax* removal and associated benefits in terms of reduction in water consumption, fire severity, and flood damage in the Ventura County stretch of the Santa Clara River. A secondary objective is to develop a model to assist in identifying land parcels in the lower SCR for priority consideration in restoration efforts. Parcel selection was based on the principle of maximizing ecological benefits while minimizing the costs of an *A. donax* removal program.

The analyses in this report sought to quantify the various costs and benefits received from the removal of *A. donax* from the lower SCR river channel and floodplain. We undertook multiple investigations: a renewed mapping effort that supplemented an effort in 2005 by Stillwater Sciences and URS Corporation; a model that assessed the water use of *A. donax* compared to native riparian vegetation; a model that examined the fire risk *A. donax* presents to the riparian habitats it invades; and, a model that analyzed the impacts *A. donax* has on flood damage. The results of these models were then input into a cost-benefit analysis that compared the costs and benefits of *A. donax* removal in the study area over time.

Our analyses found that removal of *A. donax* results in water savings that equate to approximately $900 per acre of *A. donax* removed. We also found that *A. donax* removal reduces the fire risk in the SCR. When quantified, are analyses found that removing an acre of *A. donax* is worth approximately $50 in fire-fighting cost savings. Finally, we modeled that each acre of *A. donax* removed results in approximately $60 of avoided property damage due to increased flooding. We compared these benefits against the costs of managing *A. donax* under three different scenarios in our cost-benefit analysis. The first was the present approach to restoration, defined as approximately 15 acres of restoration each year. The second and third management scenarios were contingency plans of increasing magnitude in which restoration resources are rerouted to increased management of areas removed of *A. donax* by large flood events in the river.

Our cost-benefit analysis found that the present approach management strategy, as well as both contingency plan scenarios, rarely resulted in a positive net present value (NPV) for *A. donax* removal, meaning the costs of removal were greater than the benefits received from that removal. Our analyses, however, did find that the contingency plan scenarios for managing *A. donax* elicited higher NPVs than the present approach to restoration in the SCR.

Based on our model results, we see that the monetary benefit of reduced water consumption when *A. donax* is removed and restored with native vegetation is approximately 15 times greater than both the benefits received from reduced risk of fire events and reduced magnitudes and extents of flood events. Emphasis on large, quantifiable benefits such as water savings could be a way to elicit greater participation from various stakeholders within the SCR. In addition to the benefits we analyzed, however, there are numerous other benefits that were not included in our study that should be analyzed in the future. The additional quantification of benefits, such as improved habitat quality for federally listed species, would improve the cost-benefit ratio of restoring *A. donax* within the SCR.

In moving forward with *A. donax* management, we suggest that restoration managers operating within the lower SCR develop contingency plans in preparation for periodic flood (and possibly fire) events. In these areas that have been recently removed of *A. donax* biomass by floods or fires, a majority of initial removal costs are avoided. This could allow for an increase in *A. donax* acres treated or make funds available for other restoration projects within the lower SCR. We recommend that stakeholders strategize collaboratively to further enhance the effectiveness of contingency plans that can be implemented after floods.

A. donax infestation is a problem in many of coastal California watersheds and *A. donax* control is a major financial investment for various stakeholders within the state. Our approach of modeling costs and benefits of control is highly applicable to other watersheds. It is strategic for non-profits, state agencies, county agencies, and national agencies to understand the economic implications of the *A. donax* control programs. Our approach to modeling costs and benefits of *A. donax* control can also aid these entities in answering questions of how control should be conducted in order to maximize benefits in comparison to costs over timescales that make sense to these entities' operations.

We conclude that management that capitalizes on natural disturbance events (i.e., scouring floods and fires) to remove *A. donax* biomass will be most cost-effective. This strategic approach could avoid large biomass removal budget lines and results in a higher benefit-cost ratio than simply focusing on biomass removal and treatment year to year without resources in place to treat post-flood. We suggest that our analysis serves as a framework for further investigation into quantifying the benefits of *A. donax* removal in Southern California watersheds.

Table of Contents

1. Significance

Giant reed (*A. donax*) is an invasive perennial grass that grows throughout extensive portions of riparian habitat throughout Southern California and poses a current and future threat to the human inhabitants and the native ecosystems of the Santa Clara River (SCR) watershed. There is strong evidence that *A. donax* negatively impacts the wildfire and hydrological regimes of the watershed, imperiling human and native communities. *A. donax* displaces native vegetation in riparian areas, impacting critical native habitat for endemic endangered species while also consuming groundwater and surface-water resources.

The invasion of *A. donax* has degraded the SCR watershed, an essential habitat hosting over 15 Threatened and Endangered species and providing many ecosystem services to the communities in Ventura and Los Angeles County. The SCR is one of the only rivers in the state that still retains many attributes of its natural hydrology (Orr et al., 2009). Maintenance of natural resources in the SCR allows the river to host a plethora of species including many federally listed species (Court et al., 2000). Water supplied from the watershed is used for residential, agricultural, and industrial purposes.

Programs to remove *A. donax* are underway in the SCR watershed. Progress has been made locally to restore native habitats. It is assumed that the continuation of these restoration efforts hinges on quantifying the true benefits that the people and environment in the region could receive from watershed-scale restoration. Thus, this project holistically compares the costs of restoring key areas of the SCR Valley against the benefits of long-term risk reduction of environmental hazards which include reductions in water supply, increased threat of wildfires, and increased flood damages.

2. Area of study

For the purposes of this report, our area of focus is the lower SCR (Figure 1) and associated riparian and floodplain area. We defined this area to be the entire area contained within the Federal Emergency Management Agency (FEMA) 500-year SCR floodplain from the Los Angeles County line to the Pacific Ocean (Figure 2). This area encompasses roughly the lower 50 miles of the SCR.

Figure 1. Santa Clara River watershed (orange outline). The Santa Clara River drains an area of 1,626 square miles, divided almost evenly between Ventura County (lower watershed) and Los Angeles County (upper watershed). Our area of study is represented in yellow.

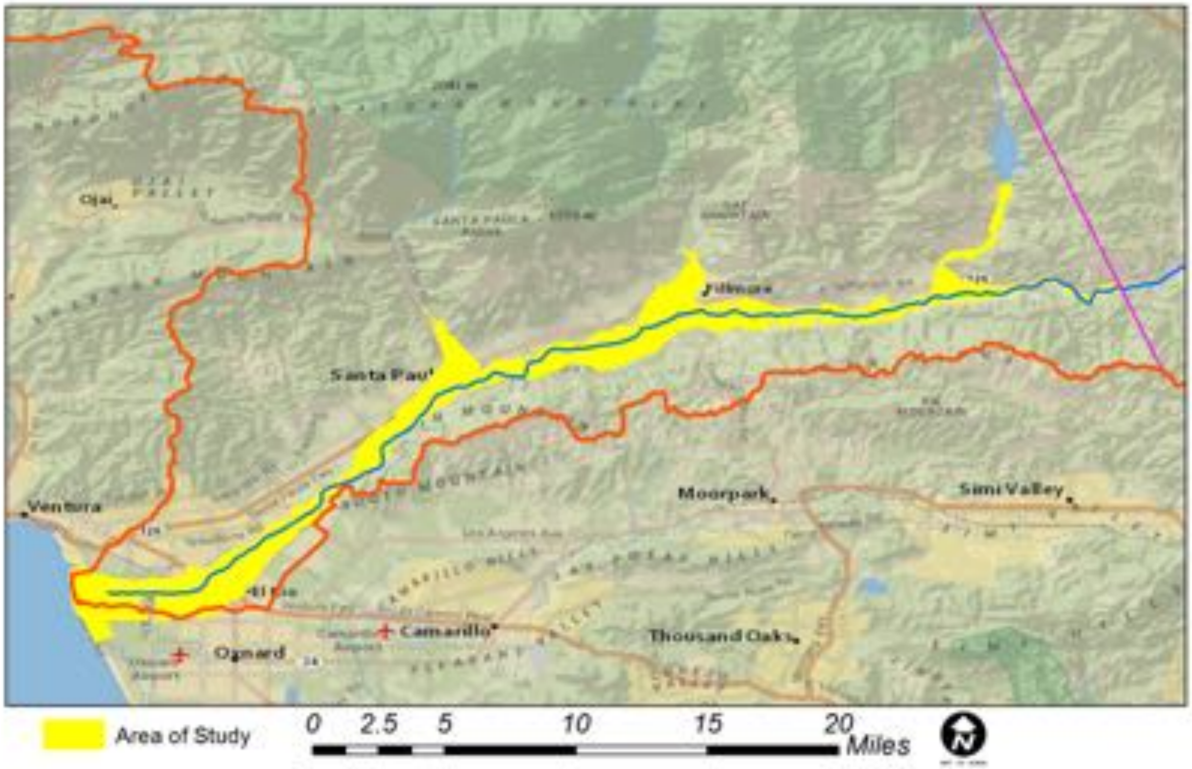


Figure 2. Detail of Area of Study. The yellow area of the map represents our project's primary area of study, the identified 500-year floodplain of the SCR within Ventura County.

3. Objectives

The overall goal of this project is to support decision-makers engaging in *A. donax* removal programs in the lower SCR. To achieve this goal, the scope of the project was defined with the following primary and secondary objectives:

Primary Objective. The primary objective is to quantify the economic costs associated with the presence of *A. donax* in the lower SCR and perform a cost-benefit analysis of *A. donax* removal. Those risks analyzed and valuated included: 1) water consumption, 2) fire susceptibility, and 3) flood damage.

Secondary Objective. A secondary objective is to develop a model to assist in identifying land parcels in the lower SCR for priority consideration in restoration efforts. Parcel selection was based on the principle of maximizing ecological benefits while minimizing the costs of an *A. donax* removal program.

4. Background

4.1 The Santa Clara River watershed

The SCR watershed is a large and dynamic region of Southern California, USA, just north of the greater Los Angeles region. The SCR stretches for over 83 miles across Los Angeles and Ventura Counties, flowing westward to the Pacific Ocean while draining a catchment area of 1,626 square miles, larger than the entire state of Rhode Island (Stillwater Sciences, 2007a).

Geologically, the basin drains a portion of the Transverse Range province. The Transverse Ranges are a series of Southern California mountain ranges caused by an east-west jog in the north–south trending San Andres Fault. The Topatopa and Sierra Pelona Ranges constrain the SCR on the north, while the Santa Susana and San Gabriel Mountains bound the river as it flows west toward the sea (Stillwater Sciences, 2011).

Most of the basin experiences a Mediterranean climate of cool, wet winters and hot, dry summers. Precipitation in the basin is further influenced by the geography of the catchment, with increasing basin elevations corresponding to heightened precipitation while areas farther from the ocean tend to receive less rainfall. The far eastern reaches of the watershed are part of the Mojave Desert ecoregion, which averages less than 10 inches of precipitation a year and is home to an array of desert ecosystems. Conversely, areas of the Coast Range near the Pacific Ocean typically receive 50+ inches of rainfall annually and sustain ecologically productive chaparral and grassland ecosystems. Rainfall strongly varies year-to-year as well as by location within the watershed. El Niño years have historically correlated with episodic heavy rains and flooding within the SCR watershed.

Despite close proximity to the second largest metropolitan area in the country, the SCR watershed retains significant areas of agricultural lands and undeveloped open space. The SCR basin has a rich history of agriculture and grazing dating back to the Rancho Period (Stillwater Sciences, 2011). Today, Ventura County is home to some of the most productive agricultural lands in the world—agriculture such as avocados, citrus, and strawberries are a $2 billion/year industry (Ventura County Office of the Agricultural Commissioner, 2014). The river and its watershed are a valuable asset for local communities, providing water to a profitable agriculture industry. These natural systems and agricultural lands face growing development pressure, however. The city of Santa Clarita and other suburban areas of the watershed have experienced rapid population growth in the past three decades, and growth is expected to continue in to the future.

The SCR watershed is distinctive from most other Southern California watersheds in that it is largely undammed and thus experiences relatively natural flow and disturbance regimes. The floodplain has limited development due to the flood hazard, leaving large expanses of remaining riparian habitat for native plant and animal species. These riparian corridors of the SCR and other natural systems within the basin are considered an ecological hotspot within Southern California, providing key habitat for 15 Endangered species at the intersection of four of California's ecoregions. The Nature Conservancy and other conservation groups have successfully acquired land within the SCR floodplain for habitat and flood mitigation purposes (Stillwater Sciences, 2007b).

4.2 *Arundo donax*

Arundo donax (A. donax, or giant reed; Figure 3) poses a critical threat to the riparian ecosystem of the SCR. The bamboo-like reed forms monocultures too dense to traverse, outcompeting native vegetation including cottonwoods (*Populus fremontii, P. trichocarpa*) and willows (*Salix* spp.) that were historically dominant within the riparian area of the SCR(Beller, Downs, Grossinger, Orr, & Salomon, 2015; Dudley, 2000).

Because *A. donax* spreads through its rhizomes, flood events also function as propagation events by spreading rhizomes downriver. A study on post-flood establishment of *A. donax* on the Santa Margarita River indicates that extent of establishment is directly correlated with flood magnitude (Else, 1996). A study assessing vegetation distribution correlations based on historical aerial photographs of the SCR indicate that *A. donax* is more common on surfaces that have been flooded in the past 40 years (Stillwater Sciences, 2007c), suggesting that *A. donax* removal and restoration plans must account for the possibility that sites may become reinfested *A. donax* after flood events.

In addition to its innate ability to spread and grow rapidly, *A. donax* threatens the health of riparian habitats through its high evapotranspiration rates, severe fire hazard, and linkage to increased flood damages through erosion, sediment deposition, and interference with the surface flow of water (G. C. Coffman, 2007).

Figure 3. A field crew carrying out *Arundo donax* removal in the city of Fillmore. *A. donax* grows up to 30 feet tall. Photo credit: William Schlegel.

4.3 Water use

A. donax uses approximately four times as much water as native riparian vegetation, limiting groundwater recharge and instream flows which are important in maintaining a natural native vegetative regime within riparian ecosystems (California Invasive Plant Council, 2011; Nackley, Vogt, & Kim, 2014; Triana, Di Nasso, Ragaglini, Roncucci, & Bonari, 2015; D. A. Watts & Moore, 2011). *A. donax*'*s* high water consumption limits groundwater recharge in the Fillmore, Santa Paula, and Oxnard Plain basins of the SCR watershed (California Invasive Plant Council, 2011). These are all areas where local agriculture is highly dependent on groundwater. Nutrient enrichment from nearby agriculture, especially elevated levels of nitrates, has been shown to increase the abundance of *A. donax* compared to areas where nitrogen is limited, like that of traditional riparian habitat (Ambrose & Rundel, 2007). This, coupled with a long-term decline in groundwater observed in the Santa Paula Basin, is allows *A. donax* to outcompete native species such as willows, mulefat, and cottonwoods (United Water Conservation District Groundwater Resources Department, 2012). *A. donax*'*s* elevated water use arises from its high transpiration from large leaf surface area (D. A. Watts & Moore, 2011).

The water quality of the watershed is also impacted by the presence of *A. donax*. *A. donax* provides less shade to aquatic areas than many native species and can lead to higher water temperatures and subsequently reduced levels of dissolved oxygen in water, potentially creating lethal habitat for some aquatic organisms. *A. donax*'*s* presence encourages algal blooms and increases water pH, which in turn facilitates the conversion of ammonia to toxic compounds (Ventura County Resource Conservation District, 2006).

4.4 Fire

Fire is a natural part of Southern California ecosystems, but the historic fire regime has been severely altered since the emergence of fire suppression and invasion of fire-accelerating, non-native species across the landscape. Southern California's Mediterranean climate is conducive to fire proliferation due to hot dry summers, scattered thunderstorms, low humidity, and prevailing winds (Jon E. Keeley, Fotheringham, & Morais, 1999). Historically, riparian areas such as the SCR have acted as a firebreak that inhibits fire from spreading across the landscape (Dwire & Kauffman, 2003). In many of the watersheds in Southern California, however, the invasion of *A. donax* has altered fire patterns in these riparian ecosystems by accelerating fire spread (G. C. Coffman, Ambrose, & Rundel, 2010).

The vegetative structure of *A. donax* acts as a bridge for fire*,* allowing fires to spread across previously protected areas (G. C. Coffman et al., 2010; Dwire & Kauffman, 2003). Since *A. donax* grows leaves on all of its above-ground biomass starting near the base of the plant and proceeding to the top, reaching heights over 30 feet, fire is able to spread into the canopy of the vegetation rapidly(Hobbs, 2000). *A. donax* increases the fuel load that allows fire to burn more completely and at higher intensities compared to fires in native riparian habitats (Hobbs, 2000).

For example, the Simi Fire that occurred in October of 2003 caused over $10 million in damages after the fire burned over a quarter-mile stretch of the SCR through an *A. donax* stand that further spread the fire an additional 100,000 acres (G. C. Coffman et al., 2010). Most recently, the River Fire in July of 2015 burned though an *A. donax* stand and threatened the Santa Paula Airport and other major commercial and residential structures. This fire burned over 160 acres of the SCR and cost over $510,000 to control (Coffman et al., 2010)(cost data provided by Ventura County Fire Department, 2015).

Post-fire, *A. donax* is capable of reestablishing within days (Brooks et al., 2004; G. C. Coffman et al., 2010). *A. donax* regenerates at 3-4 times the rate of native riparian vegetation and can become 20 times as dense as native woody species within a single year after a fire disturbance (G. C. Coffman et al., 2010). Due to the aggressive nature of *A. donax* regrowth post-fire, it creates an invasive plant fire regime in riparian ecosystems. Thus, after a large fire disturbance, an area of previously mixed native vegetation and *A. donax* can reorganize into an area almost exclusively dominated by *A. donax* (Bell, 1997; Brooks et al., 2004; G. C. Coffman et al., 2010).

After a fire, nutrients, particularly nitrogen, are redistributed throughout the ecosystem, allowing *A. donax* to proliferate and further enhance its invasive fire regime. Although the upper portion of the SCR watershed is predominantly open space with low nitrogen levels, the lower watershed is a mix of urban, developing, and agricultural land that creates elevated levels of anthropogenic nutrients (Ambrose & Rundel, 2007). These human-related increases of nitrogen enhance the abundance and productivity of *A. donax* regeneration after a fire event (G. C. Coffman et al., 2010). Compared to native riparian vegetation, such as red willow (*Salix laevigata*), *A. donax* is able to take advantage of the elevated levels of nitrogen and potassium that are common in agricultural areas and out-compete the native vegetation (Ambrose & Rundel, 2007).

4.5 Hydrology

The SCR is one of the largest and least dam-regulated watersheds in Southern California, although about 37% of the entire river basin is nonetheless impounded behind dams (E. Beller et al., 2011; Orme & O'Hirok, 2005). There are no large storage dams on the mainstream and the river maintains a braided channel and sandy bed, which is periodically scoured of vegetation by high flows (E. Beller et al., 2011). Levee construction and floodplain development have mainly occurred in the lower watershed.

During the summer, stretches of the mainstream river and its tributaries run dry or contain only intermittent low-flow periods, a result of interactions between groundwater and surface water, as well as dam controls (Stillwater Sciences, 2007a). The river receives more than half of its annual water inputs during a few high-intensity, short-duration precipitation events during the winter months (Warrick, 2002). Peak flows occur during the rainy season between November and March, with large flood events corresponding to years of increased rainfall from the El Niño–Southern Oscillation (Stillwater Sciences, 2007a). Since 1930, there have been nine flood events with discharge rates over 2,800 m^3/s (100,000 cfs). The most recent major flood occurred in January and February of 2005, when peak flows reached 136,000 cfs near the mouth of the river (Ventura County Watershed Protection District as cited in Stillwater Sciences, 2007a).

Literature shows that *A. donax* can increase the severity and extent of flood events (Kennedy/Jenks Consultants, 2014; Spencer, Colby, & Norris, 2013). Spencer et al.'s (2013) study tests this hypothesis by determining Manning *n* for A. donax and applying it in a hydraulic model to view impact of *A. donax* on flood risk. A Manning's *n* coefficient is a measure of flow roughness representing the extent to which *A. donax* will slow the flow of water downstream. To our knowledge, Spencer et al. published the only study to establish a Manning's *n* coefficient for *A. donax* from direct in-stream experiments. The study used two moderately sized tributaries of the Sacramento River (Cache Creek and Stony Creek) as case studies. These two study sites have generally higher average annual flows than the SCR, though both have lower flood peaks and smaller catchments than the SCR. Spencer et. al.

quantified *A. donax* density in these rivers in terms of stems per square meter at each sample site, noting that the stem densities they recorded were similar to those reported in 16 other *A. donax* studies from California, Mississippi, and Texas. Using a hydraulic model to evaluate the effects of changing roughness, their results showed approximately a 10% increase in flood area compared to conditions with no *A. donax*. Modeling larger floods with maximum Manning's *n* coefficients increased the flood area by up to 19% (Spencer et al., 2013).

Major flood events also can wipe out existing *A. donax* stands, removing the influence of standing vegetation on flood levels but potentially causing damage downstream. Rafts of *A. donax* floating downstream cover beaches and back up against bridges, potentially causing infrastructure damage (Kennedy/Jenks Consultants, 2014). However, there is no established threshold of water velocity or stress that will send *A. donax* rafts downstream (California Invasive Plant Council, 2011). A recent thesis (ten Brinke, 2011) looked at the impact of *A. donax* on bank stability and erosion compared to the Red Willow, a common native species. The Brinke's study concluded that *A. donax* provided greater tensile strength in the upper 10 cm of the bank and Red Willow below 10 cm. The study concluded that *A. donax* provides little stability to banks higher than one foot and that cantilever failure causes *A. donax*-dense banks to collapse (ten Brinke, 2011).

Much of the literature on *A. donax* impacts mentions *A. donax* debris covering beaches after major floods and notes that in highly *A. donax*-infested undammed river systems, the vast majority of the vegetative debris after a flood will be *A. donax* (California Invasive Plant Council, 2011; G. Coffman, 2013; Loper, Cozad, Katagi, & Beehler, 2005). However, there is no literature available that attempts to quantify or model the volume of *A. donax* debris sent downstream during a flood event, its interactions with ocean currents, or the number of miles of beaches that will be covered and subsequently require debris removal.

4.6 Biodiversity and habitat

A. donax has degraded the quality of riparian habitat within the SCR watershed. *A. donax* has displaced native vegetation throughout Southern California riparian areas, reducing habitat value for native species (Faber, Keller, Sands, & Massey, 1989). *A. donax* does offer some habitat to native species in the watershed; but in aggregate, stands of *A. donax* have been found to provide diminished complexity and diversity in comparison to native habitat (Bell, 1997; Stillwater Sciences, 2007b). There are a host of Threatened and Endangered species in the watershed that are expected to make improvements in population numbers given appropriate native habitat restoration efforts (Stillwater Sciences, 2007b). These state and/or federally listed Threatened and Endangered species include: the arroyo toad, least Bell's vireo, southwestern willow flycatcher, western yellow-billed cuckoo, Nevin's barberry, slender-horned spineflower, southern steelhead, and the tidewater goby.

A. donax invasion has been found to impact many of the Threatened and Endangered species found in the SCR Basin. Generally, the abundance and richness of riparian bird species of Southern California communities has been found to be greater in areas with less *A. donax* (Kisner, 2004). *A. donax* competes with native riparian plants that provide nesting habitat for the southwestern willow flycatcher and least Bell's vireo, two federally Endangered species that nest within the SCR watershed (Bell, 1997). It has been shown that bird species (notably least Bell's vireo) utilize restored riparian habitats to an equal degree as native habitat, highlighting that *A. donax* removal efforts that are coupled with riparian restoration efforts can benefit Endangered species population numbers (Kus, 1998). Within the SCR, it was found that dense thickets of *A. donax* had very low bird diversity, though small to moderate amounts of the invasive plant mixed with native plant species enabled a high diversity of birds (Labinger, Greaves, & Gevirtz, 2011). While *A. donax* is generally found to be poor habitat for avian species, least Bell's vireo have been found to nest in the plant in over a dozen instances in the watershed (Labinger & Greaves, 2001). This is of important concern for *A. donax* removal and native plant restoration efforts as restoration work can be hamstrung by the potential harming Endangered or Threatened species or their habitats.

A. donax can affect the hydrology of rivers in a variety of manners, influencing aquatic species such as fish and amphibians. Water consumption by *A. donax* has been measured to be many times that of native vegetation, which can reduce surface water availability and consume groundwater resources for native vegetation (Tuttolomondo, Licata, Leto, Leone, & Bella, 2015). This can also impact aquatic and amphibious species in the watershed, reducing aquatic habitat availability in critical summer and fall periods (Wishtoyo Foundation, 2008).

Additionally, *A. donax* has been shown to alter the geomorphology of Southern California river systems such as the SCR. Generally, dense *A. donax* presence can lead to the long-term narrowing of a river channel, as well as increased lateral stability and the simplification of river channel form (California Invasive Plant Council, 2011). These changes in river geomorphology can negatively impact the quality and quantity of available habitat for fish, amphibians, and stream invertebrate species (Wishtoyo Foundation, 2008). Changes in river geomorphology can also possibly affect the passage of steelhead within the stream channel during migration, though the impact of *A. donax* on this is still uncertain (Kelley, 2004; Stoecker & Kelley, 2005). There is some indication that stands of *A. donax* can capture river sediments, promoting vertical accretion in the riparian area, though the impact of this on aquatic habitats and sediment transport rates also is uncertain (California Invasive Plant Council, 2011).

4.7 *Arundo donax* control

There are three broad categories of available control/removal methods for *A. donax* in the environment: mechanical, chemical, and biological. Most recent management plans have incorporated mechanical and chemical methods, while biological controls are still being explored by some agencies for their potential effectiveness in a large-scale program. For long-term program success, removal efforts are often paired with restoration.

Mechanical control. Mechanical methods are often a preferred approach for *A. donax* control since the use of heavy machinery can drastically cut down the time needed to remove stands from the environment. Excavating and mulching are seen as particularly effective means of eradicating *A. donax*. Excavation entails the use of a backhoe or excavator that breaks apart above-ground stalks and can typically pull out below-ground biomass. Mulching only addresses the above-ground biomass and requires the use of a large mower to mulch the stalks. While both methods are highly effective at reducing *A. donax* biomass, not all sites are accessible to large machinery (steep slopes, limited road access, etc.) and the method is not ideal for sensitive habitats where heavy machinery can easily alter important habitat traits (compact soil, trample native vegetation, etc.) (USDA, 2014).

Prescribed burns, a variation of mechanical control, have also been used in some areas. Prescribed burns have typically been applied to remove dried-out stalks that have been previously treated with an herbicide. However, prescribed burns show little success in killing underground rhizomes and this method possibly enhances the post-fire regeneration of *A. donax*. It has not been a recommended approach for agencies in the SCR watershed, where fire can continue to alter the natural vegetation structure and impose serious risks for local landowners (Boose & Holt, 1999; Lambert, D'Antonio, & Dudley, 2010).

Chemical control. Many agencies have chosen to pair mechanical removal with herbicide application to reduce the likelihood of *A. donax* resprouting in treated areas. Of the chemicals available on the market, imazapyr and glyphosate are the two primary compounds that have been extensively applied to *A. donax* stands (USDA, 2010). Both act as amino acid synthesis inhibitors, blocking the production of specific amino acids required by the plant for growth (MacDonald, 2012; Stidham, 1991). However, each comes with a trade-off: glyphosate has low mobility potential and relatively short lifespan once applied (days to weeks depending on soil conditions) compared to imazapyr, but the latter requires much less chemical to be applied for effective control (DiTomaso, University of California, & Weed Research and Information Center, 2013; EPA, 1990; US Department of Agriculture (USDA), 1984). In either case, retreatment is often necessary and can typically require several years of repeat application to eradicate *A. donax* from the area (Lawson, Giessow, & Giessow, 2005).

Once a compound has been selected for use, there are several application techniques from which to choose. Cut-stump application is one method that has shown to be effective in eliminating *A. donax*, with herbicide applied directly to stalks cut down to near-ground level. Foliar spraying involves the direct application of herbicide to all above-ground biomass without first cutting the stalks. A third application technique is to utilize a helicopter for spraying, allowing for a more time-efficient treatment of expansive regions where *A. donax* has invaded (USDA, 2014). When considering which application technique to use, agencies need to consider the non-discriminatory nature of the herbicide: imazapyr and glyphosate do not selectively single out *A. donax* and can cause substantial damage to native vegetation (Puértolas, Damásio, Barata, Soares, & Prat, 2010). For this reason, the use of helicopters for aerial sprays has also not been considered as a recommended strategy in the SCR watershed, where the native plant community is of high value and commonly immediately adjacent to stands of *A. donax.*

Biological control. Agencies have also sought out the use of biological control agents to manage *A. donax* infestations. Traditionally, this has included the utilization of grazing animals to manage growth of *A. donax* and other invasive vegetation (Daar, 1983). Of those, certain species of goats have typically been preferred in the Western US, with documented successes in *A. donax* control (Hoshovsky, 1986). Grazers eliminate the need to introduce herbicides to the ecosystem and the ability to manage stands in regions inaccessible to large machinery. However, grazers often have dietary preferences that extend beyond the target species and can cause substantial damage to native vegetation (Hoshovsky, 1986). This can be counterproductive to an agency's mission of habitat restoration and can increase the susceptibility of the grazed region to weedy colonizers (Dukes & Mooney, 2004).

Research is also currently underway to evaluate the potential use of natural predators, native to the Mediterranean basin, of the giant reed (Cortés, Goolsby, Moran, & Marcos-García, 2011; USDA, 2010). Four species that have received particular attention are the arundo scale (*Rhizaspidiotus donacis*), the arundo wasp (*Tetramesa romana*), the arundo fly (*Cryptonevra spp.)*, and the arundo gall midge *(Lasioptera donacis)*. Each is specialized to damage *A. donax* stands in a unique way: the scale attacks rhizomes and underground buds (Cortés et al., 2011), the wasp forms galls on reed stems which can lead to the death of the stalk (Goolsby & Moran, 2009), the fly eats new shoot plant tissue (Dudley, Lambert, & Kirk, 2008), and the gall midge forms galls and destroys leaf tissue (Nsanganwimana, Marchand, Douay, & Mench, 2014). Studies have found that the wasp has colonized suitable regions in Southern California (Dudley et al., 2008). However, further research is needed to understand the feasibility of biological control of *A. donax* and the potential implications of introduced species on the overall regional ecology.

***Restoration*.** Many stakeholders in the SCR watershed seek to do more than just remove *A. donax*. There is a common push to restore native vegetation within treated sites to promote enhanced ecosystem services along the river (Lambert et al., 2010; Stillwater Sciences, 2011; Parker et al., 2014). It is important, however, that restoration standards are established in an agency's management plan as a framework to ensure long-term effectiveness. While it is important to emphasize the long-term status of a program's restoration site(s), it is also imperative that proper monitoring is put in place to develop case studies for future restoration activities within the watershed and properly assess a project's impact (Bash and Ryan, 2002; Palmer et al. 2005).

***General costs*.** Costs for removal and management programs vary on multiple levels (internal structure of restoration entity, ease of access to project site, etc.). The primary driver of cost, however, is the density of a reed infestation. Surprisingly, sites with high levels of *A. donax* have a lower cost of removal per acre because there is typically less native vegetation to avoid and so large-scale, machine assisted removal can be employed. Conversely, sites with low levels of *A. donax* require hand-cutting that is more labor-intensive. A 2011 analysis determined the cost per acre for three infestation levels specific to projects within the lower SCR (Stillwater Sciences, 2011). The report included a breakdown of best- and worst-case scenarios as well as an estimated cost of maintenance across all density categories (Table 1). Other analyses have provided similar results within this range (Glasser, 2003; Neill, 2006).

In addition to the variance associated with the infestation density outlined above, agencies must account for administrative costs that are often unique to their organizational structure – for example, the operations of a non-profit will differ from those of a government entity. Cal-IPC has shown that the cumulative differences between removal programs can lead to substantial cost disparities between watersheds. As an example, the Ventura River watershed has an average treatment cost of $64,000 per acre while the Salinas River watershed has typically incurred costs of approximately $4,700 per acre (California Invasive Plant Council, 2011).

Table 1. Estimated cost per acre for three treatment types based on *A. donax* density for the lower SCR (Stillwater Sciences, 2011).

Arundo density	Treatment Type	Cost/Acre ($) Best Case	Worst Case
Low	Manual	9,000	150,000
Medium	Mixed	6,500	78,500
High	Mechanical	4,000	7,000
---	Maintenance	1,000	2,000

5. Methods

The analyses in this report sought to quantify the various costs and benefits received from the removal of *A. donax* from the lower SCR riparian zone. We undertook multiple investigations: a renewed mapping effort that supplemented the Stillwater Sciences effort from 2005, a model that assessed the water use of *A. donax* compared to native riparian vegetation, a model that examined the fire risk *A. donax* presents to the riparian habitats it invades, and a model that analyzed the impacts *A. donax* has on flood damages within the watershed. The results of these models were then input into a cost-benefit analysis that compared the costs and benefits of *A. donax* removal in the study area over time.

In our analysis we chose only to analyze the Ventura County portion of the watershed. Models differed slightly in their spatial extents, but all models included the Ventura County portion of the watershed. The water model and fire model both used only the 500-year floodplain of the Ventura County portion of the watershed. The HEC-RAS model used to examine the flood impacts of *A. donax* required flow inputs from tributaries and upper portions of the watershed as well.

5.1 *Arundo donax* distribution mapping

A. donax distribution and riparian vegetation mapping for the lower SCR were conducted by Stillwater Sciences and URS Corporation in 2005 and 2006, with their results published in the 2007 report, "Riparian Vegetation Mapping and Preliminary Classification Lower Santa Clara River and Major Tributaries, Ventura County, California" (Stillwater Sciences & URS Corporation, 2007). These mapping data were used as baseline data for our analysis.

Stillwater Sciences and URS conducted their riparian vegetation mapping following the standard of State of California vegetation classification system. This standard was set by *A Manual of California Vegetation* (Sawyer, Keeler-Wolf, & Evens, 1995). Stillwater and URS made some adjustments to the standard to account for anticipated changes to the forthcoming second edition of the manual. Following this standard, they ultimately identified 13 distinct habitat types and 50 vegetation types within the SCR floodplain. Their map output included the percent cover of *A. donax* within all vegetation polygons. Stillwater Sciences and URS used the same 500-year floodplain boundaries that our analysis followed as the boundaries of their vegetation mapping work.

The vegetation map was produced through integrated field-based and photointerpretation-based mapping. A minimum mapping unit of 1 acre was the target for most vegetation types (coarser resolution was used for agriculture or development). Aerial photographs of the river (1-foot pixel resolution, natural color) were captured during September 2005 flights, approximately eight months after the floods of January and February 2005. These images were used for onscreen photointerpretation in ESRI ArcGIS by a field-experienced photo-interpreter as well as for generation of paper maps to guide field-based mapping. Field mapping was conducted during the summer of 2005, fall of 2005, and fall of 2006 to refine the vegetation classification system, guide photointerpretation, and ground truth photointerpretation. The Stillwater and URS mapping methodology is described in greater detail in their 2007 report (Stillwater Sciences & URS Corporation, 2007) and their data are publically available for download.

We made updates in 2015 to this vegetation classification, *A. donax* distribution, and *A. donax* percent cover data originally generated by Stillwater Sciences and URS Corporation. We worked within the same 500-year floodplain boundaries used by Stillwater and URS, using Google Earth imagery and the Google Earth "time slider" tool to view change in vegetation in the floodplain from January 2005 to May 2015. We were specifically focused on high-density *A. donax* stands, which can be reliably viewed from aerial photos due to their feathery texture and bright green color (during periods with water). We defined "high-density" stands as those with more than 75% *A. donax* cover (cover categories are described in more detail below). We started at the Ventura County/Los Angeles County line and worked our way to the mouth of river, reviewing primarily the most recent Google Earth imagery (Google Earth, NASA Images © 2015 DigitalGlobe, May 1, 2015) and creating new high-density *A. donax* polygons that were not present in the Stillwater and URS data.

In some cases, it was easier to see *A. donax* stands in earlier imagery, such as from 2012, 2013, or 2014, during periods of greater water availability, or when photos had slightly different coloration or resolution. Under these circumstances, new *A. donax* polygons were created only if the stands were clearly visible in earlier photos and then vegetation line distinguishing that stand from another vegetation type remained visible in the May 2015 images. This process of cross-referencing among different years of Google Earth images allowed a reliable identification of *A. donax* stands that were initially less detectable in the May 2015 images (Figure 4).

Stillwater and URS were able to do a comprehensive assessment of *A. donax* percent cover through their integrated field-based and photointerpretation-based mapping, categorizing the percent *A. donax* cover of each polygon from 0% to 100%. In Google Earth, the *A. donax* cover data is displayed in categories of 0-5%, 6-10%, 11-25%, 26-50%, 51-75%, or 76-100% *A. donax*. However, this kind of detailed assessment was not possible for our 2015 data update given our lack of field-based resources to detect *A. donax* in the understory. As such, we worked through photointerpretation and only added new *A. donax* polygons if they fell into the "76-100%" cover category. We were confident in assigning this percent cover category after careful study of Stillwater and URS's polygons with a backdrop of 2005 to 2006 Google Earth aerial images, which demonstrated that those polygons that Stillwater and URS categorized as 76-100% *A. donax* cover do not have any vegetation visible other than the feathery vegetation of the *A. donax*. The 2015 images were assessed accordingly.

In addition, we made adjustments to Stillwater and URS's existing "76-100%" and "51-75%" cover polygons (since the *A. donax* in those polygons was still visible by eye), such as adjusting their boundaries if the majority of the polygon had been converted to agricultural fields. No adjustments were made to polygons with *A. donax* densities below 50% as we could not confidently identify the *A. donax* in the air photos.

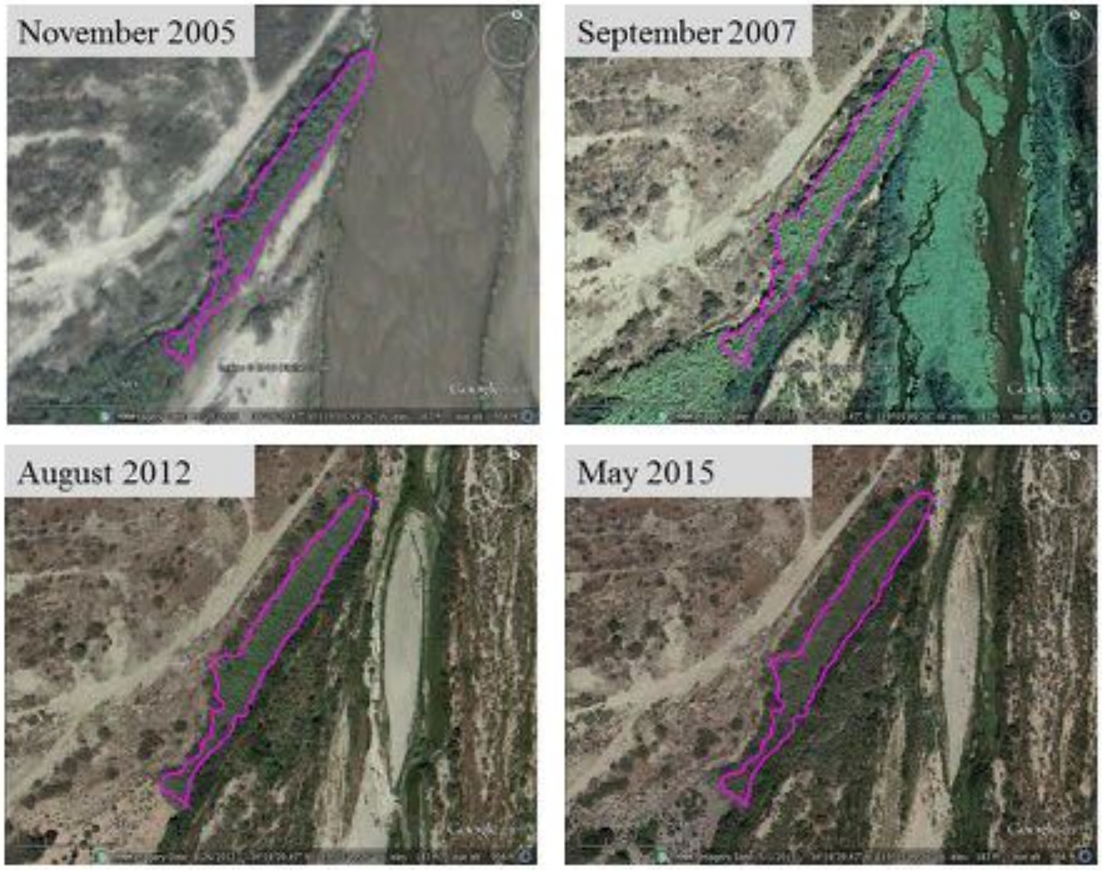


Figure 4. Example of viewing change over time for one *A. donax* stand in Google Earth. Outlined in pink is one of the *A. donax* stands that could be identified as a new, dense *A. donax* stand through the process of viewing aerial images from different years. This small stand (0.12 miles long, located between Saticoy and Santa Paula) is not clearly visible in 2005, but the bright green and feathery texture of *A. donax* jumps out in the 2007 image. In 2012 and 2015, the stand is not as apparent but is still detectable based on its feathery texture which distinguishes it from the surrounding vegetation. If only the 2015 images were viewed, this polygon may have been overlooked.

All new *A. donax* polygons, as well as the revised "51-75%" and 76-100%" *A. donax* polygons, were exported from Google Earth into ESRI ArcMap where they were combined with the Stillwater and URS vegetation polygons that remained unchanged. Through this process of combing 2015 data and 2005/2006 data, percent cover categories less than 50% were treated as unchanged since 2005/2006. This was a reasonable assumption given that Stillwater and URS's 2007 report, "Analysis of Riparian Vegetation Dynamics for the Lower Santa Clara River and Major Tributaries" (based on the Stillwater and URS data) establishes that *A. donax* is more likely to occur on surfaces that have been flooded in the last 40 years (Stillwater Sciences, 2007c). Additional literature establishes that *A. donax* spread is driven by flood (Else, 1996). Since there were no major floods in the SCR from summer of 2005 to May 2015, we do not expect major changes in *A. donax* distribution beyond expansion and contraction of existing *A. donax* stands (some of which was captured through our 2015 Google Earth photo analysis).

After the 2015 shapefile of *A. donax* cover was compiled, it was peer reviewed by Adam Lambert of the Riparian Invasion Laboratory (RIVRLab) at the University of California, Santa Barbara. Dr. Lambert is an ecologist, specializing in invasive plant species and biological control. He has years of experience studying and working on *A. donax* control along the SCR. Dr. Lambert pointed out small, dense patches that we might have missed in our analysis as well as patches in the understory. We checked these *A. donax* patches against our data and found that they all were already represented in our data. For example, Dr. Lambert pointed out small patches (less than ¼ acre of 76-100% cover). We found these small patches were contained within large polygons (2-3 acres) of vegetation categorized as 11-25% *A. donax* cover so they were represented and changes to the data were not required.

Upon finalizing the 2015 *A. donax* cover shapefile with Dr. Lambert's review, we made updates to the corresponding vegetation shapefile in ArcMap. As it was not possible to reliably identify all of the vegetation and habitat types from aerial photos, we made several assumptions. We assumed that spatial holes created in the data by deleting polygons (or sections of polygons) due to expansion of agriculture or mowing of an area for restoration was filled in by the vegetation type in the adjacent polygon (agricultural fields in the case of agricultural expansion). In addition, when our analysis identified a new high-density *A. donax* stand within another vegetation type (e.g., *Populus fremontii* alliance), the area of the *A. donax* stand was deleted from the *Populus fremontii* alliance. Otherwise, the Stillwater and URS's vegetation data were assumed to be unchanged. The result was a 2015 updated vegetation shapefile for the 500-year floodplain.

The final step in our mapping analysis was to investigate whether or not acreage of *A. donax* has increased or decreased since Stillwater and URS 2005/2006 assessment. We specifically focused on assessing change for vegetation polygons containing over 51% *A. donax* cover, given that these polygons were directly investigated in our 2015 photointerpretation-based mapping. Acreage was determined by multiplying polygon area by *A. donax* density in that polygon. Polygon areas were then summed to determine total by study year.

5.2 Water use

To estimate the water use in the Ventura County portion of the Santa Clara River watershed, ArcGIS was used to develop a model to calculate water use for both native vegetation and *A. donax*.

Vegetative cover. The vegetative cover shapefile contains polygons defined by the dominant habitat type overlaying the SCR corridor and several of its tributaries (Stillwater Sciences & URS Corporation, 2007). For this analysis, polygons were bounded by the main river corridor by removing tributaries.

Analysis. Literature was reviewed in order to determine a water use value for each of the major vegetation species within the watershed (*Arundo*, *Artemisia, Atriplex, Baccharis, Eucalyptus, Populus, Salix,* and *Tamarix*). Water use is given using the amount of water the plant loses via evapotranspiration and is measured as mm/day over one square meter. The bolded study for each vegetation type represents the study with environmental conditions closest to those in the SCR (Table 2). The mean water use value of the bolded study was used as the input for the model while the range in values from the study were used as the uncertainty in that species' water use estimate (Table 2). Water use values were given only for the growing season (approximately April-October) and converted to the same unit of measure (mm/day).

Table 2. Water use during the growing season of the most common vegetative species in the SCR. Water use values are given by the evapotranspiration in mm/day. These values were taken from literature, with the study for each vegetation type that most closely resembles our study site in bold.

Vegetation Type (Genus)	Water Use (mm/day, growing season)	Source
Arundo	**8.8 - 17.8**	**Watts & Moore, 2011**
	1.4 - 47.1	Tuttolomondo et al., 2015
	2.2 - 12.4	Triana et al., 2015
Populus	**2.68 - 3.37**	**Dahm et al., 2002**
	3.89 - 8.54	Nagler et al., 2007
	3.1- 5.7	Schaeffer et al., 2000
Salix	0.8- 1.0	Lindroth & Cienciala, 1996
	0.62 - 7.04	**Guidi et al., 2008**
Baccharis	**0.9 - 2.9**	**Pittenger et al., 2001**
Artemisia	1.5 - 2.6	Wilske et al., 2010
	0.6 - 1.31	**Wang et al., 2004**
Atriplex	0.31 - 4.26	Sharma, 1976
	1.06 - 7.56	**Bawazir et al., 2009**
Eucalyptus	0.8 - 2.2	Roberts et al., 2001
	1.9 - 3.8	**Sharma, 1984**
Tamarix	0.4 - 14.7	Devitt et al, 1998
	1.0 - 10.0	**Cleverly et al., 2002**

The habitat type polygons from the vegetative cover shapefile were assigned a native vegetation water use value by averaging the mean water use values for each of the native vegetation species defined within that habitat type (Table 3). The vegetation types contained within each habitat type were drawn from the 2007 Stillwater Vegetation Map shapefile attribute table. Polygons in the vegetative cover shapefile contain an attribute that represents the percent of the polygon that is made up of native vegetation and the percent of the polygon containing *A. donax*. Each polygon was assigned a water use value by multiplying the percent of native vegetation with the mean water use value of the habitat type, and multiplying the percent of *A. donax* and its mean water use and then averaging the two values.

Table 3. Classification of habitat types based on water use values and species composition. Mean water use for each habitat type measured as the average of the mean water use for each species within the habitat type. Habitat type species composition taken from Stillwater vegetation mapping effort. Note that the Low Estimate, Most Likely, and High Estimate columns refer to our model scenarios, and not estimations of water consumption for each vegetation type. For example, our Low Estimate scenario uses the lowest *A. donax* water consumption values and the highest water consumption values for all other vegetation types.

		Water Use (mm/day)		
Habitat Type	**Genus Used for Estimate**	**Low Estimate**	**Most Likely**	**High Estimate**
Arundo	*Arundo*	8.8	13.3	17.8
Coastal sage scrub	*Atriplex, Baccharis*	5.2	3.1	0.9
Cottonwood Willow forest	*Populus, Salix*	5.2	3.4	1.7
Desert riparian scrub	*Artemisia, Atriplex*	4.4	2.7	0.8
Disturbed	*Populus, Salix*	5.2	3.4	1.7
Herbaceous	*Artemisia, Atriplex, Baccharis*	4.8	2.9	0.9
Herbaceous (native)	*Atriplex, Baccharis*	5.2	3.1	0.9
Herbaceous (non-native)	*Artemisia, Atriplex, Baccharis, Populus, Salix*	4.9	3.1	1.2
Mixed non-native trees	*Eucalyptus*	3.8	2.9	1.9
Mixed riparian forest	*Populus, Salix*	5.2	3.4	1.7
Mixed riparian scrub	*Baccharis, Salix*	5.0	2.9	0.8
Mixed willow scrub	*Baccharis, Salix*	5.0	2.9	0.8

Polygons designated as agriculture, beach, development, freshwater wetland, restoration sites, sand dune, and tidal marsh were not given a native vegetation water use value for both before removal and replacement and after *A. donax* was removed and replaced. Agriculture was treated this way in the model because its water use is independent of the water use of native vegetation and *A. donax.* Restoration sites were treated this way because they are actively shifting vegetation types at a rate too high for the assumption that the watershed's vegetation (as was used for the rest of the model) was static and would confound the data. Beach, development, freshwater wetland, sand dune, and tidal marsh were treated this way based on two metrics. First, very few polygons in the shapefile designated as these habitat types are small in size and few in number, making their contribution to the overall model insignificant. Second, after examination of aerial photos it was concluded that these habitat types mostly lack vegetation that would warrant any measurable contribution to the model.

The habitat types that were removed from the analysis were given a water use value of 0 in the model. Once each vegetation polygon was assigned a water use value for both native vegetation and/or *A. donax*, the model was run to determine the cumulative water use in the SCR by both native vegetation and *A. donax* during the growing season. *A. donax* was then removed and replaced with native vegetation (in all cases, a Cottonwood-willow forest vegetation type). Each polygon was again taken through the process of finding that polygon's water use value by averaging the percent of native vegetation and the percent of cottonwood-willow forest used to replace *A. donax*. The model was run again to determine the cumulative water use for the growing season of the SCR when restored with native vegetation. Water use for both scenarios were converted into acre-feet of water, and then the amount of water saved from the removal of *A. donax* was calculated.

5.3 Fire

The computer programs BehavePlus (a fire modeling system that simulates fire behavior and effects used for fire management practices; Scott & Burgan, 2005) and ArcGIS were used to spatially model the fire risk in the SCR under two scenarios. The first scenario generated a fire risk map for the SCR with current levels of *A. donax* while the second scenario generated a fire risk map for the SCR with *A. donax* removed and replaced with native riparian vegetation. These two scenarios were then used to spatially display the change in fire risk when *A. donax* is removed and replaced with native vegetation, so that the benefits of its removal could be visualized and quantified.

BehavePlus consists of a set of mathematical models that generates outputs to explain the effects of fire and fire behavior in different environments based on defined fuel and moisture conditions. BehavePlus generates an output for rate of spread (ROS) of fire and an output for flame length (FL) for each defined fuel model (Scott & Burgan, 2005). Using the updated vegetation map (2015) each habitat type was reclassified into a fuel model consisting of a custom fuel model for *A. donax* and several existing fuel models used for the remaining vegetation. Fuel models use defined fuel bed inputs to mathematically calculate fire behaviors and effects (Scott & Burgan, 2005). Existing fuel models were chosen using photo verification based on the habitat type and were confirmed to match fire reports prepared by Dudek for Fire Departments throughout Southern California (Pumphrey & Bacon, 2015). An existing fuel model for *A. donax* was used and verified from *A. donax* fuel samples that were taken in September of 2015 in Santa Paula along the SCR (Guthrie, 2007).

ROS and FL characteristics for each habitat type generated from BehavePlus were spatially mapped over the lower portion of the SCR using ArcGIS to visualize how fire risk changes between the current level of *A. donax* and the scenario of total replacement of *A. donax* with native riparian vegetation. This type of analysis is analogous to pre-fire and post-fire treatment comparisons used in fire management. These results were run under two weather conditions to show how fire changes in varying wind situations, which highly influence fire behavior (Scott and Burgan, 2005). Historical weather conditions during fire season (typically from August through December in the SCR watershed), were collected from a Remote Automated Weather Station (RAWS) at the Piru, California location, within the region of interest (34˚24'16" N, 118˚48'36" W, at an elevation of 614 feet). The average wind speed over fire season months over a 10-year time period (2001–2011) was 6.7 mph, and the average maximum wind speed over the same time was 21.4 mph. These wind conditions represent low and high wind scenarios for this fire risk analysis in order to generate best- and worst-case fire conditions.

The ROS and FL outputs from BehavePlus under the two wind conditions were combined with topographic characteristics that affect fire (aspect, slope, and elevation) to create a map of fire risk. Each characteristic (ROS, FL, aspect, slope and elevation) was then assigned a weight of importance for evaluating fire risk in the SCR. These weights were set as parameters in ArcGIS such that they can be changed to value the fire characteristics differently depending on various stakeholder interests. This analysis also used a high and low weighting regime for the vegetation characteristics (ROS and FL) to underscore the sensitivity of this fire model to changing the weighting regime of fire characteristics.

The model shows how removing *A. donax* and replacing it with native vegetation changes fire characteristics in the SCR. Our analysis assessed four situations of fire risk in the SCR, with *A. donax* and with *A. donax* replaced by native vegetation, to show how sensitive the fire model is to varying conditions of wind and weighting regimes (Table 4).

Table 4. Fire risk situations for defined wind speeds and weighting regimes. Fire risk situations assessed in the SCR with *A. donax* and *A. donax* replaced with native vegetation. The varying situations for which the change in fire risk was assessed with *A. donax* removed and replaced with native vegetation. Situation 1 is the 'best-case scenario' for fire risk (low wind speed and low vegetation weighting), where fire risk is lowest overall. Situation 4 is the 'worst-case scenario' for fire risk (high wind speed and high vegetation weighting), where fire risk is the highest overall. Vegetation consists on the rate of spread (ROS) and flame length (FL) categories that affect fire risk, and the remaining weights of fire risk were distributed to aspect, slope, and elevation.

		Weighting (%)				
Situation	**Wind Speed (MPH)**	**ROS**	**FL**	**Aspect**	**Slope**	**Elevation**
1	6.7	30	30	14	14	12
2	6.7	40	40	10	5	5
3	21.4	30	30	14	14	12
4	21.4	40	40	10	5	5

Data layers and model inputs

Rate of spread. Rate of spread (ROS) of fire is measured in chains per hour (ch./hr.), the common metric for measuring wild land fire spread, where one chain is equal to 66 feet. BehavePlus computes a maximum ROS for each fuel model based on a moisture scenario, wind speed, and slope. When computing ROS in BehavePlus, our analysis used a D1L2 (Very Low Dead, 2/3 cured herbaceous) moisture scenario, 6.7 mph and 21.4 mph wind speeds, and 0% slope. Using the D1L2 generates low fire hazard conditions to offer a conservative view of fire risk. ROS is an important characteristic to determine how fire will spread throughout a landscape (Scott & Burgan, 2005). Predefined assessments of fire risk for ROS were obtained from the Scott and Burgan's fuel models with six categories ranging from low to extreme fire risk (Table 5). After each habitat type was reclassified as a fuel model, then subsequent ROS, a fire risk assessment category was assigned, where larger values represent higher fire risk (Table 6).

Flame length. Flame length (FL) of fire is measured in feet (ft.). BehavePlus computes a FL for each fuel model based on a moisture scenario, wind speed, and slope. When computing FL in BehavePlus, our analysis used a D1L2 (Very Low Dead, 2/3 cured herbaceous) moisture scenario, 6.7 mph and 21.4 mph wind speed, and 0% slope. D1L2 generates low fire hazard conditions to offer a conservative view of fire risk. FL is an important characteristic to determine how intense fire will burn in each habitat type (Scott & Burgan, 2005). Predefined assessments of fire risk for FL were obtained from the Scott and Burgan's fuel models with six categories ranging from low to extreme fire risk (Table 5). After each habitat type was reclassified as a fuel model, then subsequent FL, a fire risk assessment category was assigned, where larger values represent higher fire risk (Table 6).

Table 5. Rate of Spread and Flame Length Redefined as an Adjective Class. ROS and FL are categorized in an adjective class based on fire risk using the D1L2 moisture scenario (Scott & Burgan, 2005). These values were used to redefine the ROS and FL fire risk for the fuel models used in the fire risk analysis.

ROS (ch/h)	FL (ft)	Adjective Class
0 - 2	0 - 1	Very Low
2 - 5	1 - 4	Low
5 - 20	4 - 8	Moderate
20 - 50	8 - 12	High
50 - 150	12 - 25	Very High
> 150	> 25	Extreme

Table 6: Vegetation in the Santa Clara River reclassified as Fuel Models and Subsequent Rate of Spread (ROS) and Flame Length (FL). Calculations for ROS (ch./h.) and FL (ft.) were generated in BehavePlus using the existing fuel models, and a custom fuel model for *A. donax*. ROS and FL was then classified as adjective class for overall fire risk based on predefined intervals used in BehavePlus fire modeling (Scott & Burgan, 2005; Table 5). Two wind speeds (6.7 mph and 21.4 mph) were used to show fire risk in low and high risk weather conditions.

		Low Weight: 30% | High Weight: 40%			
		Flame Length (ft)		*Rate of Spread (ch/h)*	
		Wind Speed (mph)		Wind Speed (mph)	
Vegetation Type	**Fuel Type**	**6.7**	**21.4**	**6.7**	**21.4**
Arundo Donax	Custom	28.1	44	141	375
Coastal sage scrub	SH5	13.65	25.3	13.65	25.3
Cottonwood Willow forest	TL2	1	1	2	2.1
Desert riparian scrub	SH1	0.7	0.7	1.7	1.7
Herbaceous (native)	SH3	2.7	4.8	5.6	18.8
Herbaceous (non-native)	SH3	2.7	4.8	5.6	18.8
Mixed non-native trees	9	3.6	8.9	13.9	97.5
Mixed riparian forest	TL2	1	1	2	2.1
Mixed riparian scrub	TU1	2.2	3.9	4.4	15.1
Mixed willow scrub	TU1	2.2	3.9	4.4	15.1
Riverwash (herbaceous)	SH2	2.6	5.3	4.5	21.4
Other	Not Burnable	0	0	0	0

Elevation. Elevation was derived from the USGS Digital Elevation Model (DEM) at 10-m resolution, based on the 7.5-minute (1:24,000-scale) topographic mapping, from the National Map Archive. The elevation was reclassified into feet (ft.) and then reclassified once more in the spatial analysis toolbox in ArcGIS to address overall fire risk. For our analysis, when elevation is greater, the likelihood of fire decreases since there is presumably higher levels of precipitation at higher elevations (Caceres, 2011). High coefficient values indicate higher fire risk. These values were then delineated into six fire risk categories ranging from low to extreme (Table 7).

Table 7. Elevation of Santa Clara River Reclassified for Fire Risk. The elevation of the SCR was reclassified to generate overall fire risk. Coefficient values were assigned based on how elevation affects fire risk (Cáceres, 2011). Coefficients were redefined to an adjective class to generate overall fire risk in the SCR. Data were obtained from the USGS DEM (2015) at a 10-m resolution (1:24,000-scale).

Low Weight: 5% | High Weight: 14%		
Elevation (ft)	**Coefficient**	**Adjective Class**
> 1000	1	Very Low
800 - 1000	2	Low
600 - 800	3	Moderate
200 - 600	4	High
200 - 400	5	Very High
< 200	6	Extreme

Slope. Slope was derived from the USGS Digital Elevation Model (DEM) at 10-m resolution, based on the 7.5-minute (1:24,000-scale) topographic mapping from the National Map Archive. Slope was then reclassified to represent 5% interval changes in slope in the SCR, then reclassified into coefficients in ArcGIS using the spatial analysis toolbox to address fire risk. These coefficients were delineated into six fire risk categories ranging from low to extreme (Table 8). Higher slopes are often associated with high fire risk. Fire travels most rapidly upslope, and most slowly on downward slopes (Erten, Kurgun, & Musaoglu, 2004).

Table 8. Slope of Santa Clara River Reclassified for Fire Risk. The slope of the SCR was reclassified to generate overall fire risk. Coefficient values were assigned based on how slope affects fire risk (Caceres, 2011). Coefficients were redefined to an adjective class to generate overall fire risk in the SCR.

Low Weight: 5% | High Weight: 12%		
Slope (%)	**Coefficient**	**Adjective Class**
0 - 5	1	Very Low
5 - 10	2	Low
10 - 15	2	Low
15 - 20	3	Moderate
20 - 25	3	Moderate
25 - 30	4	High
30 - 35	5	Very High
> 35	6	Extreme

Aspect. Aspect was derived from the USGS DEM at 10-m resolution, based on the 7.5-minute (1:24,000-scale) topographic mapping from the National Map Archive. It was reclassified in ArcGIS using the aspect tool to ArcGIS and was categorized as North, Northeast, East, Southeast, South, Southwest, West, Northwest, and Flat. Each aspect categorization was then assigned a coefficient that evaluated overall fire risk. South-facing slopes in the Northern Hemisphere receive more sun light, which creates drier conditions that increase fire risk (Erten et al., 2004). These coefficients were then delineated into six fire risk categories ranging from low to extreme (Table 9).

Table 9. Aspect of Santa Clara River Reclassified for Fire Risk. The aspect of the SCR was reclassified to generate overall fire risk. Coefficient values were assigned based on how aspect affects fire risk (Caceres, 2011). Coefficients were redefined to an adjective class to generate overall fire risk in the SCR. Data were obtained from the USGS Digital Elevation Model (2015) at a 10-m resolution (1:24,000-scale).

Low Weight: 10% | High Weight: 14%		
Aspect	**Coefficient**	**Adjective Class**
North	1	Very Low
Northeast	2	Low
Northwest	2	Low
East	3	Moderate
Southeast	4	High
Flat	5	Very High
West	5	Very High
Southwest	5	Very High
South	6	Extreme

Modeling fire behavior. ROS, FL, elevation, slope, and aspect were combined in a multi-criteria analysis to generate a fire risk map in the SCR for two scenarios, *A. donax* present and *A. donax* replaced by native vegetation. The two maps were then overlaid into one map that represents the overall change in fire risk. The difference in the fire risk of the two scenarios is the overall change (benefit in fire reduction) received from removing *A. donax* in the SCR. By creating a map of fire risk reduction from the removal of *A. donax* in the SCR, the benefits received from removing *A. donax* can be realized and appropriate management action to eradicate *A. donax* is able to be considered.

Multi-criteria analysis. A multi-criteria analysis was generated to combine factors that influence fire occurrence and probability at varying degrees. Currently, there are ranges of weights in the literature for wildfire risk assessments (Chuvieco & Salas, 2007; Erten et al., 2004; Gai, Weng, & Yuan, 2011; Jaiswal, Mukherjee, Raju, & Saxena, 2002). From these, two weighting schemes were composed to address high and low vegetation-weighting regimes that are characteristic of current fire risk analyses (Equations 1 and 2).

Eq. 1 Low vegetation weighting regime

$$Fire\ Risk = 0.30 * \beta_{ROS} + 0.30 * \beta_{FL} + 0.12 * \beta_{slope} + 0.14 * \beta_{aspect} + 0.14 * \beta_{elevation}$$

where β is the respective coefficient.

Eq. 2 High vegetation weighting regime

$$Fire\ Risk = 0.40 * \beta_{ROS} + 0.40 * \beta_{FL} + 0.05 * \beta_{slope} + 0.10 * \beta_{aspect} + 0.05 * \beta_{elevation}$$

where β is the respective coefficient.

In these regimes, each coefficient (β) ranges from 1 to 6 for each fire characteristic (ROS, FL, Slope, Aspect, Elevation) with the numbers preceding each coefficient being the weights assigned to each fire characteristic. This range (1-6) was modified to fit this analysis such that each category could fit within a 6-fold risk bin, however the relative proportions of the ranges where determined from existing fire risk assessments (Chuvieco & Salas, 2007; Erten et al., 2004; Jaiswal et al., 2002). The sum of the coefficients multiplied by their respective weights and divided by the number of fire categories (six) gives a fire risk value ranging from 1 to 6. The highest fire risk is associated with a Fire Risk value equal to 6 and the lowest fire risk is represented with a Fire Risk value equal to 1. These values were then spatially mapped in ArcGIS to generate a visual display of fire risk for each scenario labeled by the combined fire risk adjective class (Very Low, Low, Moderate, High, Very High, and Extreme).

Comparison of fire scenarios to River Fire. The updated 2015 map that was used to categorize the habitat types into vegetation categories was produced using images from Google Earth taken on May 1st, 2015. On June 22nd, 2015 the River Fire was ignited in the town of Santa Paula, CA within the SCR. This fire was started in a patch of *A. donax* and burned over 160 acres, threatening the Santa Paula airport as well as other large commercial and residential structures, and costing over $510,000 to suppress. Since the vegetation map of the SCR still contained this patch of *A. donax* that has since subsequently burned, the perimeter of the River Fire was overlaid to access the accuracy of this fire model's results for this one case. The River fire perimeter was superimposed over the benefit in fire risk reduction for situations 1 through 4.

Associated fire costs. In order to quantify the benefit of fire risk reduction in monetary terms, an extensive literature review was conducted to analyze fire-fighting costs avoided along with other benefits from *A. donax* removal for reducing fire risk. This literature review gathered cost information on fires where *A. donax* was burned in either the initial, latter, or total part of a fire event. Cost information was also collected for average cost per acre of fighting a fire for high and moderate risk areas. In these areas, although the risk assessment criteria were similar, *A. donax* was not documented to be present such that higher fuel loads and increased crown fires like those caused by *A. donax* were analyzed. The cost of fighting different-sized fires was also analyzed to understand the effects *A. donax* has on small, medium, and large spatial areas. This data is generalized for fire-fighting costs throughout the US, and representative of the data collected for fire in *A. donax* at various sizes.

Fire risk reduction. Removing *A. donax* can markedly reduce the risk of a fire event. The results from the fire model analysis were partnered with an index of estimated probabilities to obtain the increased likelihood of a fire occurring. This was then multiplied by a range of fire-fighting costs to determine the low, high, and most likely benefit estimates when *A. donax* is removed.

5.4 Hydrology

A. donax grows extensively in the channel and floodplain of the lower SCR. To assess the impact of *A. donax* on the nature of flooding within the lower SCR study reach, we manipulated an existing flood model of the main channel and floodplain areas of the SCR from the Ventura County line to the Pacific Ocean. Post-flood photographs and interviews revealed that after large flood events, *A. donax* stands are largely scoured within the active flood channel area of the lower SCR. We obtained historic aerial photographs of the lower SCR to find the flood threshold at which *A. donax* is scoured, and created two model geometries based on the results. The first model geometry reflects a post-flood scenario with low levels of *A. donax* and a clear river channel, similar to the conditions present in 2005 when the model geometry was constructed. The second geometry was updated to include 2015 *A. donax* densities in the lower SCR channel and floodplain, and reflects the expected geometry for a smaller magnitude flood that does not extensively scour the lower SCR channel. Peak flood flow inputs for the lower SCR reaches were constructed for the 2-, 5-, 10-, 20-, 50-, 100-, and 200- year floods based on historic annual peak flows from nearby river gauge records. Flood simulations of each flood magnitude were run with both model geometries up to the *A. donax* scour-threshold flood to estimate the marginal difference *A. donax* has on floodwaters. Results were exported to ArcGIS and marginal flood area depths and extents were calculated.

HEC-RAS model. Our flood modeling was performed with the US Army Corps of Engineers' Hydrologic Engineering River Analysis System (HEC-RAS), a one-dimensional hydraulic modeling software package (Figure 5). For our analysis, we modified an existing HEC-RAS model geometry developed by the URS Corporation in 2006 for the California Coastal Commission (Mineart, Hudson, & Sears, 2006). URS' 2006 SCR HEC-RAS model updated an existing HEC-RAS model originally developed by the Ventura County Watershed Protection District. The 2006 model geometry was based on ground surface elevations obtained from a Light Detection and Ranging (LiDAR) flight shortly after the 2005 flood on the SCR. The model geometry consists of 183 channel cross sections, including eight bridges and one culvert. For our modeling efforts, we used a steady flow analysis, which uses only the peak discharge flow from each flood recurrence interval to route floodwaters down the length of our study area. For the steady flow analysis, water surface elevations are computed for each cross section based on the physical parameters of the cross section such as the cross section area and channel roughness. Based off prior HEC-RAS modeling of the lower SCR, our steady flow analysis was run with a subcritical flow regime (United States Army Corps of Engineers, 2012). HEC-RAS versions 4.1.0 and 5.0 Beta (2014-10-01) were used for our modeling.

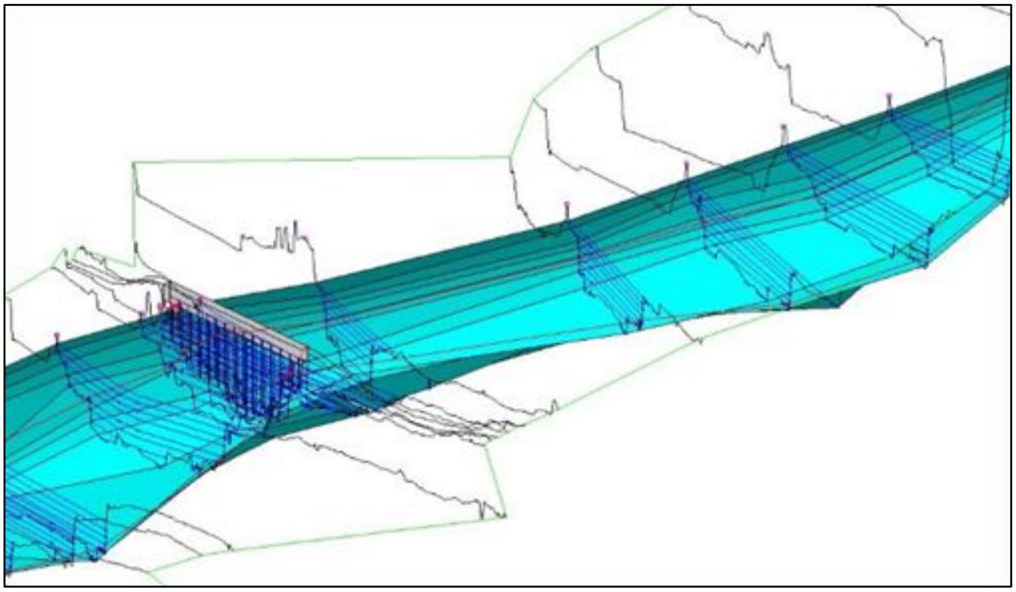


Figure 5. Example Santa Clara River HEC-RAS flood model X-Y-Z perspective plot, detailing cross sections and flood volumes upstream and downstream of the Hwy 118 Bridge.

Model flow inputs. Projected flood flows were sourced from a 2006 Ventura County Watershed Protection hydrology study of the SCR (Ventura County Watershed Protection District, 2006). These flows were calculated from peak flood flows assembled from gauged peak streamflow data published by the United States Geographical Survey (USGS) for the SCR watershed. Peak flood flows were adjusted at three locations along the main stem of the SCR to correct flood volumes due to inflows from Piru Creek, Sespe Creek, and Santa Paula Creek (Table 10). VCWPD's calculated floods have been used for past HEC-RAS flood risk analysis on the lower SCR, including a 2012 Army Corp's HEC-RAS-based flood risk analysis study (United States Army Corps of Engineers, 2012).

Table 10. Santa Clara River peak flood flow inputs, in cubic feet per second (cfs). Data were sourced from a 2006 VCWPD study of flood frequency for the Lower Santa Clara River.

Recurrence Interval (yrs)	Peak Flood Flow (cfs) at: LA County line	confluence with Piru Creek	confluence with Sespe Creek	Hwy 101
2	2,490	4,100	12,500	12,800
5	8,420	13,700	41,000	41,900
10	15,700	25,600	71,200	72,800
20	26,100	42,500	108,600	111,000
50	45,900	74,700	168,200	172,000
100	66,600	108,400	221,000	226,000
200	93,300	151,900	279,700	286,000

Historic aerial photography vegetation analysis. Given the shallow root system of *A. donax* and its propensity to colonize areas of the sandy river channel after flood events, the plant is vulnerable to scour during floods. *A. donax* flood scour has been documented in the aftermath of large flood events, when large rafts of *A. donax* stems have been observed floating in the Santa Barbara channel and accumulating on nearby beaches. However, there is uncertainty around the specific flood threshold that *A. donax* scours at during a flood. To accurately model the added roughness of *A. donax* in our HEC-RAS model, we first had to determine the flood conditions that remove *A. donax* with the channel and floodplain of the SCR. Obtaining historic aerial photographs of the lower SCR after large flood events enabled us to look at specific flood events and see the resulting vegetation within the active channel and floodplain. Based on photographic evidence, it was determined that events above the 10-year flood threshold scoured the majority of vegetation growing in the active channel, with little significant scour occurring to vegetation in the floodplain areas of the river (Figure 6a-d, Table 11). This finding is congruent with past research, which found that even in very large flood events, the floodplain riparian zone of the lower SCR retained moderate levels of vegetation after large flood events (Stillwater Sciences, 2007c, shown in Table 11). Air photos of flows within the 5- to 15- year recurrence interval show significant stands of *A. donax* within the active channel of the lower SCR, and appeared to not alter the majority of vegetation within the floodplain.

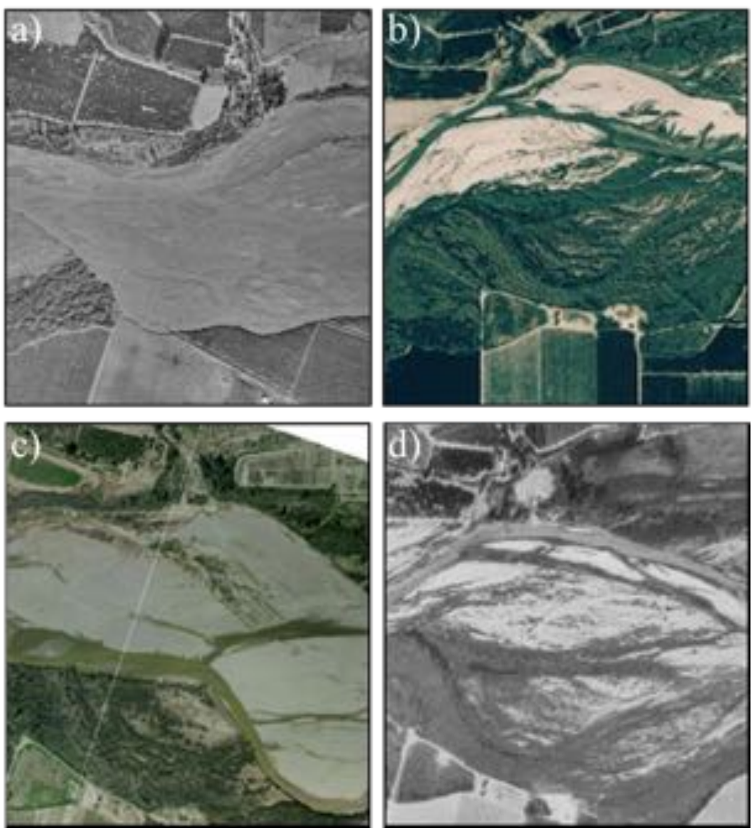


Figure 6. Comparison of post-flood channel channel scour conditions near Fillmore, CA. Each photo displays approximately one kilometer of the Santa Clara River.

a) Air photo was taken January 30, 1969, five day after a 165,000 cfs peak flow at Montalvo, the largest flood on record. Photo courtesy of UCSB Map & Imagery Laboratory. This 1969 flood was a 64-year flood.

b) Photo was taken November 21, 1998, nine months after the February 23, 1998 flood, which was a 10-year flood. Photo courtesy of Keystone Aeriel Surveys, Inc.

c) Photo taken shortly after the Januray 2005 flood. This flood was a 35-year event. Photo courtesy of VCWPD.

d) Shows the lower SCR channel conditions on May 31, 1994, more than a year after the February 19, 1993 5-year flood event. Significant post-flood vegetation regrowth is likely in this photo. Photo by USGS, obtained from Google Earth.

Table 11. Summary table of results from floods surveyed for scour analysis. Floods were selected for analysis based on photo availability. Ranks and return periods are based on a record of 64 peak annual flows between 1932 to 2005. Flows were measured at the Montalvo gaging station approximately five miles upriver from the Pacific Ocean.

Rank (of 64)	Year	Peak Flood Flow (cfs)[1]	Return Period (yrs)	Air Photo Observations	Vegetation After Flood (%)[2]	Air Photo Source
1	1969*	147,000	64	Most of the active channel scoured, extensive sediment deposition	26	UCSB Map & Imagery Laboratory
2	2005*	136,000	32	Most of the active channel scoured, extensive sediment deposition	36	Ventura County WPD
3	1992*	104,000	21	Moderate amount of the active channel scoured, moderate sediment deposition	68	Google Earth
4	1978*	102,200	16	Most of the active channel scoured, extensive sediment deposition	43	HistoricalAerials.com
7	1998*	84,000	9	Most *A. donax* not scoured, moderate sediment deposition	na	Keystone Aerial Surveys, Inc.
8	1980*	81,400	8	Moderate amount of vegetation not scoured, moderate sediment deposition	na	HistoricalAerials.com
14	1993*	44,300	5	Moderate channel scoured, moderate sediment deposition, likely impacted by 1992 flood	na	Google Earth
19	2001	32,900	3	No scour observed, channel heavily vegetated with *A. donax*	na	HistoricalAerials.com

* El Niño Year

1 From Ventura County Watershed Protection District (2006).

2 From Stillwater Sciences (2007b). GIS estimate of percent of channel bed partially or highly vegetated after flood event.

Model Manning's n geometry inputs. The roughness of a river or stream channel affects the flow, velocity, and water surface elevation of flowing water, and is an amalgam of physical channel characteristics such as bed substrate size and vegetation density. Channel and floodplain roughness is parameterized in hydraulic models as the unitless Manning's *n* coefficient. Typical Manning's *n* values range from 0.030 (e.g., a relatively clean and straight channel with little roughness) to over 0.150 (e.g., a densely vegetated floodplain). HEC-RAS modeling software allows the Manning's *n* parameter to be spatially varied throughout the length of each modeled river cross section to mimic the variable natural roughness of a river channel or floodplain.

URS' 2006 SCR HEC-RAS model update assigned Manning's *n* to the modeled river channel based on aerial photographs of the SCR taken in February and September of 2005, shortly after the January 9, 2005 flood event (roughly a 30-year flood in the area modeled). URS assigned bare, unvegetated areas a Manning's *n* of 0.035, while vegetated areas were given a higher coefficient between 0.04 and 0.07 based on observed vegetation density.

For our analysis, we modified the original URS HEC-RAS model geometry to assess the marginal difference *A. donax* has on floodwater elevations. To do this, we compared two different model geometries: (1) the original 2005 channel geometry with unchanged Manning's *n* values, and (2) the original 2005 channel geometry with adjusted Manning's *n* values based on the 2015 spatial distribution and stand densities of *A. donax*. To model the added channel roughness of *A. donax*, georeferenced channel cross sections were exported from HEC-RAS into ArcGIS and overlaid on our *A. donax* distribution map (Figure 7). Polygons of *A. donax* were classified into Moderate (25-50% *A. donax*), Moderate-High (51-75% *A. donax*), and High (>75% *A. donax*) density stands. Field experiments conducted in northern California coastal streams revealed that Manning's *n* for *A. donax* was very high, with a mean value of 0.066 and a maximum value of 0.121 (Spencer et al., 2013). Based on these numbers, we spatially varied the Manning's *n* within each HEC-RAS cross section to reflect the extent and density of *A donax* within that specific area of the study area (Figure 8). The HEC-RAS cross section Manning's *n* coefficient was based on the measured length in feet of any given *A. donax* stand intersecting with the HEC-RAS cross sections in ArcGIS. Moderate density stands of *A. donax* were assigned a Manning's *n* coefficient of 0.066, Moderate-High density stands the value of 0.100, and High density stands were given Spencer et al.'s (2013) maximum observed value of 0.121. Cross section adjustments were done manually in HEC-RAS with the Cross Section Editor tool. To adjust for the change in physical conditions during flood flows greater than the 10-year recurrence interval, we reduced the modeled vegetative roughness in the main channel for both the with- *A. donax* geometry and without- *A. donax* geometry to a single value of .04, leaving floodplain Manning's *n* values static.

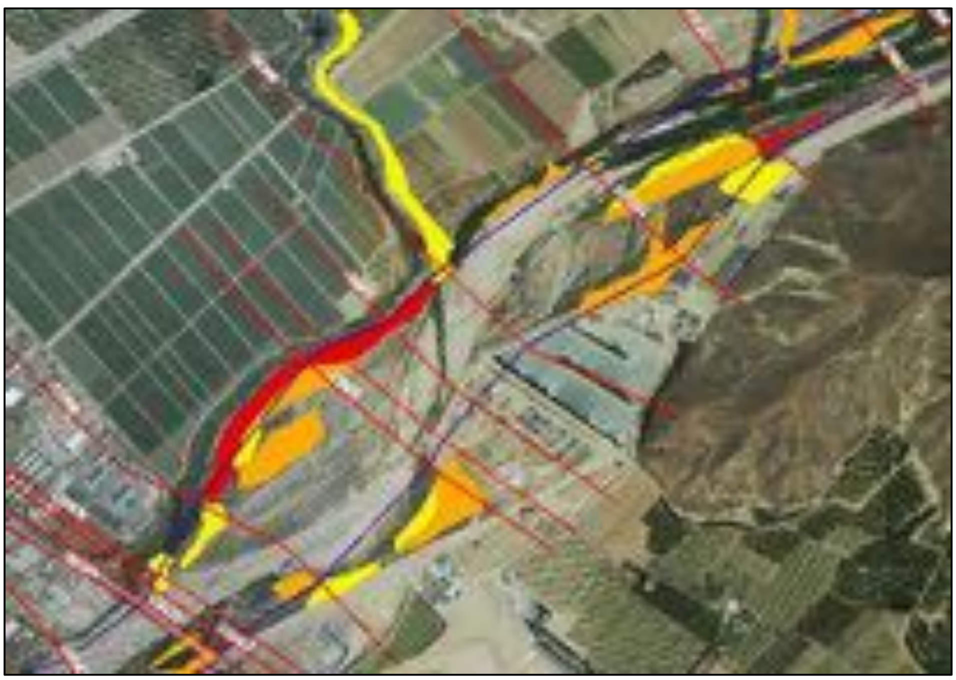


Figure 7. Example of HEC-RAS cross section geometry modification. HEC-RAS cross sections (red lines), were imported into ArcGIS and overlaid on polygons of *A. donax* density (yellow, orange, and red polygons). HEC-RAS cross sections Manning's *n* coefficients were then modified to reflect the amount of intersection with *A. donax*.

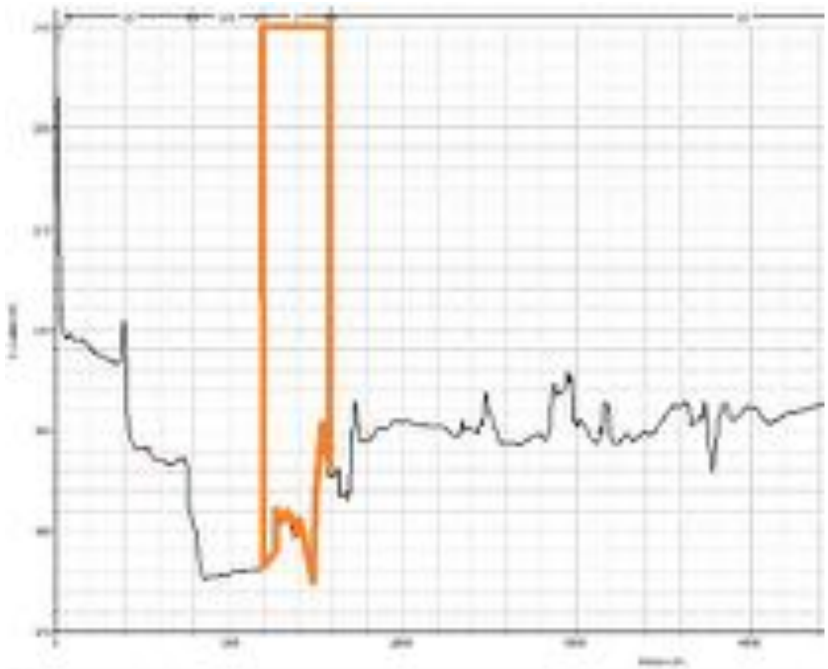


Figure 8. Example HEC-RAS cross section with Manning's *n A. donax* adjustment. The orange polygon in this figure represents the portion of the modeled Lower Santa Clara River cross section that was adjusted to reflect the higher Manning's n coefficient of a 200-foot wide Moderate-High (50-75%) density *A. donax* stand. The roughness coefficient was changed to 0.100 for this portion of the cross section, while all the other Manning's n values for the cross section were left as originally constructed and not varied.

Flood model results analysis. After manipulating the HEC-RAS modeling software geometry to create our two scenarios, we ran a steady-flow analysis with the model. The VCWPD , 2-, 5-, 10-, 20-, 50-, 100-, and 200-flood recurrence interval flows were input into both model geometries, with only the presence and absence of 2015 levels of *A. donax* varied between model runs.

After all the model runs were complete, flood results from our two model geometries were imported into RAS Mapper, a floodplain mapping tool within HEC-RAS version 5.0 Beta. To calculate precise floodwater depths and flood extents, HEC-RAS modeled water surface elevations for each recurrence interval were overlaid onto a high-resolution terrain model of the lower SCR. The terrain was derived from raw post-flood 2005 LiDAR data provided to us by the VCWPD, which we processed using ENVI LiDAR version 5.1 software. Water depths for each model run were then exported as a raster file into ArcGIS. In ArcGIS, floodwaters were manually edited for accuracy. Floodwaters unconnected to the contiguous flood area (i.e. orphaned floodwaters) were edited out, as were any floodwaters modeled to be on the non-channel side of any levee that had not visibly been overtopped. The Raster Calculator tool in ArcGIS was used at each flood recurrence interval to subtract the modeled without- *A. donax* floodwaters from the modeled with *A. donax* floodwaters to derive the marginal floodwaters caused by *A. donax.*

Flood damage analysis. The marginal floodwater extents caused by the influence of *A. donax* were overlaid with a shapefile of crop type for Ventura County. Floodwaters intersecting agricultural areas were clipped by agricultural parcel and total flood surface area was calculated for the 5- and 10-year flood. These flood magnitudes were selected because initial results suggested that these flood thresholds were large enough to cause crop damages, yet small enough to be influenced by presence of unscoured *A. donax* within the active flood channel. Crop type data came from a GIS shapefile crop type created by the Ventura County Department of the Agricultural commissioner. Some parcels were only designated as "row crops", so an average of five winter row crops (broccoli, cabbage, celery, cilantro, and bok choy) was used to estimate crop damages. Average crop values were calculated by crop type and sourced from a 2014 crop report produced by the Ventura County Agricultural Commissioner (Ventura County Office of the Agricultural Commissioner, 2014). These crop values were multiplied by acres flooded to estimate flood damage costs. Some crops, such as citrus, were assumed to be resilient to shallow flooding, and not included in the damage calculations. Other crops with long harvest seasons, such as strawberries, likely have the potential to be replanted and harvested the same season, so only a fraction of the growing season was assumed an economic loss.

A model was developed using Excel that randomly generated flood events based on flood probability over a 20-year period. Damages were calculated each year that a flood occurred between a five- and ten-year magnitude. One thousand trials were run to estimate the expected loss in damages incurred over a 20-year period when *A. donax* is present. These values were then divided by the number of years (20) to achieve an annual value and then divided by the total acreage of *A. donax* in the study region, giving an annual benefit value per acre of *A. donax* should it be removed. The median value was used as a most likely estimate, the 90th percentile value as the high estimate, and the 10th percentile value as the low estimate.

5.5 Cost-benefit analysis

A cost-benefit analysis was performed to compare the costs of *A. donax* removal to the benefits of removal. A cost-benefit analysis is an economic tool that analyzes the monetary costs and benefits of a project to better understand its cost-worthiness. There are several ways to report the results of this type of economic analysis. Here, we use the net present value (NPV) and the benefit-cost ratio (BCR). NPV tells us the actual difference (in present value) in costs and benefits across the timeframe analyzed and is typically deferred to as the 'key criterion' in economic decision-making (OECD, 2006). The BCR, however, reveals a different aspect of the relationship between costs and benefits. While it is not as widely used as NPV, it does prove useful when comparing alternative projects that a decision maker must select between (OECD, 2006), such as various *A. donax* removal strategies.

Timeframe. For the purposes of this cost-benefit analysis, we utilized a 20-year timeframe. Some agencies involved in restoration activities within the SCR watershed have indicated a preference for analyses on even longer time horizons; however, the five-year lifespan typical of current removal projects as well as the natural dynamics operating on the river system lend towards a shorter period.

Analysis of our flood model and discussions with field experts indicate that flood events of the10-year magnitude or greater can scour the active river channel, acting as a 'reset' event for much of the river. These 'reset' events can alter the distribution of *A. donax*, necessitating a reevaluation of *A. donax* cover and associated cost/benefit streams in the lower SCR. Since there is only a 65% likelihood that a 10-year flood event will occur at least once in decade (and so a 35% chance that it will not occur at all in this period), there is still a large probability that the cost and benefit streams examined here will persist past a 10-year horizon. Extending the timeframe to 20 years increases the likelihood of at least one scouring event to 88%, markedly reducing the probability that the modeled benefit streams will persist past a 20-year horizon.

Discount rate. The discount rate, *r*, refers to the time-value of money. Receiving ten dollars today is worth more to an individual than receiving ten dollars in the future; more utility is gained at the present with diminishing marginal utility into the future (Ramsey, 1928). Higher discount rates bias towards present worth, while lower rates place a higher value on future welfare.

In the case of traditional environmental restoration projects, the initial costs are typically weighted heavily at the beginning stages of the project and benefits are only realized in later stages (Dubgaard, Kallesøe, Petersen, & Ladenburg, 2002). Determining the appropriate discount rate will showcase the value of projected future benefits so that they may be compared with the tangible present costs associated with undertaking the project. Recommendations from both the U.S. Environmental Protection Agency (EPA) and the U.S. Office of Management and Budget (OMB) were assessed with regards to discount rates for similar projects. According to the EPA, projects within a short to medium lifespan are assigned a discount rate of approximately 3%, derived from consumer-time preferences based on the interest rate of a risk-free asset such as a government bond (EPA, 2010). The consumer-time preference is meant to reflect the rate at which society ignores the difference between a payment at present time and a larger payment in the future. Conversely, the OMB assigns a standard discount rate of 7%, derived from the opportunity cost of capital, measured by the before-tax rate of return to investment (OMB, 2000). However, OMB does suggest that a project conduct a sensitivity analysis by applying different discount rates if the project can justify the alternatives given varied circumstances.

Given inconsistent recommendations set forth by federal agencies, it was determined a sensitivity analysis should be performed using discount rates of 3, 5, and 7% to identify how the net present value and benefit-cost ratio responds under each scenario.

Assumptions. To conduct the cost-benefit analysis, several key assumptions were made:

- There are no natural changes in vegetation; the only alterations to river vegetation are by restoration managers.
- An equal amount of *A. donax* is removed each year based on historic removal efforts. This amount is then equally divided among three percent cover categories, each defined with a specific management cost.

- Benefits are proportional to the percent cover of each acre treated and are received immediately after removal (during the same period).
- Benefits are cumulative over time – the value in benefits during any given year are the sum of benefits for all acres treated since year 0.

Costs. As with the priority areas analysis, available cost data for *A. donax* control were limited to that provided by the RIVRLab and the variance in cost across infestation density categories was accounted for by pairing this dataset with *A. donax* density values obtained by Stillwater Sciences. Expanding upon the estimates provided in Table 1, costs reflect the most likely, low, and high cost estimates on a per acre basis for each *A. donax* cover category; maintenance costs are shown to be uniform across all infestation levels (Table 12).

Table 12. Most likely, low, and high estimates of cost per acre treatment based on *A. donax* density for the lower SCR (Stillwater Sciences, 2011).

		Cost/Acre ($)		
Arundo density	**Treatment Type**	**Most Likely**	**Low Estimate**	**High Estimate**
Low	Manual	44,250	9,000	150,000
Medium	Mixed	24,500	6,500	78,500
High	Mechanical	5,500	4,000	7,000
---	Maintenance	1,500	1,000	2,000

The typical duration of a restoration program within the lower SCR lasts five years. Removal costs are applied to acres removed during the first year with maintenance costs applied to those acres the following four years.

Benefits. Removal of *A. donax* results in a wide range of benefits. Here, we focus on those benefits which are most easily quantifiable and which we anticipate to have some of the greatest return under an *A. donax* removal program: water savings, a reduction in flood damages, and fire risk reduction. Benefits were calculated using the models defined in sections 7.2-7.4 and are summarized here (Table 13).

Table 13. Most likely, low, and high benefit estimates for the removal of *A. donax*.

	Benefit/Acre/Year ($)		
Benefit	**Most Likely**	**Low Estimate**	**High Estimate**
Water savings	934	1,644	189
Flood damage reduction	66	140	10
Fire risk reduction	56	93	9

Scenarios. To understand how the NPV and BCR change over the timeframe with different management strategies, three scenarios were run:

1. Present Approach: 15 acres of *A. donax* removed annually with no acres treated in response to a flood event.

2. Flood Contingency Plan 1: 15 acres of *A. donax* removed annually with an additional 25 acres treated after a scouring (i.e. >10 year) flood event.

3. Flood Contingency Plan 2: 15 acres of *A. donax* removed annually with an additional 50 acres treated after a scouring flood event

Each strategy was defined in consultation with the RIVRLab. The present approach considers historical levels of *A. donax* removal from the lower SCR, through which it was estimated that *A. donax* is removed from 15 acres each year. Since large flood events can scour *A. donax* biomass from the river corridor, the present approach includes a stipulation that no removal occurs within the same year as a 10-yr flood. No contingency plan is currently in place to address *A. donax*; thus, two contingency plan strategies were analyzed to explore the potential variance at different scales. Under each contingency plan, restoration managers would shift resources from removing additional acres to strictly treatment for five years following a 10-yr flood event. The first contingency plan suggests that 25 acres of 100% equivalent *A. donax* are brought into treatment and the second has a higher estimate of 50 acres. These values were determined based on anticipated variance in pre-planning and stakeholder collaboration.

Calculations. For each scenario, a Monte Carlo simulation was run with 1000 trials. During each trial, 10-yr flood events were simulated across the 20-yr timeframe based on flood recurrence probability, and the resulting costs and benefits for each time period were calculated according to the management strategy. The present value of costs and benefits were found using equations 3 and 4:

Eq. 3 $$PV_{costs} = \sum_{t=0}^{20} \frac{C_t}{(1+r)^t}$$

Eq. 4 $$PV_{benefits} = \sum_{t=0}^{20} \frac{\sum_{t=0}^{t}(B_t)}{(1+r)^t}$$

where *C* equals the costs at period *t* and *B* equals the benefits.

The NPV and BCR were then calculated using each discount rate using equations 5 and 6:

Eq. 5 $$NPV = PV_{benefits} - PV_{costs}$$

Eq. 6 $$BCR = \frac{PV_{benefits}}{PV_{costs}}$$

Trial results were then plotted by scenario to visualize variation within each and among the three management strategies.

5.6 Priority areas for ecological value

Marxan, a conservation tool for deciding an optimal portfolio of planning units, was used to develop a model that identifies priority areas for restoration with the results visualized in ArcGIS. Priority areas were identified as parcels providing high ecological benefits at minimal cost for *A. donax* removal.

Marxan develops recommendations for conservation based on costs, features, and a specified set of parameters (Ball, Possingham, & Watts, 2009). It is a widely used conservation planning tool for reserve network design in a variety of systems, including terrestrial and marine (Kark, Levin, Grantham, & Possingham, 2009; Klein, Steinback, Scholz, & Possingham, 2008). The software uses a simulated annealing algorithm to identify a set of planning units that will achieve set objectives at minimal cost. In simulated annealing, an initial, random sample of planning units is selected. The costs and benefits (achievement of defined objectives) are then calculated for that selection. Next, a single change is made to that selection and the costs and benefits are recalculated. If the new selection is better than the prior, the algorithm continues with the new change. If not, it reverts and changes another unit. This repeats for a set number of iterations with the best scenario considered to be optimal. This entire process is duplicated using other random samples to seed the model. This helps to avoid the pitfalls of selecting a local maximum that is better than neighboring solutions, but ultimately not optimal for the entire problem set (Kirkpatrick, Gelatt, & Vecchi, 1983). Marxan documents how often parcels are selected under each 'seeded' trial and records the overall best solution among the trials (Ball et al., 2009).

Planning units. The SCR watershed predominantly comprises privately held parcels. Planning units are defined by parcel boundaries as provided by the Ventura County Assessor's Office (2015). The parcel shapefile was then clipped to the bounds of the SCR corridor as defined by the vegetative cover shapefile (Stillwater Sciences & URS Corporation, 2007). Areas designated as agriculture or developed in the vegetative cover file were also removed from analysis.

Planning unit features. Each planning unit has specific features that relate to its potential as a restoration site as defined here:

Vegetative cover. The vegetative cover shapefile contains a network of polygons overlaying the SCR corridor and several of its tributaries with polygons defined by the dominant habitat type (Stillwater Sciences & URS Corporation, 2007). Dominant habitat types were aggregated into four categories based on their function for Endangered avian species in the lower SCR.

A. donax density. The updated *A. donax* cover shapefile discussed in section 4.1 was used to calculate the acreage of *A. donax* for each planning unit and the density (% cover) was used to determine which cost category to apply (see *Planning Unit Costs*).

Trout habitat. The presence of suitable oversummering habitat for steelhead trout in planning units increases the value of a planning unit. Data for potential sites were gathered by Stoecker Ecological (Stoecker & Kelley, 2005). Planning units are given a 1 designation if potential oversummering habitat exists within that unit or 0 if not.

Restoration sites. Current restoration sites are dispersed along the corridor and managed by several different agencies and organizations, primarily the Riparian InVasion Lab (RIVR) at UCSB, The Nature Conservancy (TNC), and the Ventura County Watershed

Protection District (VCWPD). Restoration site files were merged into a single file and bounded to the SCR corridor similar to the planning units. Current restoration sites were 'locked-out' during planning unit selection.

Planning unit costs. Available cost data for *A. donax* control were limited to the data provided by the RIVRLab. To account for the variance in cost across infestation density categories (Table 1), RIVRLab data were paired with best- and worst-case values from Stillwater Sciences' assessment and a most likely estimate was obtained (Table 12). These data show that outlays for any given *A. donax* control project are not uniform across years of the project. Higher expenditures are typically seen within the first year when biomass removal dominates. Proceeding years are considered to be maintenance years with occasional spot treatments of *A. donax* regrowth. To account for interannual variability, total costs per project were aggregated across five years, the typical length of a RIVRLab *A. donax* control program. The five-year cost per acre for each density category was then multiplied by the acreage of each planning unit to obtain the most likely five-year cost for that unit.

Feature targets. Marxan operates by meeting specified feature targets, or goals, at least cost. The target for steelhead trout habitat is the minimum number of parcels to include with potential oversummering habitat. For habitat categories, the target is defined as the minimum acreage for each category to include. Three scenarios were defined with collaborators at the RIVRLab, in which different targets are set to achieve 10, 15, and 20% removal of total acreage of *A. donax* (95, 142.5, and 190 acres respectively).

Feature multipliers. To account for the various ecological benefits of a parcel (habitat type and Steelhead oversummering locations), a multiplier scheme was developed to modify each parcels value based on our literature review and through a consultation with collaborators at the RIVRLab (Table 14). Since weights are applied to the planning unit's cost of removal, they are inversely correlated with the value of a parcel. For instance, a low-value habitat type will have a high weight (increasing the cost for analysis purposes) while a high value habitat type will have a low weight (decreasing the cost). Multiplier values were averaged across parcels that had two or more features with different weights.\

Table 14. Feature multipliers used for analysis.

Parameter	Multiplier
Habitat Type	
Ideal	0.75
Good	0.85
Low	0.95
Other (Poor)	1.00
Steelhead Trout Habitat	
Present	0.50
Not Present	1.00

Boundary length modifier. Building on the concept of establishing restoration networks, the boundary length modifier tool in Marxan was used. A boundary length modifier influences the connectivity of parcels during planning unit selection. Modifier values range from zero to one, with one placing the highest influence on network creation. For this analysis, the boundary length modifier was set to one.

Analysis. Costs for each planning unit were multiplied by the respective weights for each unit based on the respective attributes from each data layer. The files were loaded into Marxan along with the current percent cover of *A. donax*. The model was processed for each of the three target scenarios identified above and the results were spatially visualized with ArcGIS. Total acreage and estimated cost for each target was also found.

6. Results

6.1 *Arundo donax* distribution mapping

We assessed change in *A. donax* cover over time (2005 to 2015) for vegetation polygons containing over 51% *A. donax* cover. We started with the Stillwater Sciences and URS dataset collected in 2005-2006, which included a precise value of *A. donax* cover for every polygon. Converting the fractional *A. donax* cover in every polygon to 100% *A. donax* cover equivalent in acres and then summing for all polygons yields a single 2005-2006 result of 436 acres.

In contrast, our 2015 updated data included *A. donax* cover categories for each polygon (i.e., 51-75% or 76-100%). Only for those polygons with more than 50% Arundo cover were assessed as those with less than 50% could not be distinguished reliably from air photos and so were assumed to have not significantly changed from 2005-2015. *A. donax* distribution around Fillmore displayed in Figure 9 provides an example of the results of the 2015 mapping update. Appendix A provides *A. donax* 2015 distribution maps for the entire lower SCR. Owing to the range within each category, the total number of acres of 100% *A. donax* cover equivalent is also a range when all polygons were summed. This range of 419 acres to 576 acres is based on whether the minimum cover values of 51% and 76% were selected; average cover values of 63% and 88% were selected; or maximum cover values of 75% and 100% were selected for these calculations (Figure 10).

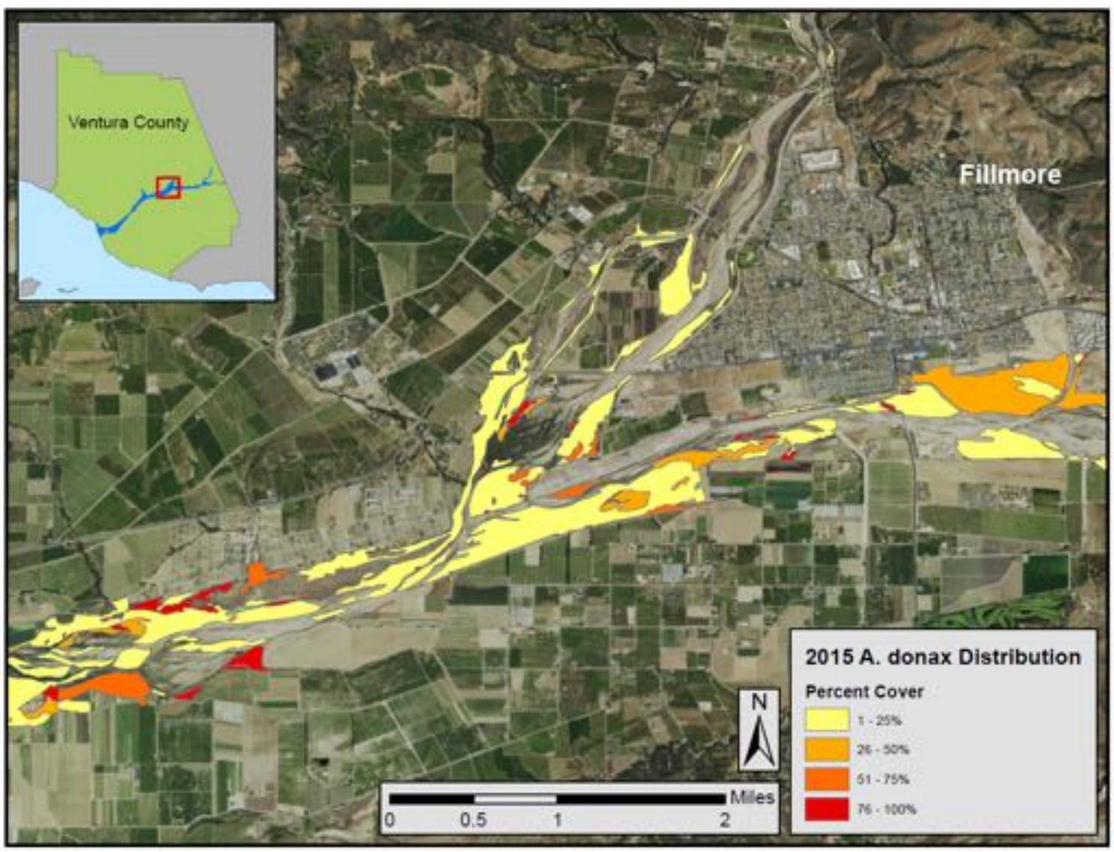


Figure 9. *A. donax* distribution and percent cover around Fillmore based on 2015 mapping efforts.

Given the range in our 2015 data, we cannot identify a statistically significant change in the area of dense *A. donax* stands (i.e., polygons containing more than 51% *A. donax*) over the past decade. However, the 2015 area calculated using mean cover values (499 acres) suggests an observable increase in area of dense *A. donax* stands of perhaps 10–20% over the past decade. The vast majority of the expansion of dense *A. donax* stands observed from 2005 to 2015 in the photointerpretation process occurred into parcels smaller than a quarter of an acre in size.

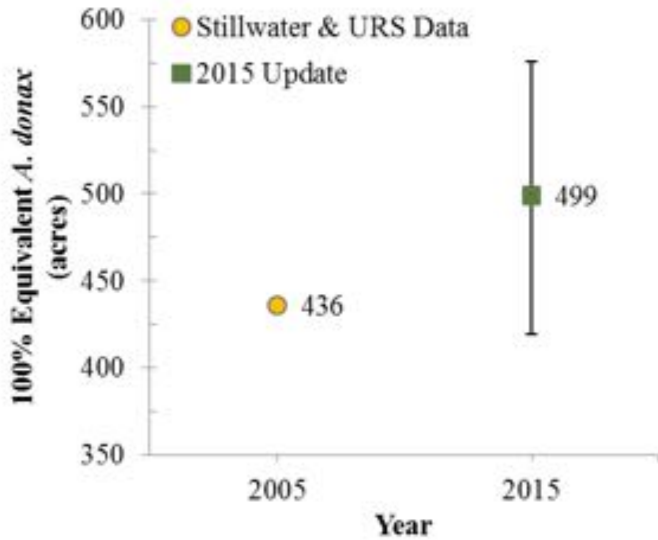


Figure 10. Comparison of dense *A. donax* stands (*A. donax* cover over 50%) for the Stillwater and URS 2005-2006 Data and our 2015 update of the data. The data sets were compared by converting *A. donax* densities per area into acres of 100% *A. donax* equivalent.

We are able to use the mean area of dense *A. donax* stands in 2015 to estimate the total acreage of *A. donax* in the watershed in 2015. This was accomplished by summing 499 acres (the mean area of dense stands in 2015) and the area of low-density stands (less than 51% *A. donax*). The latter was assumed to have remained unchanged from 2005 to 2015 since there were not major floods during this timeframe to redistribute rhizomes and we were unable to undertake field-based mapping. By summing the mean area of 2015 dense stands and the unchanged area of low-density stands, we estimated that as of May 2015, there were 949 acres of 100% *A. donax* cover equivalent in the study area. This is 6-7% higher than 890 acres of 100% *A. donax* cover equivalent that Stillwater and URS identified in the study area through their 2005-2006 mapping. Our estimate of 949 acres of 100% *A. donax* cover equivalent played a role in our cost-benefit analysis as some costs and benefits were converted to per acre prices by simply dividing (or multiplying) by 949.

6.2 Water use

The water consumption model estimated the amount of water savings (Figure 11) and associated monetary savings (Figure 12) for three different scenarios of the removal and replacement of *A. donax* in the SCR. Low estimate uses high water use values for native vegetation and low water use values for *A. donax*. The high estimate uses low water use values for native vegetation and high water use values for *A. donax*. The most likely estimate uses the mean water use value for both native vegetation and *A. donax*.

Using the 2015/2016 pricing for agricultural and municipal water ($39.75 and $119.25, respectively; United Water Conservation District , 2015) in the Ventura County portion of the SCR estimates a potential savings of $887,000 if all *A. donax* is removed from the study area and replaced with native vegetation in the most likely water use scenario.

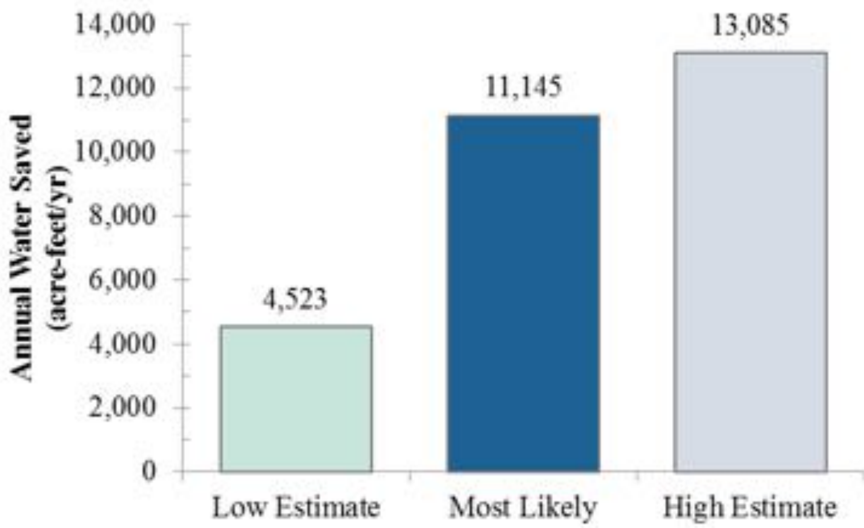


Figure 11. Water saved from the removal and replacement of *A. donax* in the Santa Clara River. The amount of water saved is provided for three estimates (low, most likely, and high) where different water use values for native vegetation and *A. donax* were input into the model.

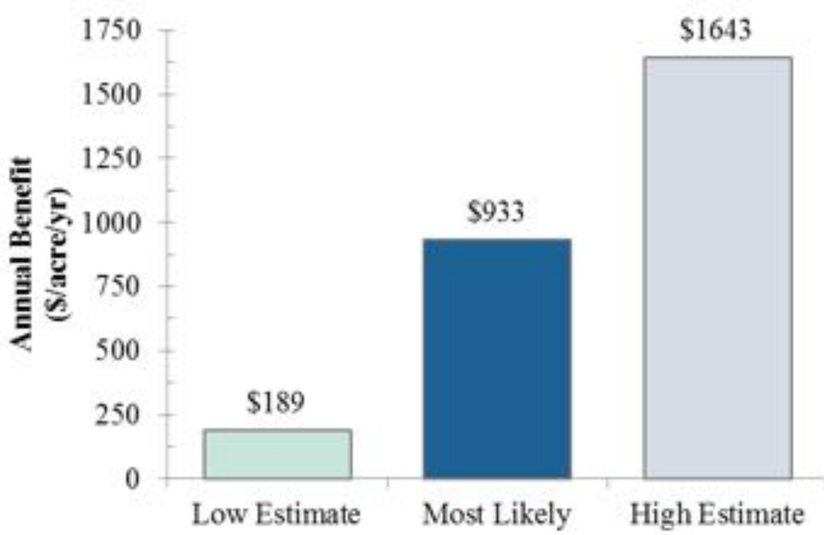


Figure 12. Monetary savings from reduced vegetative water consumption when *A. donax* is removed and replaced with native vegetation in the Santa Clara River, per-acre. Three estimates (low, most likely, high) were assessed in the model using varying water use values for native vegetation and *A. donax*.

6.3 Fire

Fire risk in each situation was lower when *A. donax* was removed from the SCR. The benefit of removing *A. donax,* was seen as the reduction in fire-fighting costs which differed across all situations (Table 15). The change in fire risk for each situation for the lower entire SCR can be visualized in Appendix B.

Table 15. Fire risk situations for defined wind speeds and vegetation-weighting regimes.

Situation	Wind Speed (MPH)		Vegetation Weight (%)	
1	Low	6.7	Low	60
2	Low	6.7	High	80
3	High	21	Low	60
4	High	21	High	80

Situation 1. Situation 1 represents the best-case scenario for overall fire risk, with a low wind speed of 6.7 mph and a low vegetation-weighting regime (Figure 13).

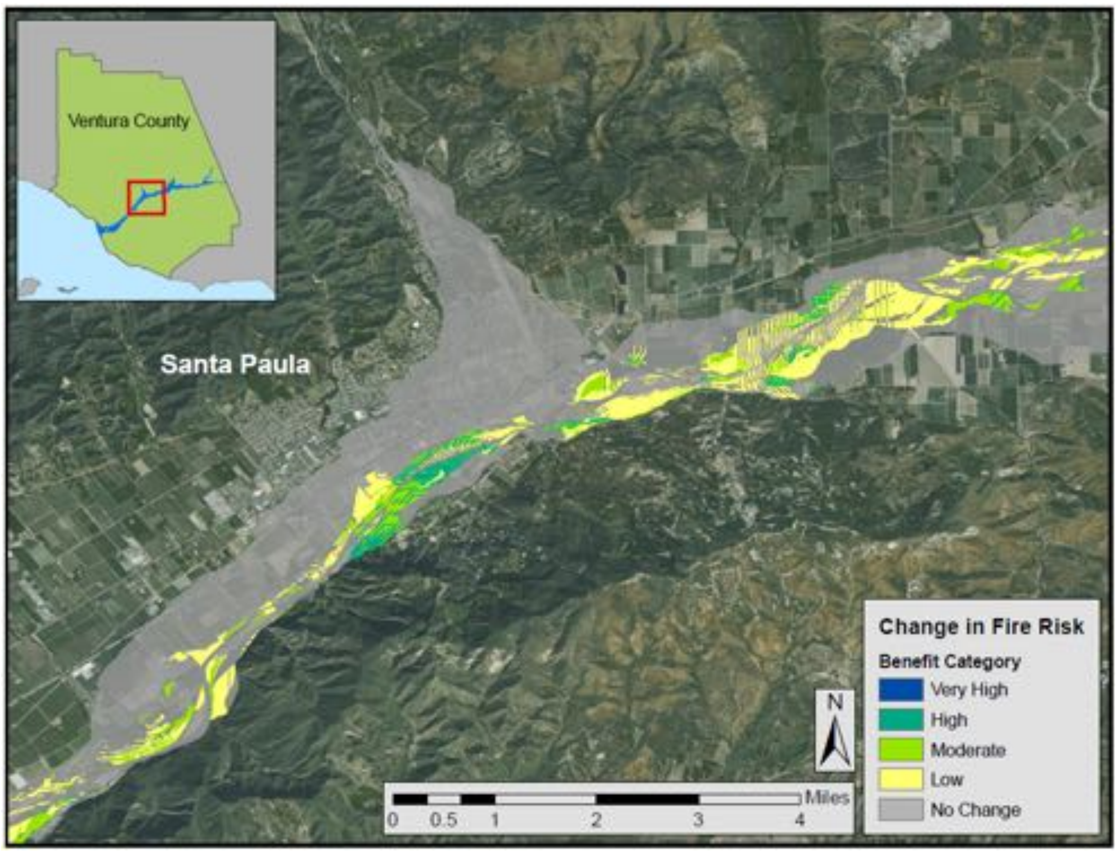


Figure 13: The change in fire risk in the Santa Clara River when *A. donax* is removed for Situation 1. Higher benefits in fire risk reduction are indicated by darker colors, and gray represents no change. Note the large amount of low benefits generated in this situation.

Overall, the fire risk in the SCR decreased when *A. donax* was removed, with no area increasing in fire risk. The total area that reduced in fire risk was 14.9% of the entire study area. For this situation, the benefit from removing *A. donax* falls primarily into a low category, which represents a relatively low change in fire risk with removal efforts in place. This is likely due to the low wind speed and lower vegetation-weighting regime used, which are important drivers of fire risk.

Situation 2. Situation 2 represents a moderate fire risk assessment, with a low wind speed of 6.7 mph and a high vegetation-weighting regime (Figure 14).

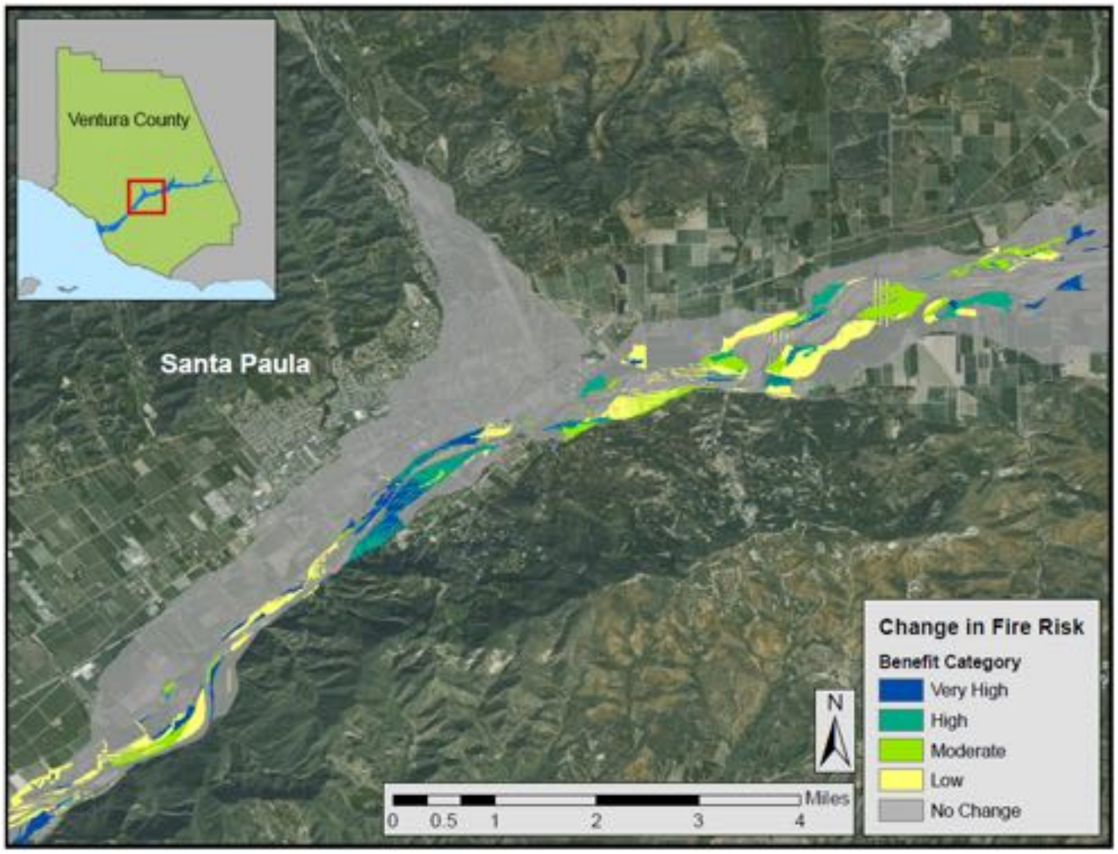


Figure 14: The change in fire risk in the Santa Clara River when *A. donax* is removed for Situation 2. Higher benefits in fire risk reduction are indicated by darker colors, and gray represents no change. Note there are more benefit categories delineated as high and very high fire risk, with less overall area generating benefits.

Overall, the fire risk in the SCR decreased when *A. donax* was removed, with no area increasing in fire risk. The total area that had reduced fire risk was 12.4% of the entire study area. When increasing the vegetation-weighting regime, the low benefit category retains almost half the total area where fire risk was reduced. However, the effect of increasing vegetation added an additional benefit category of very high. Increasing the vegetation-weighting regime increased the total benefits of fire risk reduction, but over a lower total area than Situation 1.

Situation 3. Situation 3 represents secondary moderate fire risk assessment, with a high wind speed of 21.4 mph and a low vegetation-weighting regime (Figure 15).

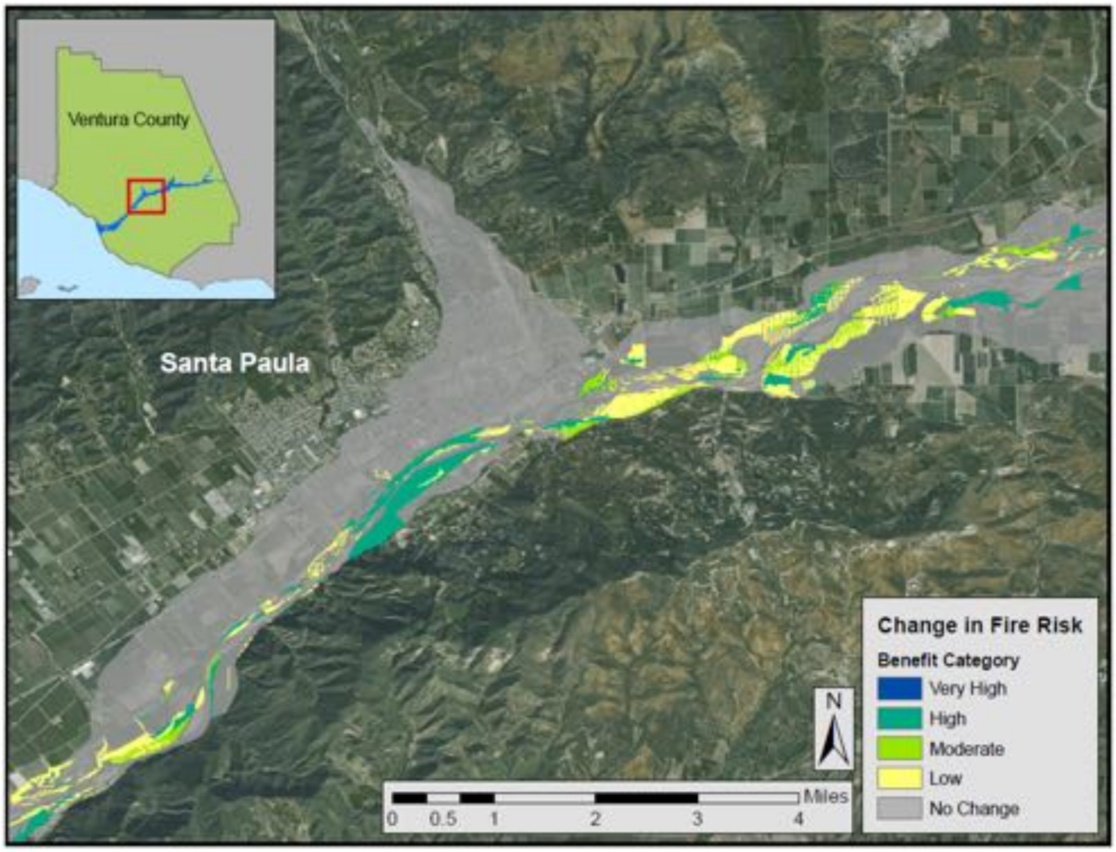


Figure 15: The change in fire risk in the Santa Clara River when *A. donax* is removed for Situation 3. Higher benefits in fire risk reduction are indicated by darker colors, and gray represents no change. Note the more evenly distributed benefit categories throughout the region of interest.

Overall, the fire risk in the SCR decreased when *A. donax* was removed, with no area increasing in fire risk. The total area that had reduced fire risk was 13.1% of the entire study area. Using a low vegetation weighting regime paired with a high wind scenario, the benefits of removing *A. donax* distributes more evenly across the SCR. However, the very high benefit category, generated when a high weighting regime scenario is used, disappears. Thus it seems that the increased wind scenarios increase fire risk over the lowest three categories but do not significantly influence the very high benefit category.

Situation 4. Situation 4 represents the worst-case scenario for fire risk with a high wind speed of 21.4 mph and a high vegetation-weighting regime (Figure 16).

Overall, the fire risk in the SCR decreased when *A. donax* was removed, with no area increasing in fire risk. The total area that reduced in fire risk was 17.1% of the entire study area. Using a high vegetation-weighting regime and a high wind scenario increases the total area where benefits are received. This is likely due to increased winds, like those in situation 3. There is also a very high benefit category in this situation, like that of situation 2, which is due to higher vegetation-weighting regime. Thus, wind is likely the driver of the total area burned, and more evenly distributes benefits among categories. When using a higher vegetation-weighting regime there is an increase in the amount of benefits received, as well as an increase in the range of benefit categories generated (Table 16).

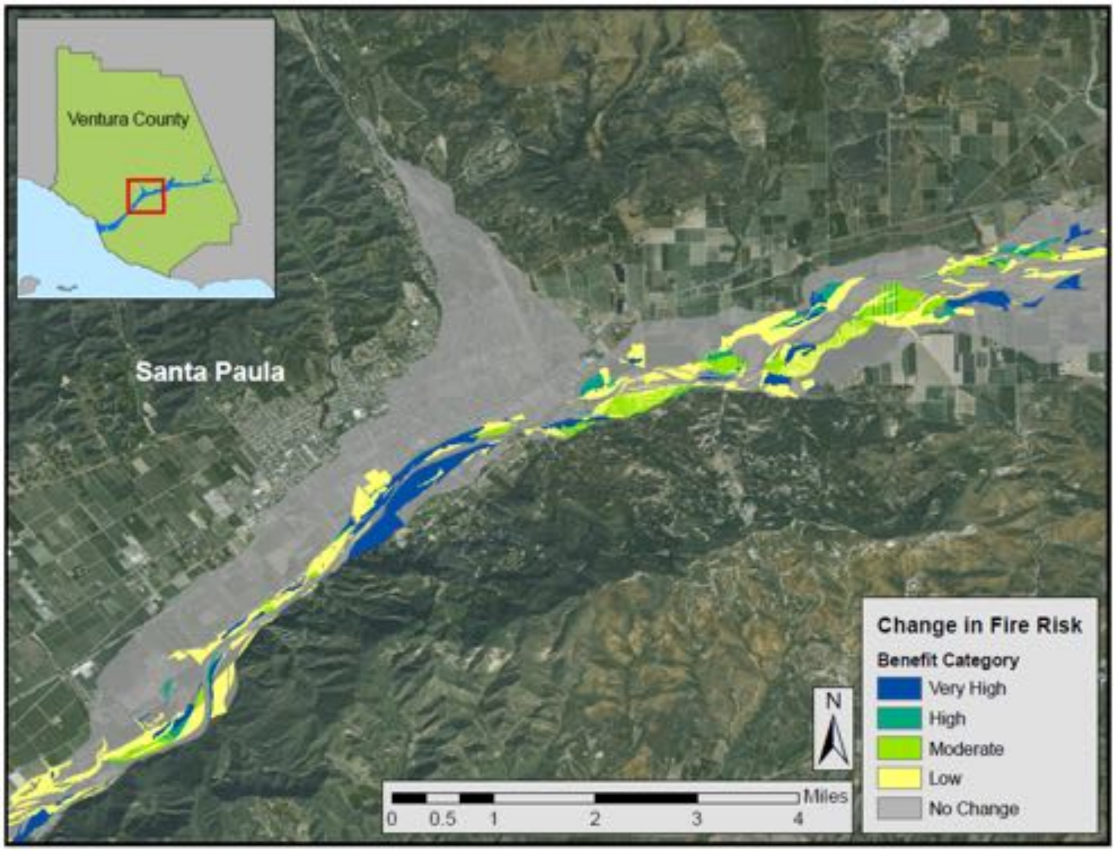


Figure 16: The change in fire risk in the Santa Clara River when *A. donax* is removed for Situation 4. Higher benefits from fire risk reduction are indicated by darker colors, and gray representing no change. Note the total area of benefits is largest here, and the high proportion of very high benefits comparatively.

Table 16. Fire risk situation with corresponding benefits. The percent of acres where a benefit in fire risk reduction was generated over the entire area of study. The percent of area for each benefit category is the percent of the total area that fire reduction was generated for each situation.

Situation	Percent Area With Fire Risk Reduction Benefit (%)	Percent Area by Benefit Category (%) Low	Moderate	High	Very High
1	15%	62%	22%	16%	0%
2	12%	46%	16%	16%	23%
3	13%	43%	25%	33%	0%
4	17%	47%	19%	10%	24%

The total area in acres of the benefit from fire risk reduction varied between each situation with a range between 1,156 acres for the highest and lowest calculated acreage (Figure 17).

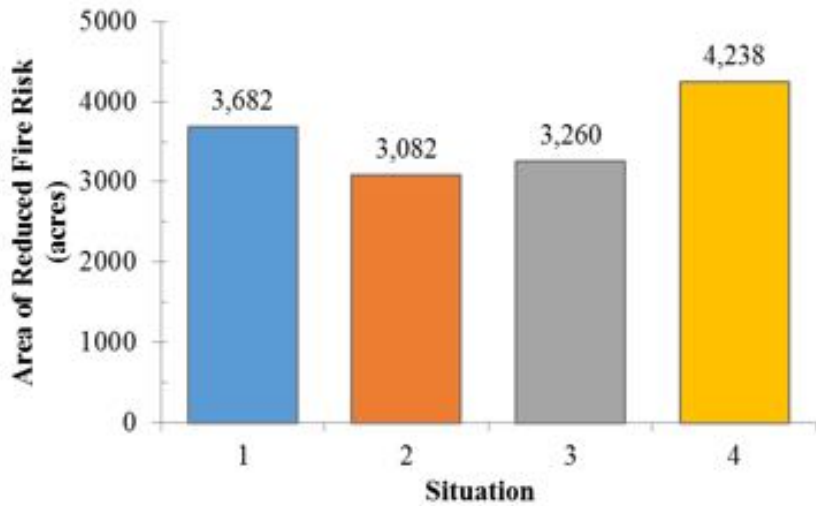


Figure 17. The total acreage of fire risk reduction in the Santa Clara River for each situation. This figure represents the sum of all the acres in the SCR that experienced a decrease in fire risk for each situation. The total acreage of areas where fire risk was reduced by removing *A. donax* and replacing it with native vegetation for each situation was calculated.

Based on output of the model, the lowest total acres of reduced fire risk come from situation 3 and totals 3,260 acres. Conversely, situation 4 represents the highest total acres of fire risk reduction with a total of 4,238 acres. These results indicate that a combination of high winds and high vegetation weighting regimes leads to the highest total acreage of benefit that could be generated from fire risk reduction. However, a low vegetation weighting regime paired with a low wind speed derived the next highest total acreage of reduced fire risk. This indicates that the pairing of a combined low and high wind with high and low vegetation weights acts to diminish the fire risk overall.

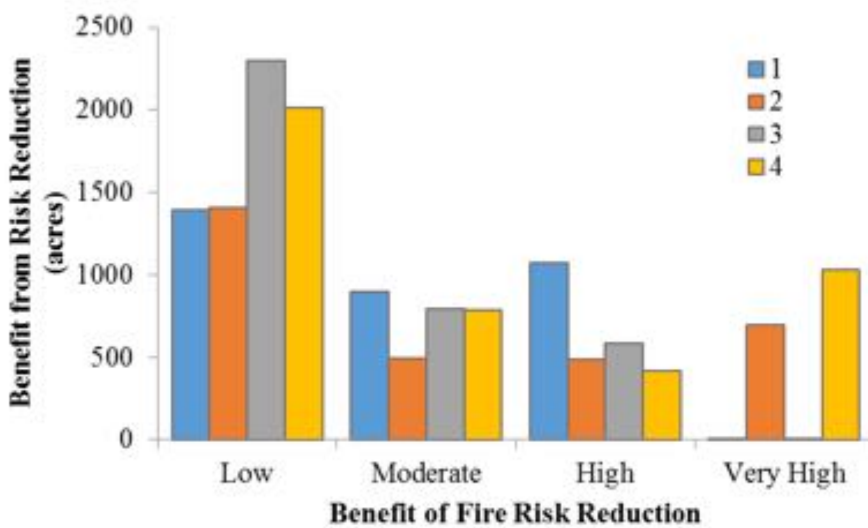


Figure 18. The acres of fire risk reduction for each benefit category (very high, high, moderate, and low) in each situation when *A. donax* is removed and replaced with native vegetation. This chart represents the total acres for which a benefit in terms of fire risk reduction is received when *A. donax* is removed.

The benefit of fire risk reduction with *A. donax* removal for each category varies (Figure 18). However, the overall trend for each situation highlights that removal efforts generate a low benefit. This indicated that removing *A. donax* changes the benefit of fire risk reduction only by one fire risk category. This likely comes from the large percent of areas that have low *A. donax* coverage (less than 50%). The areas that receive a higher benefit in fire risk reduction are those with large, dense stands of *A. donax* (greater than 50%), which represent a smaller portion of the *A. donax* area in this area of interest.

In order to translate fire risk into a yearly likelihood of area burned for each fire risk category the Ventura County Fire Department Fire Perimeter data was used (VCFD Fire Perimeter, 2015). The data was analyzed in ArcGIS by generating the total acreage where a fire occurred for each fire risk category in the study area over the last 15 years, 2000-2015. Taking this calculated acreage and dividing it by the total acreage of each fire risk category and the years analyzed, the likelihood of burning in any given year for each category was generated (Table 17).

Table 17. Fire risk and corresponding fire likelihoods. The percentages associated with the likelihood of burning in any year were derived from the VCFD shapefile of fire perimeters from 2000 to 2015 (VCFD Fire Perimeter, 2015).

Fire Risk	Likelihood of Burning in a Given Year (%)
Very Low	0.05
Low	0.12
Moderate	0.40
High	0.40
Very High	0.66
Extreme	1.00

The results from changing fire risk to likelihood of fire occurrence demonstrate that the highest likelihood of a fire event in any given year occurs in Extreme fire risk areas, with a decrease in the fire likelihood for each preceding category.

In order to calculate the value of removing *A. donax* in terms of fire risk reduction, the change in acres for each fire risk category was calculated. The change in fire risk when *A. donax* is removed and replaced with native vegetation varied for each situation with an overall trend of increasing area in the Low fire risk category, and decreasing areas with all other higher fire risk categories (Figure 19 and Table 18).

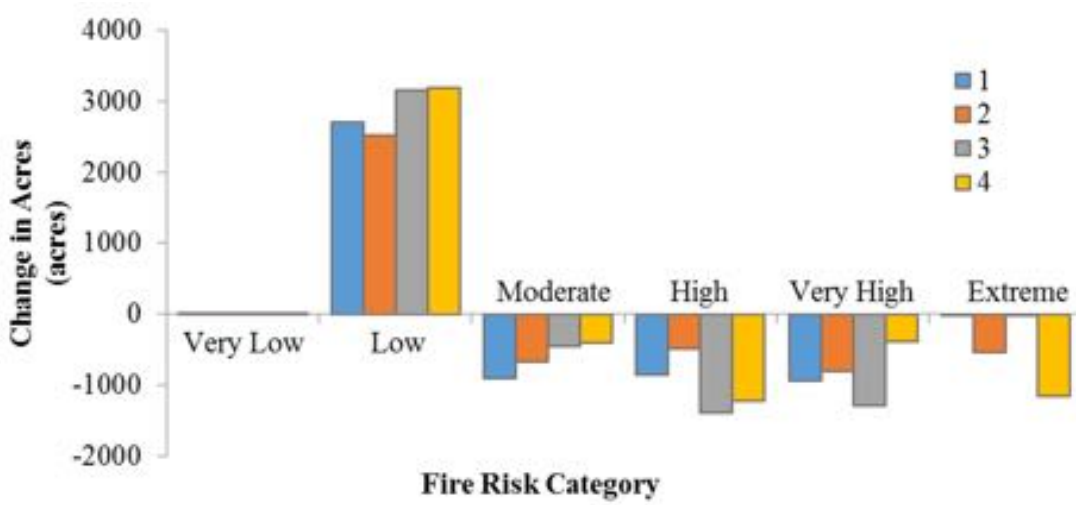


Figure 19. The total change of acres of each fire risk category with *A. donax* removal. These values were generated by subtracting the total acres of fire risk with *A. donax* from the total acres of fire risk with *A. donax* removed and replaced with native vegetation for each fire risk category.

Table 18. The total change of acres of each fire risk category with *A. donax* removal.

	Change in Acres of Fire Risk with A. donax Removal					
Situation	**Very Low**	**Low**	**Moderate**	**High**	**Very High**	**Extreme**
1	0	2,709	-909	-861	-939	0
2	0	2,527	-675	-498	-812	-542
3	0	3,149	-457	-1,391	-1,296	-6
4	0	3,182	-406	-1,229	-391	-1,157

The results for the change in acres of fire risk for each category when *A. donax* is removed and replaced demonstrates that the highest change occurs by increasing the Low fire risk area in each situation. This indicates that removing *A. donax* can reduce the total acres that have fire risks categories greater than Low risk for every situation.

To generate the change in the total acres burned within the lower SCR, the change in total acres of fire risk for each category was multiplied by the likelihood of fire occurrence for scenarios both with *A. donax* and with *A. donax* removed and replaced with native vegetation (Figure 20).

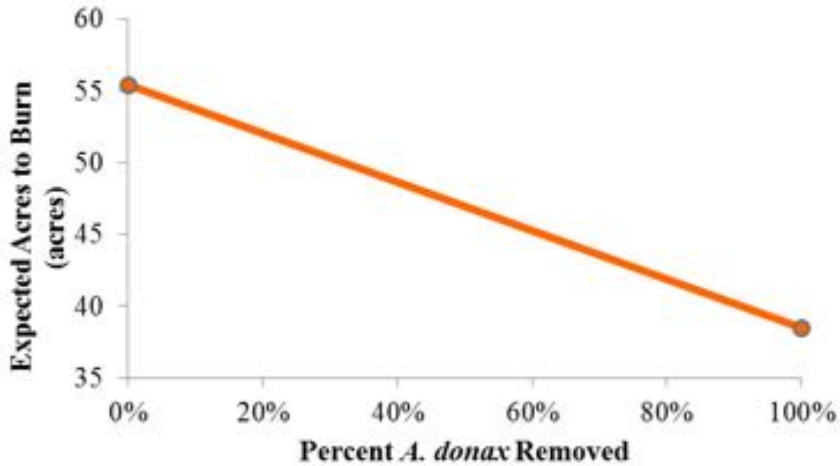


Figure 20. Change in estimated burn acres in the SCR with *A. donax* removal. Change in estimated acres burned was extrapolated between 2015 levels of *A. donax* cover, and complete removal.

Comparison of fire scenarios to River Fire. Depictions of the River Fire perimeter were superimposed over the fire risk map with 2015 levels of *A. donax* for every situation and were used to identify which situation most closely matches the conditions that actually occurred (Figure 21).

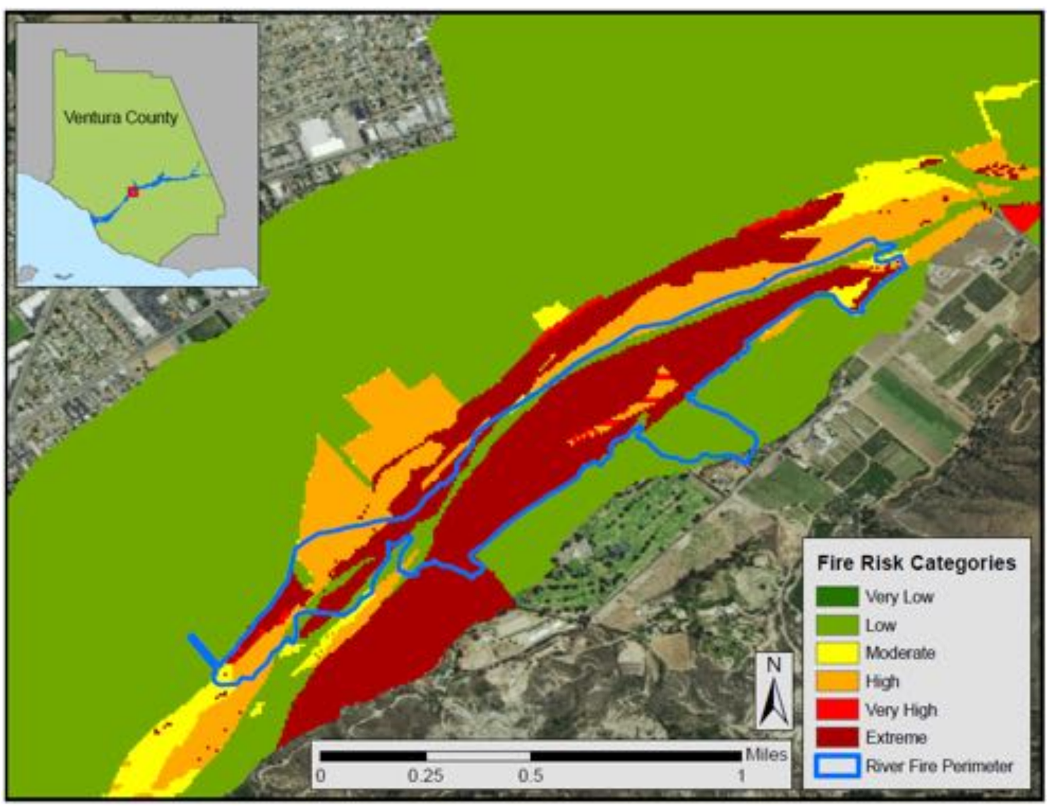


Figure 21: The River Fire extent compared to the associated fire risk prior to removing *A. donax* for situation 4. The perimeter of the River Fire that occurred in June of 2015 was mapped over the fire risk prior to *A. donax* removal to visualize the accuracy of the model's ability to accurately assess how fire risk is altered.

Situation 4 offered the most accurate depiction of fire risk when compared to the extent of the River Fire that occurred in the summer of 2015. This fire burned through over 160 acres, much of which was dominated by dense *A. donax* monocultures. This situation categorized much of the burned area as Extreme fire risk, which was indicative of this fire that threatened the Santa Paula Airport and other nearby structures and cost over half a million dollars to suppress. Hence, this situation was used when calculating the benefit that could be received as fire risk reduction when *A. donax* is removed and replaced with native vegetation. Although each accuracy test differed in the extent of the fire risk categories, the model was able to predict the areas that are likely to burn in each situation.

Associated fire costs. Fire suppression costs vary by size and fire intensity. For the River Fire, the ultimate suppression cost $510,000, which translates into a cost of $3,100 per acre to fight for the 160 acres that ultimately burned. A breakdown of the firefighting costs obtained from the Ventura County Fire Department for the River Fire is presented (Table 18).

Fire cost and acreage information were gathered from a variety of sources to get the best estimate of fire cost, total acreage, and fire occurrence. Fire suppression costs were categorized based on three size classes. Size class indicates that the smaller fires cost less than larger fires to extinguish on a per acre basis (Mason et al., 2005). Fires suppression cost data collected in the 1990's indicate small fires (less than 10 acres) cost $5,400 to $8000 per acre to control in Okanogan and Fremont National Forest, respectively. Additionally, medium sized fires (10 to 100 acres) cost $3,200 to $3,000 to suppress and large fires (greater than 100 acres) cost $500 to $1,100 per acre to suppress on average in Okanogan and Fremont National Forest, respectively (Mason et al., 2005). These data are consistent with what was found for firefighting costs in Ventura County and the greater Southern California region. Therefore, these fire sizes and costs per acre were used to extrapolate values when data were missing. For a conservative estimate of fire suppression costs, the data from Okanogan National Forest was used to compute cost estimates where costs were unknown (Table 19).

Additionally, fire costs associated with *A. donax* were averaged using known fire costs and acreages for all fires where *A. donax* burned, as well as for fires where either the cost or acreage was extrapolated. Fire cost information was also averaged for fires where *A. donax* was the dominate vegetation that burned for all small fires (less than 20 acres), and for all fires that occurred in 2012 (Table 20).

Table 19. Fires cost and acreage information for Ventura and the greater Southern California area. This table indicates the name of the fire when one is reported, the date the fire started, the total suppression cost of the fire, the total acreage of each fire, the cost per acre of each fire, and whether or not *A. donax* was known to be present in the fire. Italicized fire names indicate fires that occurred in Ventura County. An asterisk (*) indicates values that were not explicitly given but extrapolated based on fire suppression cost data.

Fire Name	Date	Cost ($)	Acres Burned	Cost/Acre ($)	*A. donax*
Shekell Fire	12/3/06	4,500,000	13,600	330	Yes
Simi Fire	10/25/03	10,000,000	108,204	92	Yes
Verdale Fire	10/24/03	2,407,000	8,650	278	Yes
Freeway Complex	11/15/08	16,100,000	30,305	531	Yes
Santiago Fire	10/21/07	21,600,000	28,445	759	Yes
Witch Fire	10/21/07	18,000,000	197,990	90	Yes
Harris Fire	10/21/07	21,000,000	90,440	232	Yes
Piru Fire	10/23/03	7,700,000	63,911	120	Likely
River Fire	6/22/15	510,000	164	3,109	Yes
Rice Fire	10/22/07	6,500,000	9,472	686	Yes
None	3/12/15	54,400*	17	3,000*	Yes
None	3/9/15	unknown	0.25	5,400*	Likely
None	3/11/15	unknown	0.005	5,400*	Yes
None	9/21/14	unknown	0.0367	5,400*	Yes
None	11/3/15	unknown	0.0574	5,400*	Yes
Toland Fire	5/5/15	15,660*	2.9	5,400*	Yes

Table 20. The average cost, median cost, acreage, and cost per acreage to suppress fires. The known costs and acreages were calculated using data from only fires where both the costs and acreages were explicitly stated. The extrapolated cost and/or acreage data were used from fires with either known costs or known acreages. Small *A. donax* fires used all of the *A. donax* dominated fire events less than 20 acres in size. *A. donax* fires in 2015 used all fires that burned primarily *A. donax* in only the year 2015.

	Cost ($)	Acres	Cost/Acre ($)
Known costs/acres			
average	10,831,700	50,109	623
median	10,000,000	30,305	278
Extrapolated costs/acres			
average	6,927,000	35,840	2,300
median	4,500,000	9,472	723
Small *A. donax* dominated fires			
average	14,000	3	4,250
median	4,000	0	26,000
A. donax fires in 2015			
average	98,677	31	3,200
median	4,000	2	2,540

The River Fire that occurred in the summer of 2015 can be viewed as a case study for how *A. donax* affects fires within the SCR. A breakdown of the fire costs associated with this fire is presented (Table 21).

Table 21. Fire Fighting costs for the River Fire. Estimated costs for the 'River Incident' from the Ventura County Fire Department, Incident #15-0041060, June 22-27th, 2015. All costs are rounded to nearest $100. Data obtained from Ventura County.

Agency/Department	Cost
VCFD Total Cost (before billing CALFIRE)	$318,300
CAL FIRE Total Cost (before VNC bill)	$110,000
Ventura City Fire	$4,600
Santa Paula City Fire	$24,100
Fillmore City Fire	$2,700
Oxnard City Fire	$5,600
LA County Fire	$25,400
Air Unit	$68,500
Hand Crew Unit	$118,600
Equipment	$206,200
Overhead Personnel	$91,900
Service & Supply Expense	$25,100

In order to generate the per acres benefit of removing *A. donax* and replacing it with native vegetation in terms of fire risk reduction, the range of firefighting cost based on fire sizes were used (Mason et al., 2005). These values were the input to the change in total acres burned in the lower SCR (Figure 22)

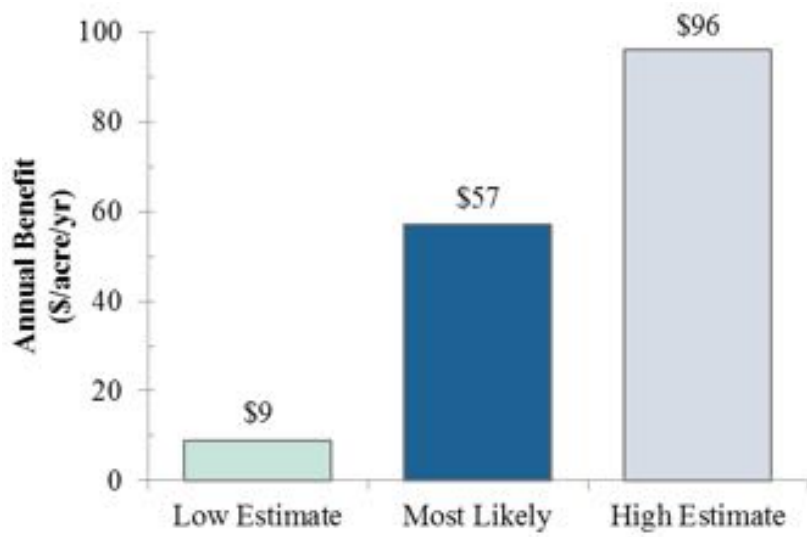


Figure 22. The estimated annual saving in fire-fighting costs per acre of *A. donax* removed and replaced with native vegetation. Benefits generated from the reduction in expected burn area multiplied by a range of fire-fighting costs based on fire size (Mason et al., 2006).

The costs from Tables 18-19 do not account for the multitude of damages associated with fire, given that there are additional benefits from the avoided damages when a fire does not occur. Benefits from the removal of *A. donax*, which are associated with fuel treatments that reduce fuel loads, decrease the risk of fire and add additional monetary benefits. These additional benefits include avoided fatalities and avoided structure losses. In addition, there are other values that are more difficult to quantify as a monetary value but that should be considered a benefit from removing *A. donax* and avoiding fire disturbances that it causes. These benefits include avoided habitat degradation, loss in water quality, erosion, and smoke.

In 2003, fire burned over 750,000 acres of land in California alone. The loss of structures was valued at over $2 billion (Mason et al., 2005). In fires documented in the previous section, where information was attainable, there were 2,969 structures destroyed, over 551,181 acres burned, with an additional 258 structures damaged over the same area. Although the cost of each structure varied, using a very conservative value of $25,000 per structure for each acre that burned, an additional cost of $135 was generated from destroyed structures, not including the structures that were damaged. Mason et al. (2005) found similar numbers for high risk fire areas, where they attributed over $150 per acres to structures loss in burned areas. To what extent the loss in structures can be attributed to *A. donax* cannot be know with certainty. This does, however, highlight that these costs should be considered when linking fire costs to *A. donax*.

In the Santa Clara River watershed, fire has historically been prolific ("VCFPD Fire Origins and Perimeters," 2015). Much of the watershed is dominated by chaparral vegetation in which fire is necessary for germination and regeneration (Keeley, 1981, 1987). Due to the vegetation's proclivity for fire events, almost the entire watershed has burned at least once over the past century, with some areas burning up to eight times within the same time period (Stillwater Sciences, 2011). The highest burn area is along South Mountain Road, which parallels the SCR through Santa Paula and Fillmore. Between 1911 and 2009, the average total area that burned within the SCR watershed was 18,000 acres (Stillwater Sciences, 2011).

Historically, the SCR has acted a fire-break, which can be visually determined using the Ventura County Fire Department data of historical fire occurrences. However, fire occurrences within the river associated with *A. donax* are increasing in frequency but are relatively small in size. In the year 2015 over 181 acres of *A. donax* burned in the SCR watershed, with a majority occurring within the SCR. Excluding the large River Fire, which composed 164 of the 181 acres, over 17 acres of *A. donax* burned within the SCR watershed. Using a moderate fire-fighting estimate of $3,200 per acre, over $54,400 could have been avoided in firefighting costs in 2015 as well as the additional $510,000 for suppressing the River Fire. Based on the 2015 *A. donax* fire events, a conservative estimate of 15 acres of fires per year occurs in *A. donax*. This means there is the potential to save $48,000 of firefighting costs per year if *A. donax* was removed and replaced with native vegetation.

6.4 Hydrology

Flood area results. Spatial analysis of our modeled HEC-RAS flood extents in ArcGIS revealed that the total modeled flood area of both the 5- and 10- year flood flows increased modestly when 2015 levels of *A. donax* were present in the river channel and floodplain of the lower SCR. For a flood with a 5-year recurrence interval, our model predicted that the total extent of flooding would increase from 251,272 acres to 262,419 acres due to the presence of *A. donax,* which represents an 11,147 acre (+4.4%) increase in total flooded area within our region of study (Figure 23, Appendix C). For the 10-year flood flow, our model results show that the total flood area increased from 308,712 acres to 326,253 because of the presence of *A. donax,* an increase of 17,541 acres (+5.7%) in area flooded (Figure 24, Appendix C). Visual surveys of the data suggest that model geometry with *A. donax* only in the floodplain does have localized effects on flood area, but not to the same degree as when *A. donax* is located in the active channel and not scoured away by (very) high flows.

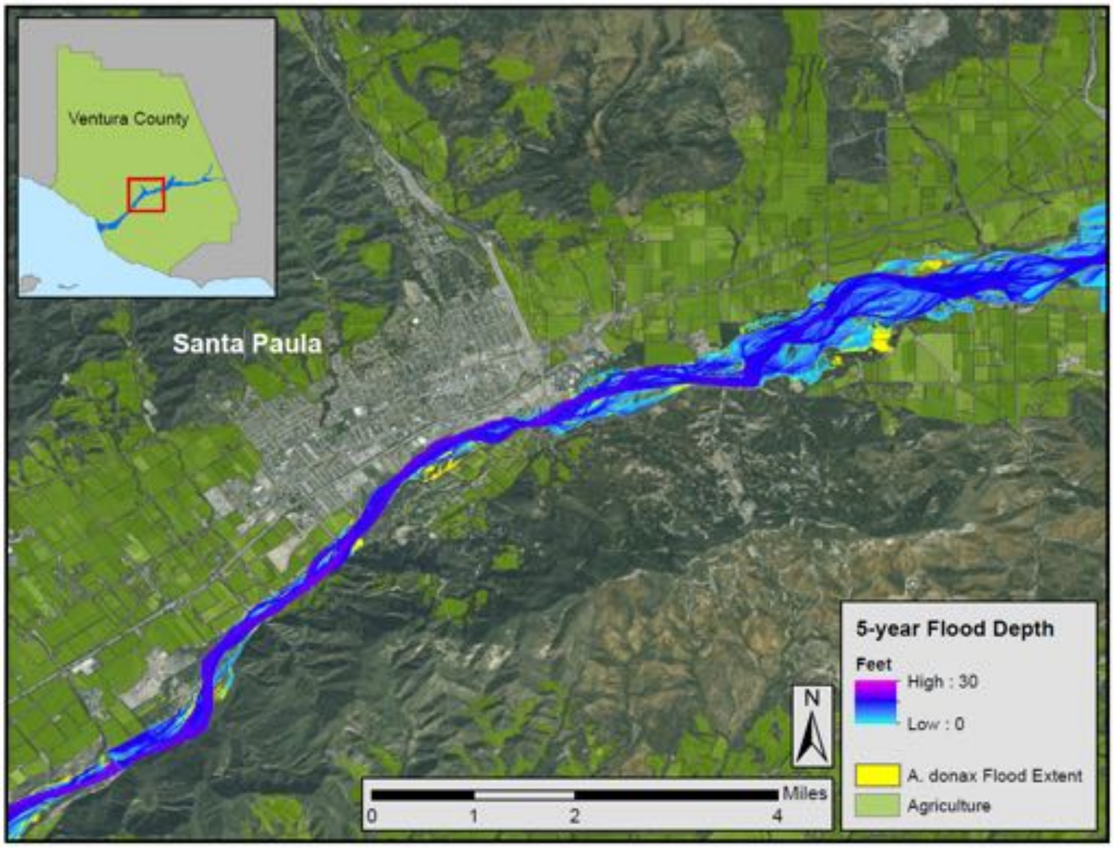


Figure 23. Modeled 5-year recurrence interval flood of the lower Santa Clara River near Santa Paula, CA. Yellow areas represent areas of additional flooding caused by varying channel and floodplain roughness in our HEC-RAS model to reflect 2015 *A. donax* densities and extents.

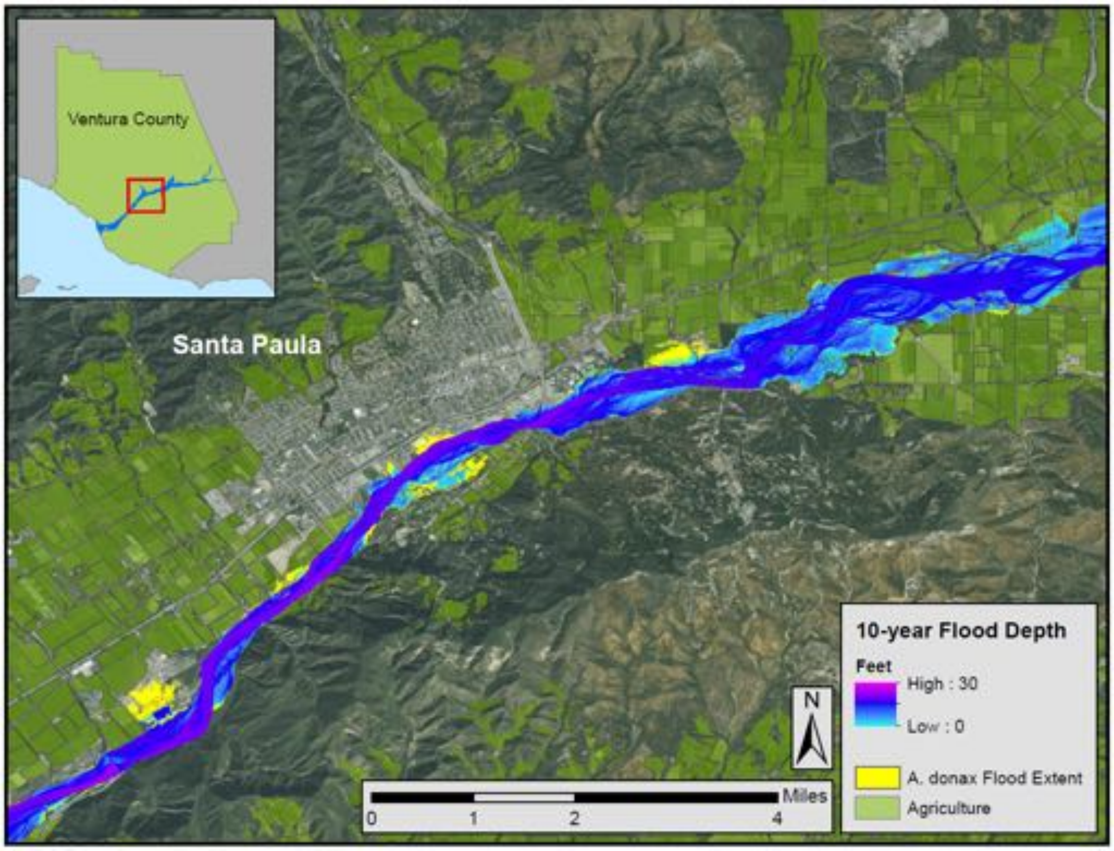


Figure 24. Modeled 10-year recurrence interval flood of the lower Santa Clara River near Santa Paula, CA and intersection with agricultural lands. Yellow areas represent areas of additional flooding caused by varying channel and floodplain roughness in our HEC-RAS model to reflect 2015 *A. donax* densities and extents, under the assumption that this discharge is (just) insufficient to scour out the *A. donax* stands.

Flooding cost estimates. By spatially overlaying our modeled flood areas with land cover GIS layers, we modeled the effect that *A. donax*-caused floodwaters have on crops and developed land within the lower SCR. A considerable amount of farming is located within the bounds of the 100-year FEMA floodplain of the SCR, which leaves agriculture particularly vulnerable to flood damages. We found that for the simulated 5-year flood, *A. donax*-caused floodwaters occupied an additional 35.5 acres of agriculture within the lower SCR floodplain. Our estimation of flood costs due to the presence of *A. donax* predicts that a 5-year flood caused $165,000 in crop damages within the lower SCR (Table 21). For the 10-year flood event, the marginal modeled floodwaters caused by *A. donax* flooded an added 182.6 acres of crops, and caused an additional $1,100,000 in crop losses, mainly from damages to winter row crops and strawberries during the flood season (Table 22).

Table 22. Summary of marginal crop damage GIS estimations by crop type due to *A. donax*. Row crop values were estimated as the average value of the winter row crops broccoli, cabbage, celery, cilantro, and bok choy. Some crop types, namely orchard crops, were assumed resilient to flooding and no damages were calculated. Other crops, such as strawberries, were assumed damaged for a fraction of the growing season due to fast growth rates. Crop values sourced from Ventura County Crop and Livestock Report 2014 (Ventura County Office of the Agricultural Commissioner, 2014).

Crop Type	Additional Acres Flooded 5-yr Flood	Additional Acres Flooded 10-yr Flood	Likely Flood Damage per Acre ($)	Cost Due to *A. donax* ($) 5-yr Flood	Cost Due to *A. donax* ($) 10-yr Flood
carrot	0.1	0.1	5,758	406	721
cut flowers	0	6	34,537	9	208,469
herbs	1.5	2.5	9,416	14,034	23,872
row crops	10.7	44.3	9,416	100,550	417,207
strawberry	4.7	41.5	10,799	50,265	448,343
			Total Cost	**$165,264**	**$1,098,612**

6.5 Cost-benefit analysis

The cost-benefit analysis calculated the net present value (NPV) and benefit-cost ratio at each discount rate for each management strategy (Table 23). The NPV represents the difference in present value of the benefits and costs of *A. donax* removal, while the BCR is the ratio of the two.

Table 23. Mean benefit-cost ratios and net present values (in millions $) for Monte Carlo simulations using the Present Approach, Contingency Plan 1, and Contingency Plan 2 (n=1000 for each). Results are shown for three discount rates (3, 5, and 7%).

	Estimate	3% BCR	3% NPV*	5% BCR	5% NPV*	7% BCR	7% NPV*
Present Approach	*High*	0.38	-3.62	0.36	-3.14	0.34	-2.76
	Most Likely	0.19	-5.23	0.18	-4.48	0.17	-3.89
	Low	0.01	-18.14	0.01	-15.36	0.01	-13.21
Contingency Plan 1	*High*	0.62	-2.01	0.58	-1.81	0.55	-1.64
	Most Likely	0.29	-3.56	0.27	-3.11	0.26	-2.74
	Low	0.02	-13.09	0.02	-11.19	0.02	-9.73
Contingency Plan 2	*High*	0.81	-1.33	0.76	-1.28	0.72	-1.23
	Most Likely	0.38	-3.31	0.35	-2.92	0.33	-2.61
	Low	0.03	-13.06	0.03	-11.20	0.03	-9.76

*All NPVs shown are in millions of dollars

For the present approach management strategy, no iteration yielded a positive NPV (Figure 25a). For both contingency strategies, there is a modest number of iterations with the high estimate that achieve an NPV greater than zero, although the most likely estimates have few occurrences of positive NPVs (Figure 25b,c). The results also indicate that the discount rate has little influence on the most likely and high estimates for all three management strategies; however, the higher discount rate results in somewhat less negative NPVs for the low estimate (Figure 25a-c).

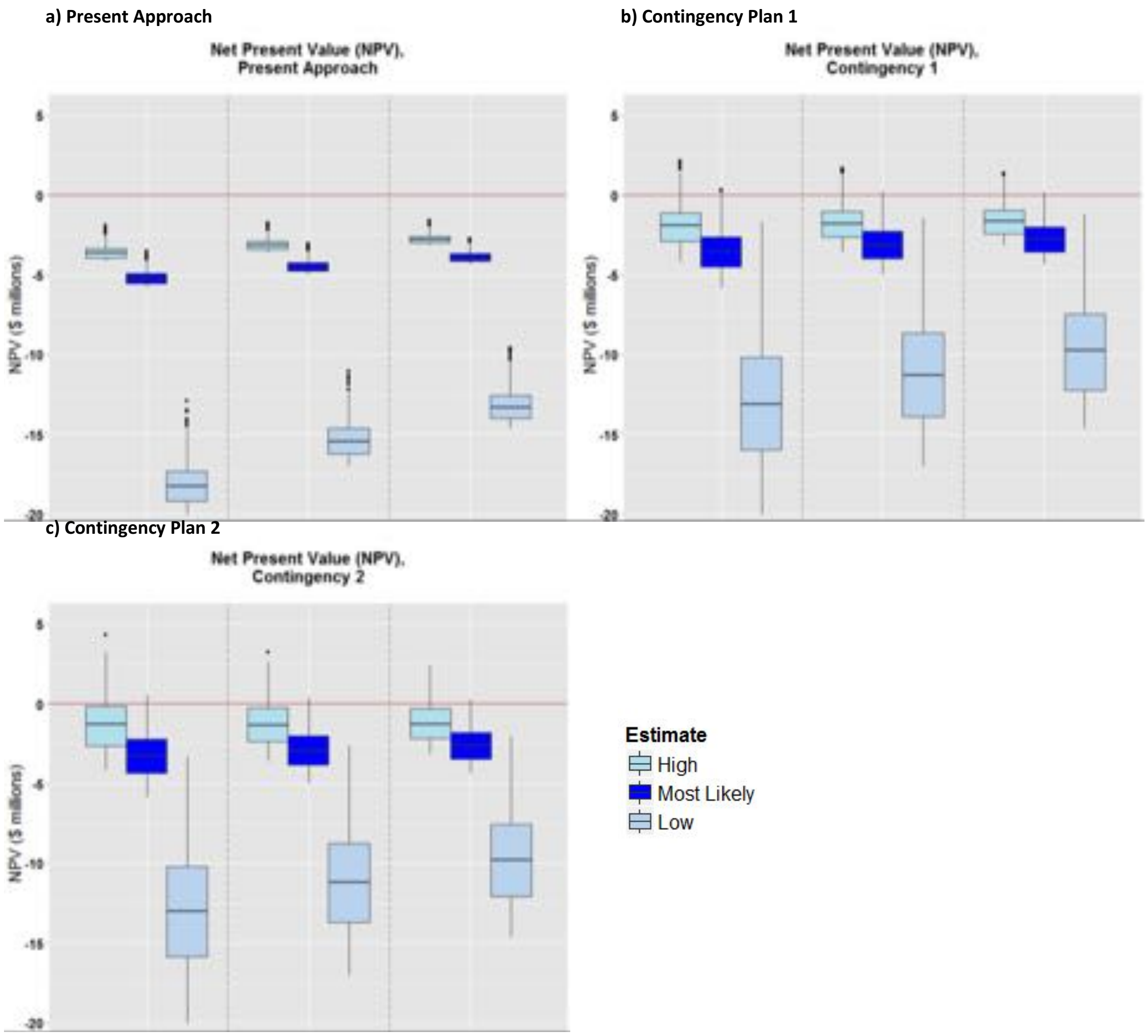


Figure 25a-c. Net present value ($ million) for a) Present Approach, b) Contingency Plan 1, and c) Contingency Plan 2. Results are shown for each discount rate and each estimate. The break-even point ($0) is indicated with a red line.

Comparing across strategies with a uniform discount rate (5%), both contingency plans are more cost-efficient relative to the present approach (Figure 26). The greatest BCR is achieved when more acreage is treated post-flood (Contingency Plan 2, with a mean BCR = 0.35) and the lowest is achieved under the present approach (mean BCR = 0.18).

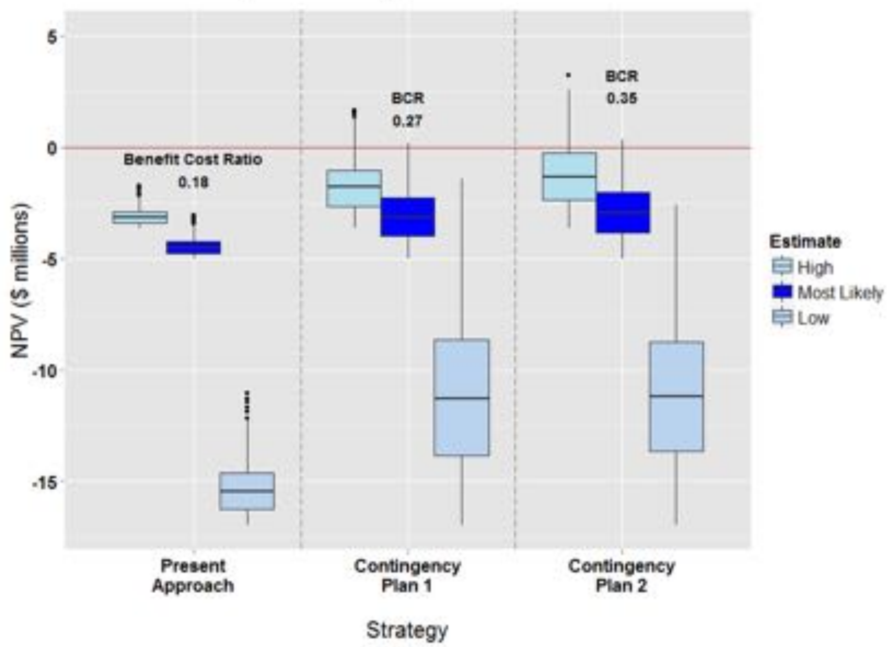


Figure 26. Net present value for all estimates at a 5% discount rate for each management strategy. The mean benefit-cost ratio for the most likely estimate is provided for each strategy.

6.6 Priority areas for ecological value

The optimization model used to identify parcels for priority restoration based on ecological value and the estimated cost of *A. donax* removal was run for each of the three defined *A. donax* removal targets: 10, 15, and 20%. The results of each Marxan trial indicate which parcels would be best suited for removal to achieve the greatest ecological gain and at least cost (Figure 27a-d, Appendix D). For the 10% removal target, 69 parcels were selected to achieve the goal, requiring 413 acres to be treated at an estimated cost of $4.2 million. Achieving a 15% removal target would require approximately $8.1 million and 20%, $13.1 million (Table 24).

Table 24. Results for each *A. donax* removal target (10, 15, and 20% removal of current acreage). The total number of planning units, acres treated and most likely estimated cost are indicated for each.

Removal Target	Planning Units Selected	Acres Treated	Cost ($)
10%	69	413	4,186,000
15%	94	71	8,051,000
20%	105	812	13,102,000

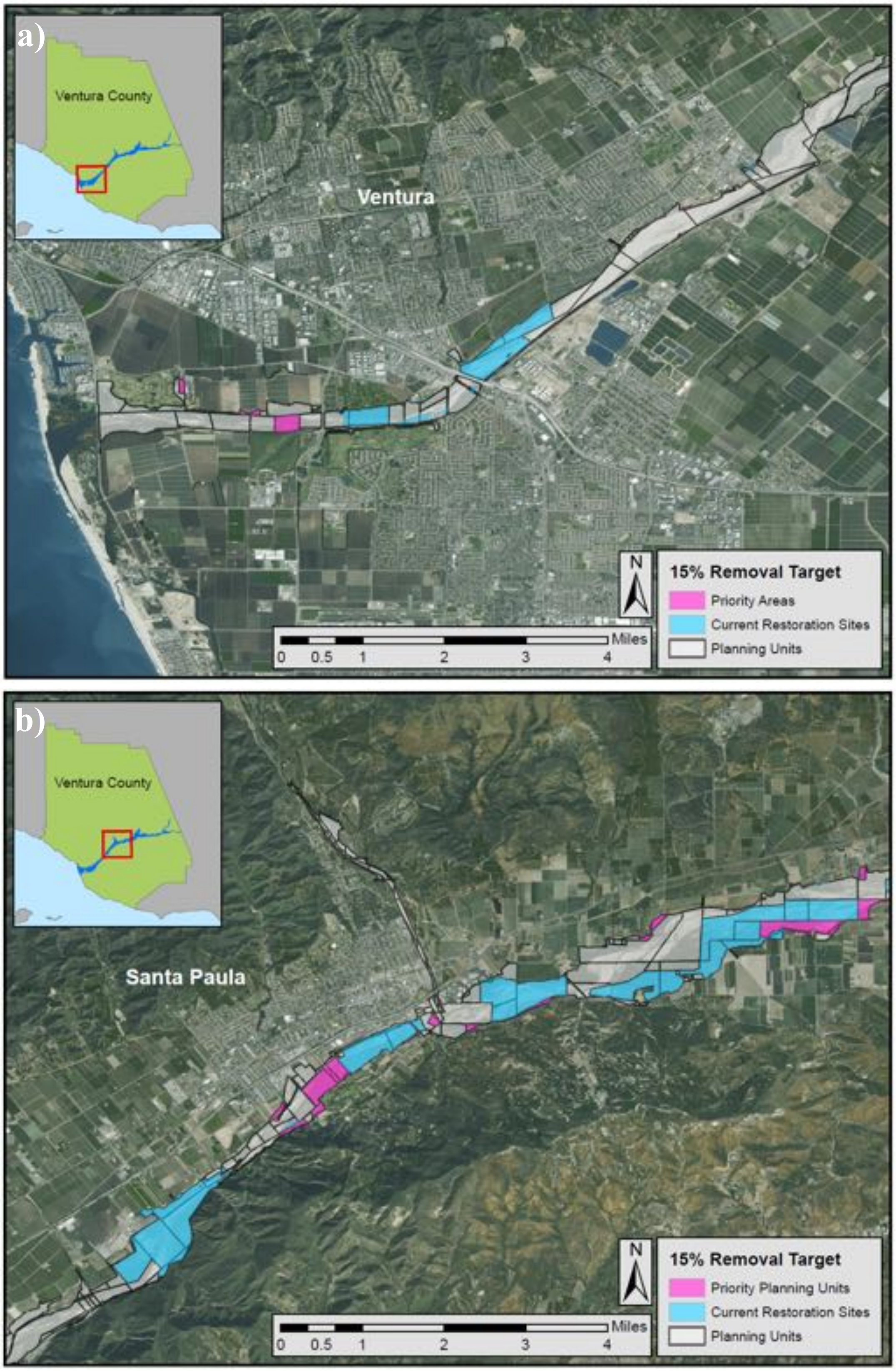
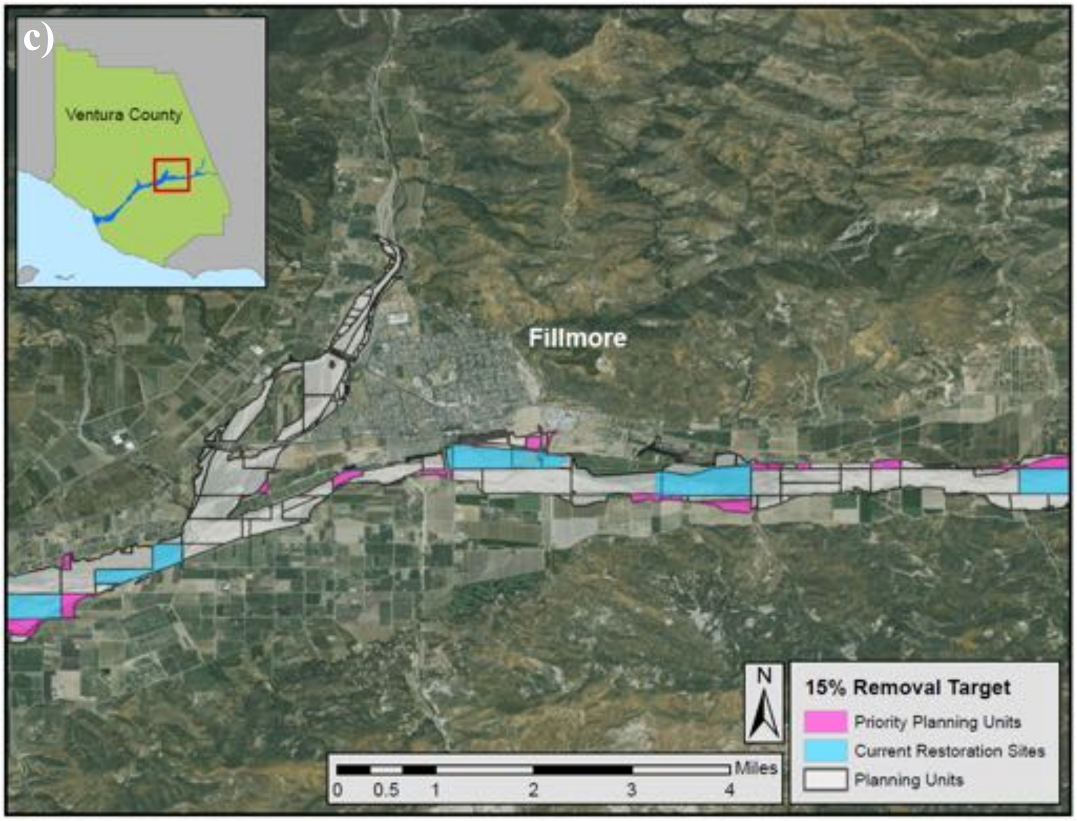


Figure 27a-d. Priority areas (pink) selected to achieve a 15% *A.* donax removal target in the lower Santa Clara River.



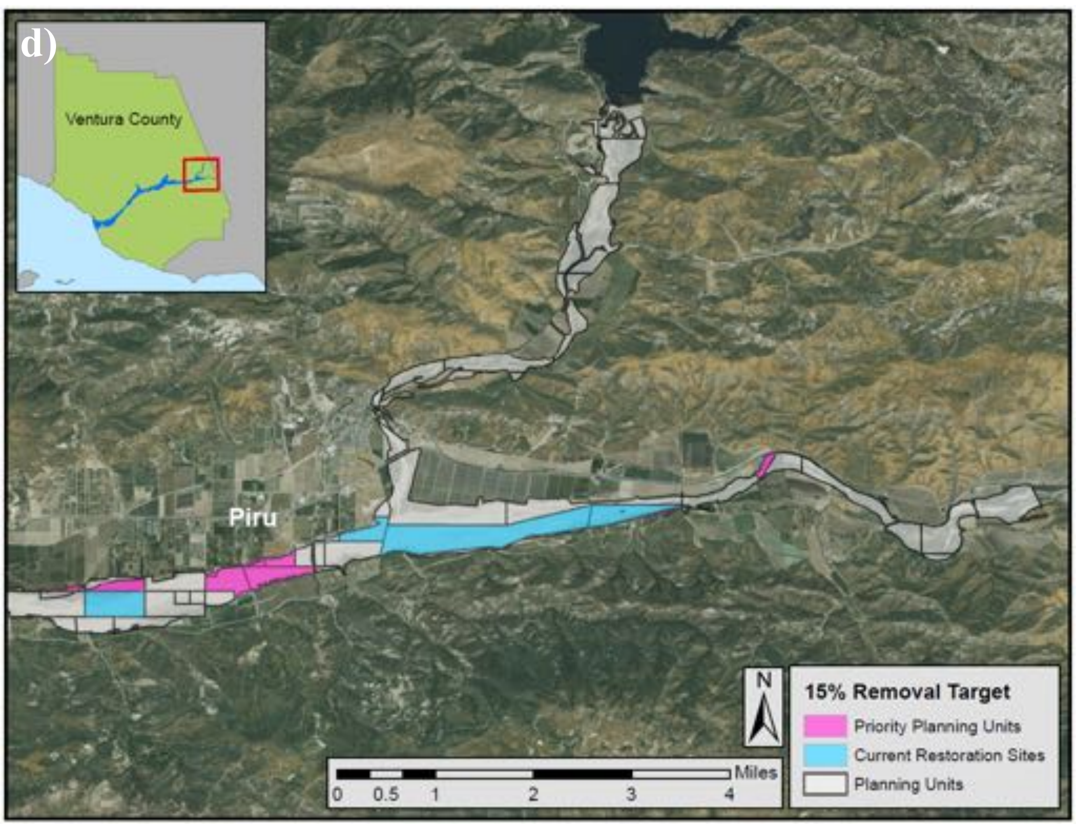


Figure 27a-d. Priority areas (pink) selected to achieve a 15% *A.* donax removal target in the lower Santa Clara River.

7. Discussion

Putting benefits in context
Based on our model results, the greatest monetary benefit from the replacement of *A. donax* with native vegetation is from reduced water consumption. This action results in a benefit approximately 15 times greater than the individual benefits received from reduced risk of fire events and reduced flood extents. Thus, an analysis of the benefits from water savings of restoration deserves a closer examination.

Water benefits
Although there is some degree of variance and uncertainty within the water model, it strives to account for most of this variance by incorporating ranges in water use for the different vegetation types within the SCR used in our model. This variance in water use results from the dependence of evapotranspiration on a variety of ambient environmental conditions. At any given point in time, an area's current and past precipitation, temperature, wind, and soil moisture impact the evapotranspiration of the area's vegetation (Allen, Bastiaanssen, Tasumi, & Morse, 1998). Environmental conditions such as long periods of drought or periods of increased precipitation, such as El Niño events, change the current water availability to vegetation within the watershed while different life stages of vegetation transpire at different rates (Teuling, Seneviratne, Williams, & Troch, 2006).

Monetary values for water use are difficult to effectively assign to the vegetation's water consumption. We chose to use both municipal and agricultural water prices from one of the primary water distributors within the SCR, United Water District, to assign a value to the amount of water conserved. United delivers both surface water from the SCR and groundwater to its customers. United operates artificial recharge basins into which it diverts SCR surface water for recharging groundwater (Dorrington & Council, 2012). However, it is not clear what proportion of any saved water would directly translate into greater water availability for human use, and it is likely that the vegetation within the river will receive the majority of the benefit from increased water levels following restoration. Our analysis applied the price that humans pay for water in order to assign a monetary value to the increased water present for vegetative use. A more sophisticated, future analysis could first assess the portion of saved water that will be used by people as opposed to plants, and tie pricing into a combined study that includes the monetary value of enhanced habitat as well as that of increased water supply.

An additional limitation of the current model is that the benefits predicted by the water model are not impacted by shifts in the presence of vegetation when stochastic events such as floods occur. Therefore, water use values are not affected in our model in years when large floods or fires occur. In the event of a fire or flood, water use for any particular year could change drastically. When thinking of effectively managing the SCR, a more comprehensive watershed restoration management plan should account for these unique events and their impacts on the vegetation within the river.

Flood and fire benefits
While flood and fire events have obvious disastrous outcomes for humans within the watershed, these types of events also impact the vegetation of the SCR and do so in ways that are not so apparent. For example, these events can be viewed as a benefit in that they remove *A. donax* biomass. These benefits can increase substantially with proper management in place.

Floods are a mixed blessing for *A. donax* management. Large flood events scour *A. donax* from the active river channel, which can achieve a large amount of removal without the reducing the need for the typical removal costs, such as removal crews and heavy equipment. Unfortunately, large-scale flood events can also be affected by the presence *A. donax* in the river channel and floodplain. Scoured *A. donax* debris can build up against bridges and other infrastructure within the river and cause structural damage. During flood events, county maintenance crews are forced to patrol the lower watershed to ensure infrastructure is not damaged from *A. donax* debris. Debris transported to the ocean can be deposited on beaches and require extensive clean-up to be removed. Perhaps one of the most bittersweet aspects of scouring floods is that they spread *A. donax* rhizomes, which cause areas of the watershed and the coast to be colonized or repopulated by the plant.

Similarly, fires can eliminate the above-ground biomass of *A. donax*, which substantially reduces overall removal and restoration costs. Taking advantage of these events can benefit restoration efforts over longer timeframes if there are proper permits and management action plans in place. Given some of the challenges of modeling fire severity and extent (e.g., proximity to an ignition source like homeless encampments and bridges where cigarettes are often discarded), our cost-benefit analysis did not include scenarios related to treating *A. donax* stands post-fire. However, we hypothesize that treatment immediately post-fire will be cost-effective and suggest further research in this area.

Benefits of A. donax removal to landowners
Private land ownership of the SCR channel and floodplain has been a hurdle for scaling up *A. donax* removal programs. Past and current removal projects in the watershed have often relied on private landowners to willingly cooperate with restoration efforts. A number of landowners have been extremely involved and supportive of *A. donax* removal, such as a local rancher who sold over 200 acres of property expressly for *A. donax* removal and native habitat restoration. Others have had a more lukewarm enthusiasm towards *A. donax* removal projects, perhaps due to a perception the *A. donax* does not pose a threat to their property or livelihoods. These differences in landowner cooperation have created an *A. donax* restoration strategy of opportunistic projects limited to sites with cooperative landowners.

We feel that highlighting the direct benefits of *A. donax* removal to landowners will increase interest and broaden the involvement in removal efforts within the watershed. Our analysis demonstrates that the presence of *A. donax* can locally increase wildfire risk and flood damages, and cause greater water consumption. We have shown that these *A. donax*-caused impacts can translate to costly and disruptive damages for private landowners in our study area. By emphasizing these potential risks and uncertainties involved with the invasive plant, we may be successful at expanding the number of landowners and community members interested in *A. donax* removal projects. This could allow for the freedom to plan restoration on a watershed-wide scale, allowing for a more flexible and spatially focused *A. donax* removal approach that could optimize the number of co-benefits (such as areas that could provide habitat value to Endangered species while at the same time reducing wildfire risk) received from *A. donax* removal.

Comparing removal strategies

Contingency planning

Results of the cost-benefit analyses indicate that contingency planning can reduce the disparity between the costs of an *A. donax* removal program and the quantifiable benefits received thereafter. While our cost-benefit analysis was limited by our ability to predict the degree to which managers could allocate resources to contingency treatments, the results of the two contingency strategies analyzed are quite similar. This indicates that even a small effort post-flood (i.e., 25 acres of treatment) can achieve better results. As such, we suggest restoration managers operating within the lower SCR develop contingency plans in preparation for periodic flood (and possibly fire) events. By responding to areas that have been scoured of *A. donax* biomass, the vast majority of removal costs are avoided. This could allow for increases in acres treated or make funds available for other restoration projects within the lower watershed. We recommend that stakeholders strategize collaboratively to further enhance the effectiveness of contingency plans.

An effective contingency plan must address the following: permitting, funding, and site selection. There are several permits that may be required dependent on site conditions, all of which take time to process. Restoration managers should be proactive in their efforts to secure permits that can be amended to cover additional acres outside of their current project boundaries or to establish a blanket permit that covers the entire lower SCR for *A. donax* removal (for example, the upper SCR already has such a blanket permit, held by the Natural Resources Defense Council).

It is recommended that a contingency fund be established to address post-flood treatment costs along with a mitigation banking system. By having a fund, managers will have resources in place to promptly begin treatment, avoiding significant regrowth. A mitigation banking system will likewise allow entities needing mitigation credits to allocate funding as needed for restoration projects with the agreement that they will receive credit for a later construction or development project.

Site prioritization

Additionally, stakeholders should discuss areas to prioritize within the watershed for regular removal and for post-flood treatments. Doing so will allow restoration managers to maximize the benefits of their efforts, while simultaneously minimizing the costs incurred. Landowner engagement is necessary in any restoration project; developing partnerships and working agreements prior to a scouring event will allow for a more efficient and timely response. The results from the Marxan analysis can assist in guiding future restoration efforts in the lower SCR so as to more efficiently allocate resources. In addition, it provides a clear indication of which parcels to prioritize and, since the model retains parcel identification throughout the analysis, it enables stakeholders to identify property owners of prioritized planning units so that they can strategically focus their outreach to this group. It is assumed that not all landowners will be willing to participate in *A. donax* removal; however, restoration managers can expand outreach efforts to another target category (from 10% to 15% or 20% *A. donax* removal) should they exhaust all other options. The results also identify the approximate funds that would be necessary to achieve the selected target, enhancing the understanding of the planning necessary for grant applications and private fundraising.

Similar to the Marxan model developed in this study, an optimization model can be developed using stakeholder preferences as additional benefits. Additionally, the benefits in fire and flood risk reduction can be integrated, allowing for a more comprehensive and collaborative effort for optimizing the removal of *A. donax* that accounts for the value of these benefits. This analysis would have the potential to influence the design of a comprehensive *A. donax* removal program within the lower SCR and will help to guide restoration efforts while strengthening the ability of multiple restoration agencies and organizations to collaborate.

Other benefits

Our analysis focused on fire risk reduction benefits, water consumption saving benefits, and flood damage reduction benefits that can be achieved from *A. donax* removal. There are additional benefits that could be added to future analyses to provide a more comprehensive picture of the impacts *A. donax* has on local economies and ecology.

Benefits to Threatened and Endangered species

Quantifying the impact of *A. donax* removal on biodiversity and Endangered species habitat should be a priority in future analyses. Our literature review found that *A. donax* is poor habitat for terrestrial animals and birds, and alters habitat characteristics for aquatic species. Proxies for biotic health (aquatic macroinvertebrates, terrestrial arthropods, and bat communities) have been shown to be weaker within *A. donax* stands relative to native vegetation.

In addition to the direct impact of being poor habitat, *A. donax* has the secondary impact of altering the natural disturbance regimes within the lower SCR, which can in turn affect biotic populations and their habitats. Our research has demonstrated that current concentrations of *A. donax* within our study area increase fire risk compared to native vegetation. Today, due to the comparatively more-flammable nature of *A. donax*, fires have been shown to bridge across these riparian zones and continue burning. In addition to alterations in the fire regime, we have found that concentrations of *A. donax* in the lower SCR can change the elevation floodwaters. It can also influence the behavior of floods in other ways, such as locally redirecting floodwaters. Flooding and fire are natural processes within our study area, and a degree of disturbance can be healthy and necessary for proper ecological function. However, these exacerbating flooding and fire impacts can cause increased damage and disturbance to ecologically valuable riparian areas and floodplains along the lower SCR, causing direct harm to biotic life and destroying critical habitat for Threatened and Endangered species.

Coupled with this ecological impact is the economic cost *A. donax* causes due to the need for more intensive Endangered and Threatened species management in the watershed. Agencies such as the California Department of Fish and Wildlife and the US Fish and Wildlife Service are charged with the conservation of specific species and their critical habitat, and have the mandate to restore populations of Threatened and Endangered species regardless of cost considerations. These agencies spend millions of dollars restoring and managing Endangered species populations and habitats through the SCR.

There are a variety of approaches researchers can take to calculating the economic benefit of *A. donax* removal on Threatened and Endangered species and habitat quality in future work. One approach could be to determine what percentage of those government agency dollars (for Threatened and Endangered species) go specifically to *A. donax* removal. From there, the study could turn to determining a ratio of acres of *A. donax* removed and restored to a resulting gain for Threatened and Endangered species. Another approach is a hedonic study which would focus on identifying a river system with similar characteristics (in terms of natural vegetation, agricultural land, residential developments), but in which invasive species are under control and there are healthy populations of iconic species. A comparative study would be undertaken to see how home and land values differ between the SCR and the restored river system. There are major limitations and challenges to the two approaches we have suggested for looking at economic benefits to Threatened and Endangered species and habitat quality. However, these challenges can likely be addressed through drawing on the work of others that have focused on quantifying ecosystem services.

Benefits related to widespread fire events

Economic benefits to *A. donax* control could be further explored in future studies through inclusion of infrequent, widespread fire events. Fires are highly variable through time and space, and can be attributed to many events that are impossible to predict with accuracy. Weather conditions such as wind, temperature, humidity level, and precipitation fluctuate daily and all have varying effects on fire risk. El Niño events or multi-year patterns, such as droughts, also affect the probability of fire occurrence.

Additionally, as to not overestimate the fire risk in the SCR, conservative estimates for all assumptions were made in our models, thus the benefit that could be generated from reduced risk of these events is likely underestimated. For example, our fire models considered only costs associated with fights fires. We did not consider fires so widespread that costs of lost property would far exceed fire-fighting costs nor so widespread that they would burn past of area of study and into adjacent landscapes. While it is not probable that a large fire, facilitated by *A. donax* would burn major structures, it is not outside the realm of possibility and would substantially alter benefit calculations.

The Simi and Verdale fires that occurred in the floodplain in 2003 are an example of the type of severe fire event was not accounted for in our fire model. Both fires provide evidence of *A. donax* facilitating fire through the SCR. Prior to this incident there had not been a fire that burned over one acre of land in the 500-year floodplain since 1918 (Coffman et al., 2010). These fires reached the SCR from the north and were whisked across the riverbed through dense stands of *A. donax*, where it was then able to spread through over an additional 100,000 acres including more *A. donax* along the western portion of the riverbed (Coffman et al., 2010). This fire cost over $10 million, destroyed 37 residences and 278 outbuildings, damaged an additional 11 residences, and cause injuries to 21 persons ("CDF Internet: INCIDENT INFORMATION," 2003). Although it was not possible to model such events in this analysis, the calculated benefit from removing *A. donax* would substantially increase if these high-risk events could be accounted for quantitatively.

Possible benefits of A. donax removal for multi-decadal flood events
Additional research is required to investigate the impact of *A. donax* on sedimentation, channel form and other aspects of physical river process and then quantify the economic implications. *A. donax* can influence the nature of floodwaters in our study area; dense *A. donax* can add channel and floodplain roughness and locally raise floodwater elevations. Complicating this relationship are the other influences *A. donax* has on the physical processes of the river: *A. donax* has been shown to entrain sediment, alter river planform by constricting flow to a single channel, and redirect floodwaters, among other effects. Our hydraulic modeling effort takes on just one facet of *A. donax*'s influence on flooding dynamics; however, *A. donax* has a host of complex and interrelated influences upon the physical river form, and consequently, the nature of flood events. The presence of *A. donax* in the SCR channel and floodplain creates a potentially increased risk to local infrastructure, human communities, and ecosystems that deserves further study and analysis.

Benefits of removal in the context of potential A . donax dispersal
In future work, an addition to the *A. donax* cost-benefit analysis would be to consider the worst- case scenario of *A. donax* spread in the SCR. Our analysis assumes a baseline scenario of a constant amount of *A. donax* in the study area over 20 years (approximately 949 acres of 100% *A. donax* cover equivalent). All benefits are measured against removing acres of *A. donax* from this 949 acre total; our models did not account for the possibility of *A. donax* spread due to inadequate treatment post-flood, given the challenge of estimating spread. It is established that dispersal of *A. donax* is generally episodic as it is dispersed during flood events (Decruyenaere & Holt, 2005; Else, 1996). However, there is no literature that documents the rate or directionality of spread.

It was also not possible to assume a rate of spread based on our analysis of the 2005 to 2015 data on *A. donax* cover in the study area. Our assessment of change in *A. donax* cover over time was based on our update of Stillwater Science's 2005 cover data, which was initiated at least five months after the winter 2005 floods. By this time, *A. donax* had time to begin reestablishing itself before mapping commenced. We did not expect to see major changes in *A. donax* dispersal (only lateral growth) over the last decade in the absence of a major flood. This lack of significant change is reflected in the *A. donax* mapping results, insofar as the vast majority of the expansion of *A. donax* stands observed from 2005 to 2015 occurred into parcels smaller than a quarter of an acre in size. While dispersal was not observed during our decade of study, it is undoubtedly a risk. Without prompt and likely extensive treatment of redistributed *A. donax* rhizomes after a flood or series of floods, *A. donax* cover may increase in the SCR. If a rate of spread under various flood scenarios could be established for the SCR, the cost of inaction (and greater benefits of action) over time could be incorporated.

Applications to other watersheds

Given that *A. donax* infestation is a problem in many of coastal California watersheds and its control is a major financial investment for various stakeholders, our approach of modeling costs and benefits is highly applicable to other watersheds. It is strategic for County and State Departments of Water Resources, California Department of Fish and Wildlife, non-profits, and additional state, county, and federal agencies to fully understand the economic implications of the *A. donax* control programs they fund. Our approach can aid these entities in answering questions on how control efforts should be strategized in order to maximize benefits in comparison to costs over timescales that make sense to these entities' operations.

Our study's specific focus on fire risk reduction and water saving benefits are most applicable to other watersheds. Drought, loss of instream flows, and overdrawing groundwater are a major concern across the state in the face of the current water crisis. All water managers have an interest in keeping water in stream for both in stream and groundwater replenishment purposes. In our analysis, water savings produced approximately 15 times the dollar benefits of fire or flood-related benefits. As such, we expect that water savings will be an important component of cost-benefit analyses for all California watersheds managing *A. donax*.

Similarly, wildfires are increasing in frequency (above historical fire patterns) in many of California watersheds, driven by several years of drought, a changing climate, and increasingly human altered landscape (Stillwater Sciences, 2011). The increased fire prevalence, coupled with the high flammability index of *A. donax* means that further heightened fire risk from *A. donax* infestation is of concern in many California river systems.

Flood damage reduction benefits may be less applicable to other river systems due to some of the unique attributes of the SCR. It is the perhaps the most dynamic river system in Southern California with relatively few dams and levees, allowing the active channel to reset after flood events unlike some of the more constrained rivers further south (Orr et al., 2009). In addition, unlike many other Southern California rivers, the floodplain is dominated by high-value agricultural land that can be damaged during floods. As such, our method of modeling damage to agricultural fields may not be directly applicable to other systems.

One unique feature of *A. donax* management on the Santa Clara River is that it is not following the top-down control approach that has become a fixture of a number of rivers impacted by *A. donax*. Removal of *A. donax* from the entirety of the watershed is the ultimate goal of restoration efforts in the SCR. While there are a number of watersheds in Southern California that focus removal efforts from the top of the watershed downward, such as the Santa Ana River (Coffmann & Ambrose, 2011; Glasser, 2003), it is impractical and inadvisable to halt removal efforts in the lower portion of the watershed before the upper watershed removal efforts are complete (Stillwater Sciences, 2011). Because of discrepancies in management, policies, and decision-making, *A. donax* removal may not occur at the same rate in the upper portions of the watershed as the lower portions. Prolonging or delaying down valley removal and restoration efforts in the name of top-down removal would further degrade suitable native habitat and allow *A. donax* to invade more extensive reaches of critical habitat. Enhancing extensive areas of habitat though *A. donax* control in the lower watershed increases the connectivity of suitable habitat on which species depend, and buffers against events that would otherwise redistribute *A. donax* throughout extensive portions of the watershed (Stillwater Sciences, 2011).

Therefore, a strategic and opportunistic approach to control that focuses removal efforts on high priority areas and allocate funds to treat areas where natural fire and flood events remove *A. donax* should be considered in overall restoration projects in the SCR. Lessons learned from applying this approach in the SCR, may be applicable to other watersheds. Regardless of where in a watershed *A. donax* removal is initiated, the cost-benefit analysis framework we have provided should be generally applicable to decision-making in other river systems after an initial assessment is made of the most relevant benefits streams for consideration.

8. Conclusion

Our study applied a cost-benefit analysis framework to investigate the costs of *A. donax* removal and associated benefits in terms of reduction in water consumption, fire severity, and flood damage in the Ventura County stretch of the Santa Clara River. Through this analysis, we conclude that reduced water consumption provides the greatest monetary savings of *A. donax* removal in the floodplain, with nearly $1,000 in water savings annually per acre of *A. donax* removed.

While water savings from *A. donax* removal represent approximately 15 times the monetary benefits of fire and flood in our analysis, our models show that *A. donax* removal can also reduce localized flood damage and fire risks within the floodplain. For example, complete *A. donax* removal from the study area reduces the number of acres of land expected to burn each year from 55 acres to less than 40 acres. Similarly, our model results found that by removing *A. donax* from the study area reduced flood damages to high-value agriculture by 183 acres within the 10-year flood extent.

Capitalizing on natural disturbance events (i.e., scouring floods and fires) to remove *A. donax* biomass will be the most cost-effective removal strategy. We determined from historic air photos that *A. donax* is often scoured and flushed to the ocean at flood magnitudes greater than the 10-year recurrence interval. Because of the high expense of current methods of *A. donax* removal, it will likely be most cost-effective to have funds available after a flood to immediately and aggressively treat areas of *A. donax* that have been scoured. This strategic approach could avoid large biomass removal budget lines and result in a higher benefit-cost ratio than simply focusing on biomass removal and treatment year to year without resources in place to treat post-flood. The same logic can likely be applied to fire events, although this is a less probable occurrence than a scouring flood and was not explicitly modeled in our analysis.

With these primary conclusions in mind, we have several recommendations for managers and researchers in the Santa Clara River watershed and beyond:

1. **Apply the *A. donax* cost-benefit modeling framework to other watersheds as a planning tool.** The approach we have developed of modeling *A. donax* removal costs and benefit streams and then feeding them into a cost-benefit analysis framework provides a useful planning tool. It allows managers to compare different management approaches and timelines. While water savings benefits are likely to be essential in most Southern California watersheds, some managers may choose to add and remove model inputs. For instance, some might incorporate an Endangered species habitat benefit model into the framework in place of the flood damage benefit model used in our analysis. There is flexibility to this framework depending on regional and local needs and priorities.

2. **Capitalize on natural disturbance events that remove *A. donax* biomass.** A contingency fund should be created so that resources are available to act immediately

after a flood or fire event to treat those areas where the disturbance has opportunistically removed *A. donax* stands. The immediate treatment will prevent the plant from recolonizing and avoid the high cost of typical *A. donax* biomass removal programs.

3. **Quantify additional benefits of *A. donax* removal, especially benefits to Threatened and Endangered species.** There are many additional benefits of *A. donax* removal to be quantified in the future, both in the SCR and in other regions. These benefits include: improved habitat for Threatened and Endangered species; reduced damage to bridge pilings and infrastructure from the stress of *A. donax* buildup during floods; and reduced beach clean-up costs from *A. donax* debris post-flood. Quantifying these benefits will provide a more complete picture of the impacts of *A. donax* and riparian restoration. These additional benefit streams will also encourage stakeholder collaboration in the watershed. This is especially true for the Endangered species benefit stream since Endangered species work involves collaboration with agencies such as the California Department of Fish and Wildlife and the US Fish and Wildlife Service.

4. **4. Spatially identify areas for A. donax removal where greatest benefits can be received at lowest cost.** Future analyses should spatially identify parcels where the greatest water savings, fire risk reduction, and flood damage reduction (and other benefits) can be achieved at the lowest cost. Given that we do not expect 100% removal of A. donax from the study area in the twenty-year timeframe of our study, it is important to optimize the impact of A. donax removal by targeting specific areas of the watershed. Spatially integrated modeling can highlight areas of critical importance for flood and fire reduction or Endangered species, and guide strategic control efforts.

Implementation of these recommendations will likely increase the economic benefit that a diverse range of stakeholders receive from *A. donax* removal and restoration in the SCR.

9. References

Allen, R. G., Bastiaanssen, W., Tasumi, M., & Morse, A. (1998). Evapotranspiration on the watershed scale using the SEBAL Model and landsat images. *American Society of Agricultural and Biological Engineers*.

Ambrose, R. F., & Rundel, P. W. (2007). Influence of Nutrient Loading on the Invasion of an Alien Plant Species, Giant Reed (Arundo donax), in Southern California Riparian Ecosystems. *University of California Water Resources Center*. Retrieved from http://escholarship.org/uc/item/3qt3s5c4

Ball, I. R., Possingham, H. P., & Watts, M. E. (2009). *Marxan and relatives: Software for spatial conservation prioritization*. Oxford University Press. Retrieved from http://espace.library.uq.edu.au/view/UQ:200259

Bawazir, A. S., Samani, Z., Bleiweiss, M., Skaggs, R., & Schmugge, T. (2009). Using ASTER satellite data to calculate riparian evapotranspiration in the Middle Rio Grande, New Mexico. *International Journal of Remote Sensing*, *30*, 5593–5603. http://doi.org/0.1080/01431160802695683

Beller, E., Downs, P. W., Grossinger, R. M., Orr, B. K., & Salomon, M. N. (2015). From past patterns to future potential: using historical ecology to inform river restoration on an intermittent California river. *Landscape Ecology*, 1–20. http://doi.org/10.1007/s10980-015-0264-7

Beller, E. E., Askevold, R., Salomon, M., Dark, S., Stein, E., Orr, B. K., … Beagle, J. (2011). *Historical Ecology of the lower Santa Clara River, Ventura River, and Oxnard Plain: an analysis of terrestrial, riverine, and coastal habitats*. San Francisco Estuary Institute. Retrieved from http://www.sfei.org/projects/VenturaHE

Bell, G. (1997). Ecology and Management of Arundo donax, and Approaches to Riparian Habitat Restoration in Southern California. In *Plant Invasions: Studies from North America and Europe.* (pp. 103–113). Leiden, The Netherlands: Backhuys.

Boose, A. B., & Holt, J. S. (1999). Environmental effects on asexual reproduction in Arundo donax. *Weed Research*, *39*(2), 117–127. http://doi.org/10.1046/j.1365-3180.1999.00129.x

Brooks, M. L., D'Antonio, C. M., Richardson, D. M., Grace, J. B., Keeley, J. E., DiTomaso, J. M., … Pyke, D. (2004). Effects of Invasive Alien Plants on Fire Regimes. *BioScience*, *54*(7), 677–688. http://doi.org/10.1641/0006-3568(2004)054[0677:EOIAPO]2.0.CO;2

Caceres, C. (2011). Using GIS in Hotspot Analysis and for Forest Fire Risk Zones Mapping in the Yeguare Region, Southeastern Honduras. *Papers in Resource Analysis*, *13*, 14.

California Invasive Plant Council. (2011). *Arundo donax Distribution and Impact Report*. California Invasive Plant Council. Retrieved from http://www.cal-ipc.org/ip/research/arundo/Arundo%20Distribution%20and%20Impact%20Report_Cal-IPC_March%202011.pdf

CDF Internet: INCIDENT INFORMATION. (2003, November 5). [California Department of Foresty]. Retrieved March 9, 2016, from http://www.fire.ca.gov/cdf/incidents/Simi%20Incident_124/incident_info

Chuvieco, E., & Salas, J. (2007). Mapping the Spatial Distribution of Forest Fire Danger using GIS. *International Journal of Geographic Information Systems*, *10*(3), 333–345. http://doi.org/10.1080/02693799608902082

Cleverly, J. R., Dahm, C. N., Thibault, J. R., Gilroy, D. J., & Coonrod, J. E. A. (2002). Seasonal estimates of actual evapo-transpiration from Tamarix ramosissima stands using three-dimensional eddy covariance. *Journal of Arid Environments*, *52*, 181–197. http://doi.org/10.1006/jare.2002.0972

Coffman, G. (2013). Giant Reed (Arundo donax): Streams and Water Resources. In *Encyclopedia of Environmental Management* (pp. 1182–1188). Taylor & Francis. Retrieved from http://www.tandfonline.com/doi/abs/10.1081/E-EEM-120041274

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

Coffman, G. C., Ambrose, R. F., & Rundel, P. W. (2010). Wildfire promotes dominance of invasive giant reed (Arundo donax) in riparian ecosystems. *Biological Invasions*, *12*(8), 2723–2734. http://doi.org/10.1007/s10530-009-9677-z

Coffmann, G., & Ambrose, R. F. (2011). *Santa Clara River Riparian Revegetation and Monitoring Handbook* (Handbook). Santa Clara River Trustee Council. Retrieved from https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=60234

Cortés, E., Goolsby, J. A., Moran, P. J., & Marcos-García, M. A. (2011). The effect of the armored scale, Rhizaspidiotus donacis (Hemiptera: Diaspididae), on shoot growth of the invasive plant Arundo donax (Poaceae: Arundinoideae). *Biocontrol Science and Technology*, *21*(5), 535–545. http://doi.org/10.1080/09583157.2011.559534

Court, D., Glatzer, J., Hard, S., Keith, K., McDonald, J., & Ogushi, F. (2000, June). *Prioritizing Sites along the Santa Clara River for Conservation of Threatened and Endangered Species* (Master's Thesis). University of California, Santa Barbara.

Daar, S. (1983). Using goats for brush control. *The IPM Practitioner*, *4*(4), 4–6.

Dahm, C. N., Cleverly, J. R., Coonrod, J. E. A., Thibault, J. R., McDonnell, D. E., & Gilroy, D. J. (2002). Evapotranspiration at the land/water interface in a semi-arid drainage basin. *Freshwater Biology*, *47*, 831–843. http://doi.org/10.1046/j.1365-2427.2002.00917.x

Decruyenaere, J. G., & Holt, J. S. (2005). Ramet Demography of a Clonal Invader, Arundo donax (Poaceae), in Southern California. *Plant and Soil*, *277*(1-2), 41–52. http://doi.org/10.1007/s11104-005-0264-5

Devitt, D. A., Sala, A., Smith, S. D., Cleverly, J., Shaulis, L. K., & Hammett, R. (1998). Bowen ratio estimates of evapotranspiration stands on the Virgin River in Southern Nevada. *Water Resources Research*, *34*, 2407–2414. http://doi.org/10.1029/98WR01551

DiTomaso, J. M., University of California, & Weed Research and Information Center. (2013). *Weed control in natural areas in the Western United States*. Davis, California: University of California Weed Research and Information Center.

Dorrington, J., & Council, B. (2012). *2012 Groundwater Section Annual Report*. Ventura County Watershed Protection District Water & Environmental Resources Division. Retrieved from http://obgma.com/wp-content/uploads/2015/05/WPD_Grndwtr_Annual_Rpt_2012.pdf

Dubgaard, A., Kallesøe, M. F., Petersen, M. L., & Ladenburg, J. (2002). *Cost-Benefit Analysis of the Skjern River Restoration Project*. Copenhagen: Department of Economics and Natural Resources Royal Veterinary and Agricultural University Copenhagen. Retrieved from http://www.globalrestorationnetwork.org/uploads/files/LiteratureAttachments/447_cost-benefit-analysis-of-the-skjern-river-restoration-project.pdf

Dudley, T. (2000). Arundo donax L. In *Invasive Plants of California's Wildlands* (pp. 53–58).

Dudley, T. L., Lambert, A. M., & Kirk, A. (2008). Herbivores associated with Arundo donax in California. In *Proceedings of the XII International Symposium on Biological Control of Weeds*. La Grand Motte, France.

Dukes, J. S., & Mooney, H. A. (2004). Disruption of ecosystem processes in western North America by invasive species. *Revista Chilena de Historia Natural*, *77*(3), 411–437. http://doi.org/10.4067/S0716-078X2004000300003

Dwire, K., & Kauffman, B. (2003). Fire and riparian ecosystems in landscapes of the western USA. *Forest Ecology and Management*, *178*(1-2), 67–74. http://doi.org/10.1016/S0378-1127(03)00053-7

Else, J. (1996). Post-flood establishment of native woody species and an exotic, Arundo donax, in a southern Californian riparian system. In *Proceedings of the California Exotic Pest Plant Council symposium* (p. 103). San Diego, CA.

EPA. (1990). *Pesticide Fact Handbook*. Noyes. US Environmental Protection Agengy.

EPA. (2010). Ch. 6 Discounting Future Benefits and Costs. In *Guidelines for Preparing Economic Analyses*. National Center for Environmental Economics. US Environmental Protection Agency. Retrieved from https://yosemite.epa.gov/ee/epa/eed.nsf/webpages/Guidelines.html

Erten, E., Kurgun, V., & Musaoglu, N. (2004). Forest fire risk zone mapping from satellite imagery and GIS: a case study. *Congress of the International Society for Photogrammetry and Remote Sensing, Istanbul, Turkey*, 222–230.

Faber, P. A., Keller, E., Sands, A., & Massey, B. M. (1989). *The Ecology of Riparian Habitats of the Southern California Coastal Region: A Community Profile* (No. Biological Report 85(7.27)). Washington, D.C.: U.S. Fish and Wildlife Service.

Gai, C., Weng, W., & Yuan, H. (2011). GIS-Based Forest Fire Risk Assessment and Mapping (pp. 1240–1244). IEEE. http://doi.org/10.1109/CSO.2011.140

Glasser, J. (2003). Arundo Donax Removal in the Santa Ana River Watershed. *Southwest Hydrology*, 6, 33.

Goolsby, J. A., & Moran, P. (2009). Host range of Tetramesa romana Walker (Hymenoptera: Eurytomidae), a potential biological control of giant reed, Arundo donax L. in North America. *Biological Control*, *49*(2), 160–168. http://doi.org/10.1016/j.biocontrol.2009.01.019

Guidi, W., Piccioni, E., & Bonari, E. (2008). Evapotranspiration and crop coefficient of poplar and willow short-rotation coppice used as vegetation filter. *Biosource Technology*, *99*, 4832–4840. http://doi.org/10.1016/j.biortech.2007.09.055

Guthrie, G. (2007). *Impacts of the invasive reed Arundo donax on biodiversity at the community-ecosystem level* (MSc Thesis). University of the Western Cape. Retrieved from http://etd.uwc.ac.za/xmlui/handle/11394/2313

Hobbs, R. J. (2000). *Invasive Species in a Changing World*. Island Press.

Hoshovsky, M. (1986). Element stewardship abstract for Arundo donax. The Nature Conservancy. Retrieved from http://www.ventura.org/wcvc/prop84/docs/Implementation2/Att8_IG2_BenCost_7of7.pdf

Jaiswal, R. K., Mukherjee, S., Raju, K. D., & Saxena, R. (2002). Forest fire risk zone mapping from satellite imagery and GIS. *International Journal of Applied Earth Observation and Geoinformation*, *4*, 1–10. http://doi.org/10.1016/S0303-2434(02)00006-5

Kark, S., Levin, N., Grantham, H. S., & Possingham, H. P. (2009). Between-country collaboration and consideration of costs increase conservation planning efficiency in the Mediterranean Basin. *Proceedings of the National Academy of Sciences*, *106*(36), 15368–15373. http://doi.org/10.1073/pnas.0901001106

Keeley, J. E. (1981). Reproductive cycles and fire regimes. *Proceedings of the Symposium on Fire Regimes and Ecosystem Properties*, 231–277.

Keeley, J. E. (1987). Role of fire in seed germination of woody taxa in California chaparral. *Ecology*, *68*, 434–443.

Keeley, J. E., Fotheringham, C. J., & Morais, M. (1999). Reexamining Fire Suppression Impacts on Brushland Fire Regimes. *Science*, *284*(5421), 1829–1832. http://doi.org/10.1126/science.284.5421.1829

Kelley, E. (2004). *Information synthesis and priorities regarding steelhead trout (Oncorhynchus mykiss) on the Santa Clara River* (p. 88). The Nature Conservancy.

Kennedy/Jenks Consultants. (2014). *Upper Santa Clara River Integrated Regional Management Plan*. Los Angeles County. Retrieved from http://www.ladpw.org/wmd/scr/docs/2014/1.%20USCR%20IRWMP%20Final%20February%202014.pdf

Kirkpatrick, S., Gelatt, C. D., & Vecchi, M. P. (1983). Optimization by Simulated Annealing. *Science*, *220*(4598), 671–680. http://doi.org/10.1126/science.220.4598.671

Kisner, D. (2004, Spring). *The Effect of Giant Reed (Arundo donax) on the Southern California Riparian Bird Community* (Master's Thesis). San Diego State University.

Klein, C. J., Steinback, C., Scholz, A. J., & Possingham, H. P. (2008). Effectiveness of marine reserve networks in representing biodiversity and minimizing impact to fishermen: a comparison of two approaches used in California. *Conservation Letters*, *1*(1), 44–51. http://doi.org/10.1111/j.1755-263X.2008.00005.x

Kus, B. (1998). Use of Restored Habitat by the Endangered Least Bell's Vireo (Vireo bellii pusillus). *Restoration Ecology*, *6*(1), 75–82. http://doi.org/10.1046/j.1526-100x.1998.06110.x

Labinger, Z., & Greaves, J. (2001). *Summary Report of Avian Studies (1994-1999) following the Arco/Four Corners January 17, 1994 oil spill on the Santa Clara River, California*. Prepared for U.S. Fish and Wildlife Service.

Labinger, Z., Greaves, J., & Gevirtz, E. (2011). *Avian Populations on the Santa Clara River in 2005 and 2006: An Evaluation and Monitoring Tool for Habitat Restoration Ventura and Los Angeles County, California*. The Santa Clara River Trustee Council.

Lambert, A. M., D'Antonio, C. M., & Dudley, T. L. (2010). Invasive Species and Fire in California Ecosystems. *Fremontia*, *38*(2/3), 29–36.

Lawson, D. M., Giessow, J. A., & Giessow, J. H. (2005). The Santa Margarita River Arundo donax control project: development of methods and plant community response. In *Planning for Biodversity: Bringing Research and Management Together. Gen. Tech. Rep. PSW-GTR-195.* (pp. 229–244). Albany, CA: Pacific Southwest Research Station. Retrieved from http://www.treesearch.fs.fed.us/pubs/27025

Lindroth, A., & Cienciala, E. (1996). Water use efficiency of short-rotation Salix viminalis at leaf, tree and stand scales. *Tree Physiology*, *16*, 257–262. http://doi.org/10.1093/treephys/16.1-2.257

Loper, C., Cozad, D., Katagi, W., & Beehler, J. (2005). Thinking Native in Southern California: Coastal Benefits of a Watershed Approach to Invasive Exotic Plant Removal (pp. 1036–1050). American Society of Civil Engineers. http://doi.org/10.1061/40761(175)91

MacDonald, G. E. (2012). The Development and Implications of Herbicide Resistance in Aquatic Plant Management. In *Weed Management in a Changing World*. Queensland, Australia.

Mason, C. L., Lippke, B. R., Zobrist, K. W., Bloxton, T. D., Ceder, K. R., Comnick, J. M., … Rogers, H. K. (2005). Investment in Fuel Removals to Avoid Forest Fires Result in Substantial Benefits. *Journal of Forestry*, *104*(1), 27–31.

Mineart, P., Hudson, J., & Sears, B. (2006). Revised Set-Up and Verification of Hydraulic Model of Santa Clara River. Memo from URS Corporation to Stillwater Sciences.

Nackley, L. L., Vogt, K. A., & Kim, S. (2014). Arundo donax water use and photosynthetic responses to drought and elevated CO2. *Agricultural Water Management*, *136*, 13–22. http://doi.org/10.1016/j.agwat.2014.01.004

Nagler, P., Jetton, A., Fleming, J., Didan, K., Glenn, E., Erker, J., … Gloss, S. (2007). Evapotranspiration in a cottonwood (Populus fremontii) restoration plantation estimated by sap flow and remote sensing methods. *Agricultural and Forest Meteorology*, *144*, 95–110.

Neill, B. (2006). Low-Volume Foliar Treatment of Arundo Using Imazapyr. *Cal-IPC News*, *14*(1), 6–7.

Nsanganwimana, F., Marchand, L., Douay, F., & Mench, M. (2014). Arundo donax L., a Candidate for Phytomanaging Water and Soils Contaminated by Trace Elements and Producing Plant-Based Feedstock. A Review. *International Journal of Phytoremediation*, *16*(10), 982–1017. http://doi.org/10.1080/15226514.2013.810580

OECD. (2006). *Cost-Benefit Analysis and the Environment*. Paris: Organisation for Economic Co-operation and Development. Retrieved from http://www.oecd-ilibrary.org/content/book/9789264010055-en

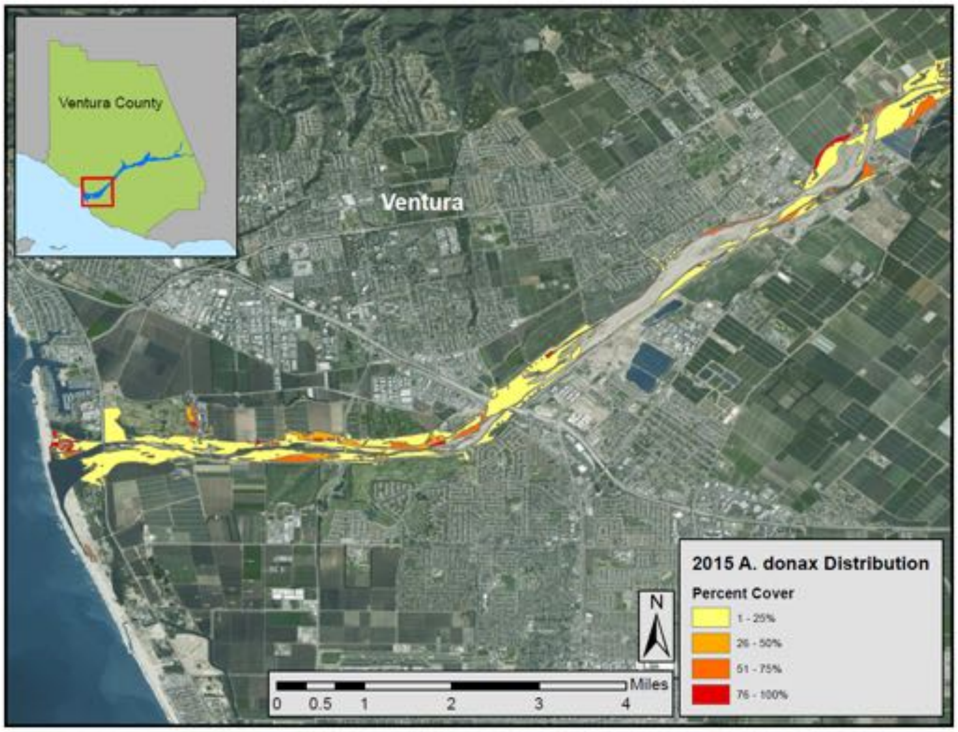
OMB. (2000). *Guidelines to Standardize Measures of Costs and Benefits and the Format of Accounting Statements* (No. M-00-08). US Office of Management and Budget.
Orme, A. R., & O'Hirok, L. (2005). *Rincon Point to Santa Monica*. Living with the Changing California Coast. Los Angeles, CA: University of California Press.
Orr, B., Diggory, Z., Gretchen, C., Sears, W., Dudley, T., & Merrill, A. (2009). Riparian Vegetation Classification and Mapping: Important Tools for Large-Scale River Corridor Restoration in a Semi-Arid Landscape. In *Proceedings of the CNPS Conservation Conference*.
Pittenger, D. R., Shaw, D. A., Hodel, D. R., & Holt, D. B. (2001). Responses of landscape groundcovers to minimum irrigation. *Journal of Environmental Horticulture*, *19*, 78–84.
Puértolas, L., Damásio, J., Barata, C., Soares, A. M. V. M., & Prat, N. (2010). Evaluation of side-effects of glyphosate mediated control of giant reed (Arundo donax) on the structure and function of a nearby Mediterranean river ecosystem. *Environmental Research*, *110*(6), 556–564. http://doi.org/10.1016/j.envres.2010.05.004
Pumphrey, D., & Bacon, D. (2015). *Fire Protection Plan* (Final Report No. GPA 3800-12-001) (pp. 1–130). County of San Diego: Firewise 2000. Retrieved from http://www.sandiegocounty.gov/content/dam/sdc/pds/regulatory/docs/LILAC_HILLS_RANCH/dfeir/DFEIR%20-%20Appendix%20J%20-%20Fire%20Protection%20Plan.pdf
Ramsey, F. P. (1928). A Mathematical Theory of Saving. *The Economic Journal*, *38*(152), 543–559. http://doi.org/10.2307/2224098
Roberts, S., Vertessy, R., & Grayson, R. (2001). Transpiration from Eucalyptus sieberi (L. Johnson) forests of different age. *Forest Ecology and Management*, *143*, 153–161. http://doi.org/10.1016/S0168-1923(00)00186-6
Sawyer, J. O., Keeler-Wolf, T., & Evens, J. (1995). *A manual of California vegetation*. California Native Plant Society Press.
Schaeffer, S. M., Williams, D. G., & Goodrich, D. C. (2000). Transpiration of cottonwood/willow forest estimated from sap flux. *Agricultural and Forest Meteorology*, *105*, 257–270. http://doi.org/10.1016/S0168-1923(00)00186-6
Scott, J., & Burgan, R. (2005). *Standard Fire Behavior Fuel Models: A Comprehansive Set for Use with Rothermel's Surface Fire Spread Model* (General Technical Report No. RMRS-GTR-153) (pp. 1–80). Rocky Mountain Research Station: Forest Service. Retrieved from http://www.fs.fed.us/rm/pubs/rmrs_gtr153.pdf
Sharma, M. L. (1976). Soil water regimes and water extraction patterns under two semi-arid shrub (Atriplex spp.) communities. *Australian Journal of Ecology*, *1*, 249–258. http://doi.org/10.1111/j.1442-9993.1976.tb01114.x
Sharma, M. L. (1984). Evapotranspiration from a Eucalyptus community. *Agricultural Water Management*, *8*, 41–56.
Spencer, D. F., Colby, L., & Norris, G. R. (2013). An evaluation of flooding risks associated with giant reed (Arundo donax). *Journal of Freshwater Ecology*, *28*(3), 397–409. http://doi.org/10.1080/02705060.2013.769467
Stidham, M. A. (1991). Herbicides That Inhibit Acetohydroxyacid Synthase. *Weed Science*, *39*(3), 428–434.
Stillwater Sciences. (2007c). *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.
Stillwater Sciences. (2007a). *Assessment of Geomorphic Processes for the Santa Clara River Watershed, Ventura and Los Angeles counties, California*. Prepared for the California State Coastal Conservancy.
Stillwater Sciences. (2007b). *Focal Species Analysis and Habitat Characterization for the Lower Santa Clara River and Major Tributaries, Ventura County, California. Santa Clara River*

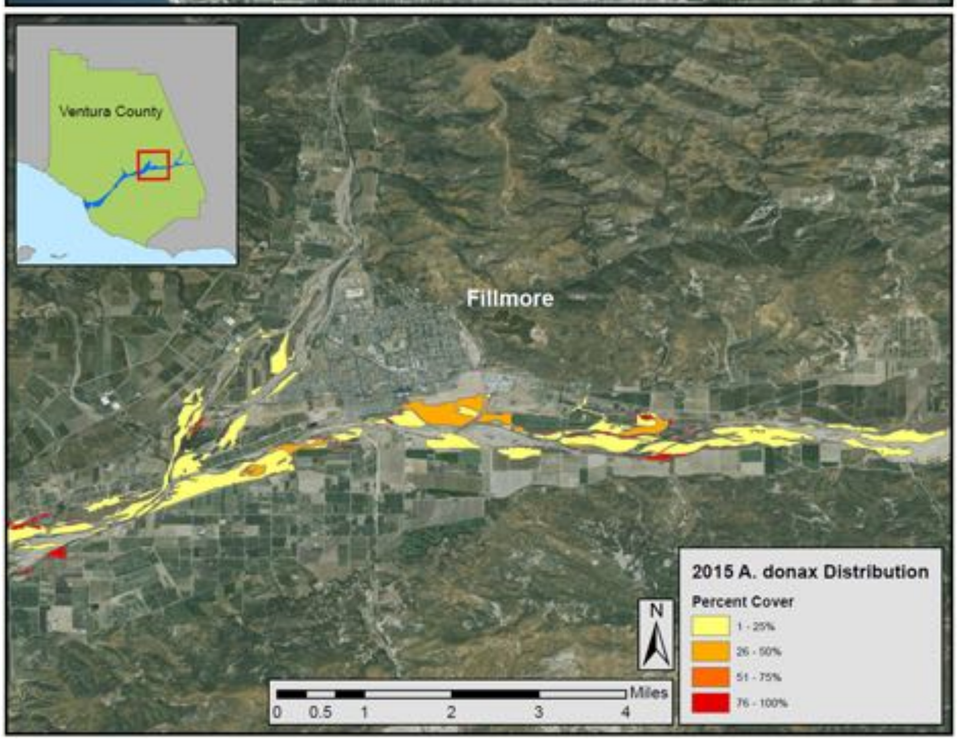
Parkway Floodplain Restoration Feasibility Study. Prepared for The California Coastal Conservancy.
Stillwater Sciences. (2011). *Strategic Plan for Arundo Treatment and Post-treatment Revegetation*. Santa Clara River Parkway.
Stillwater Sciences, & URS Corporation. (2007). *Santa Clara River Parkway Floodplain Restoration Feasibility Study: Riparian Vegetation Mapping and Preliminary Classification for the Lower Santa Clara River, Ventura County, California. Volume I.*
Stoecker, M., & Kelley, E. (2005). *Santa Clara River Steelhead Trout: Assessment and Recovery Opportunities* (p. 294). Prepared for the Nature Conservancy and the Santa Clara River Trustee Council.
ten Brinke, J. (2011, March). *Effects of the Invasive Reed Arundo donax on Rivers in Southern California* (Master's Thesis). UC Santa Barbara.
Teuling, A. J., Seneviratne, S. I., Williams, C., & Troch, P. A. (2006). Observed timescales of evapotranspiration response to soil moisture. *Geophysical Research Letters*, *33*, L23403. http://doi.org/10.1029/2006GL028178
Triana, F., Di Nasso, N. N., Ragaglini, G., Roncucci, N., & Bonari, E. (2015). Evapotranspiration, crop coefficient and water use efficiency of giant reed (Arundo donax L.) and miscanthus (Miscanthus x giganteus Greef et Deu.) in a Mediterranean environment. *GCB Bioenergy*, *7*, 811–819. http://doi.org/10.1111/gcbb.12172
Tuttolomondo, T., Licata, M., Leto, C., Leone, R., & Bella, S. L. (2015). Effect of plant species on water balance in a pilot-scale horizontal subsurface flow constructed wetland planted with Arundo donax L. and Cyperus alternifolius L. – Two-year tests in a Mediterranean environment in the West of Sicily (Italy). *Ecological Engineering*, *74*, 79–92. http://doi.org/10.1016/j.ecoleng.2014.10.020
United States Army Corps of Engineers. (2012). Santa Clara River Watershed Feasibility Study: Without Project Conditions Overflow Analysis Report. Prepared by CDM Smith.
United Water Conservation District. "Adopted Annual Budget Fiscal Year 2015/2016," June 3, 2015.
United Water Conservation District Groundwater Resources Department. (2012). Groundwater and Surface Water Conditions Report 2012.
USDA. (2010). *Field Release of the Arundo Scale, Rhizaspidiotus donacis (Hemiptera: Diaspididae), an Insect for Biological Control of Arundo donax (Poaceae) in the Continental United States* (Environmental Assessment). United States Department of Agriculture. Retrieved from https://www.aphis.usda.gov/plant_health/ea/downloads/RhizaspidiotusdonacisEA-Fonsi.pdf
USDA. (2014). *Field Guide for Managing Giant Reed in the Southwest*. United States Department of Agriculture. Retrieved from http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5410114.pdf
US Department of Agriculture (USDA). (1984). Pesticide background statements. In *Agriculture Handbook No. 633 Vol.1. Herbicides. Part 2* (pp. G1–G72).
VCFPD Fire Origins and Perimeters. (2015). Ventura County Fire Department.
Ventura County Office of the Agricultural Commissioner. (2014). Ventura County Crop & Livestock Report 2014: Resilience During Drought. Retrieved from http://vcportal.ventura.org/AgComm/docs/crop-reports/Ag%20Crop%20Report%202014%20v10_11%2002%2015.pdf
Ventura County Resource Conservation District. (2006). Final Report for the Arundo and Tamarisk Removal Plan in the Upper Santa Clara River Watershed. Retrieved from http://www.waterboards.ca.gov/losangeles/water_issues/programs/grants_loans/fundings/arundotamarisk%20%20removal%20project.pdf
Ventura County Watershed Protection District. (2006). Santa Clara River 2006 Hydrology Update: Phase I From Ocean to County Line. Retrieved from http://portal.countyofventura.org/portal/page/portal/PUBLIC_WORKS/Watershed_Protection

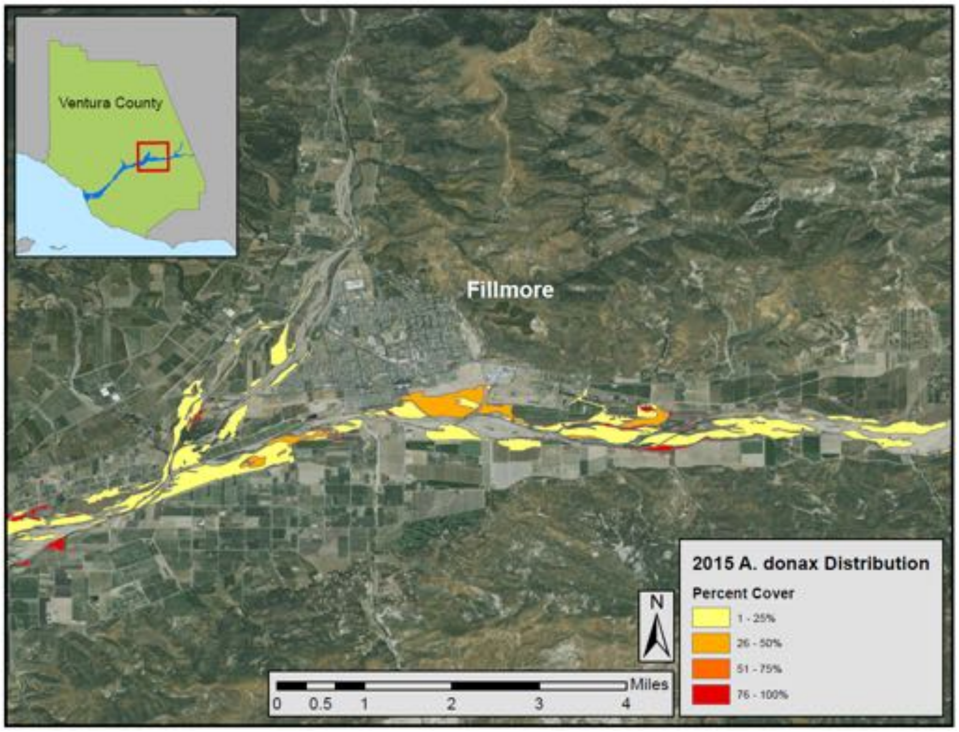
_District/Programs_and_Projects/Santa%20Clara%20River%20Hydrology%20Report%20-%20Phase%20I/santaclarariverhydrologyreportphaseI.pdf
Wang, S., Wan, C., Wang, Y., Chen, H., Zhou, Z., Fu, H., & Sosebee, R. E. (2004). The characteristics of Na+, K+ and free proline distribution in several drought-resistant plants of the Alxa Desert, China. *Journal of Arid Environments*, *56*, 525–539. http://doi.org/10.1016/S0140-1963(03)00063-6
Warrick, J. A. (2002). Short-term (1997-2000) and long-term (1928-2000) observations of river water and sediment discharge to the Santa Barbara Channel, California.
Watts, D. A., & Moore, G. W. (2011). Water-use dynamics of an invasive reed, Arundo donax, from leaf to stand. *Wetlands*, *31*, 725–734.
Watts, D. A., & Moore, G. W. (2011). Water-Use Dynamics of an Invasive Reed, Arundo donax, from Leaf to Stand. *Wetlands*, *31*(4), 725–734. http://doi.org/10.1007/s13157-011-0188-1
Wilske, B., Kwon, H., Wei, L., Chen, S., Lu, N., Lin, G., … Chen, J. (2010). Evapotranspiration (ET) and regulating mechanisms in two semiarid Artemisia-dominated shrub steppes at opposite sides of the globe. *Journal of Arid Environments*, *74*, 1461–1470. http://doi.org/10.1016/j.jaridenv.2010.05.013
Wishtoyo Foundation. (2008). *Santa Clara River Watershed Amphibian and Macroinvertebrate Bioassessment Project. Los Angeles and Ventura Counties, California.* Santa Clara River Trustee Council. Retrieved from https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=65389

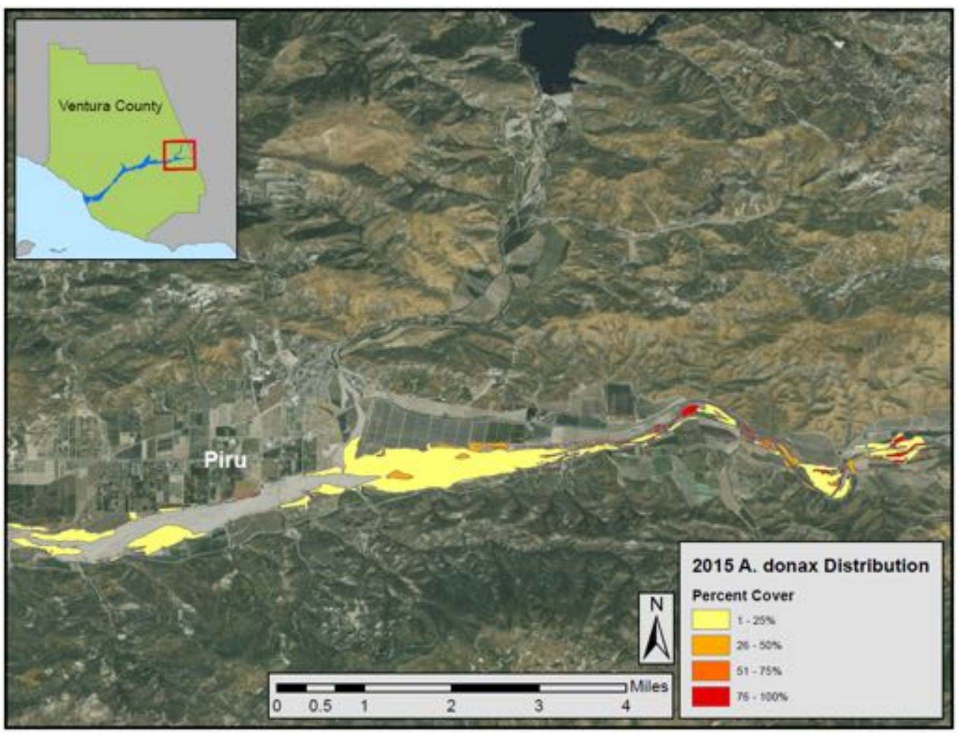
Appendix A: *Arundo donax* distribution mapping (2015 Update)

A. donax distribution and percent cover along the lower SCR based on 2015 mapping efforts. The four maps below show the distribution along the entire lower SCR moving eastward from the mouth of the river to the Ventura-Los Angeles County line.





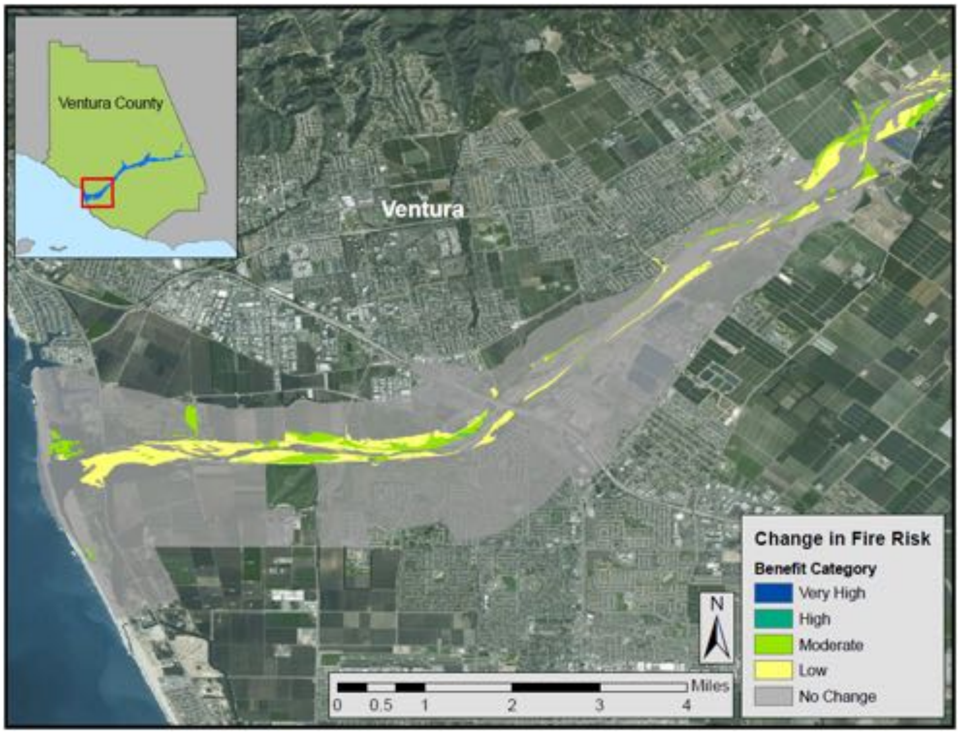

Ventura County
Fillmore
2015 A. donax Distribution
Percent Cover
1 - 25%
26 - 50%
51 - 75%
76 - 100%
N
Miles
0 0.5 1 2 3 4

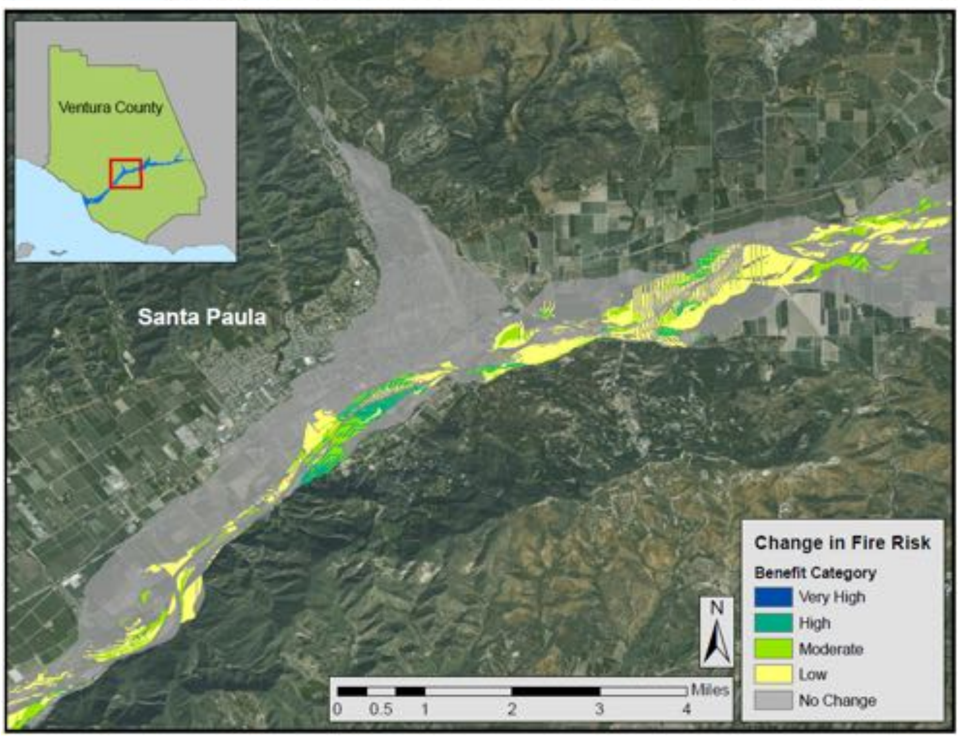

Ventura County
Piru
2015 A. donax Distribution
Percent Cover
1 - 25%
26 - 50%
51 - 75%
76 - 100%
N
Miles
0 0.5 1 2 3 4

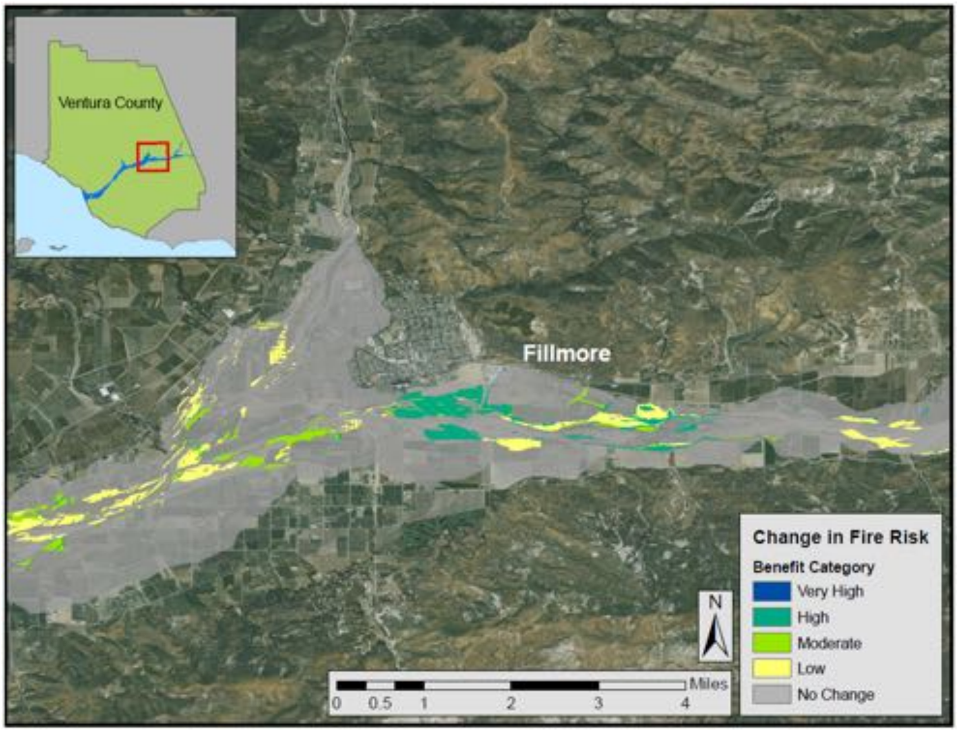
Appendix B: Fire scenario mapping

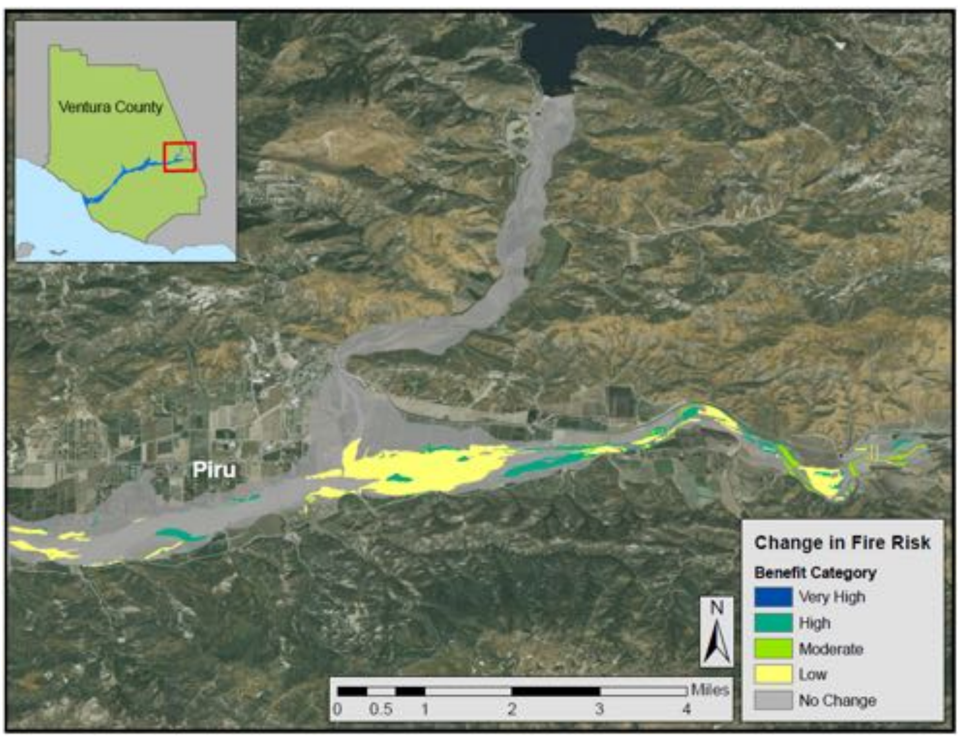
The change in fire risk over the extent of the lower SCR for each fire risk situation (1-4). Each situation includes four maps to display the entire extent of the lower SCR moving upriver from the mouth of the river to the Ventura-Los Angeles County line.

Situation 1. Situation 1 represents the best-case scenario for overall fire risk, with a low wind speed of 6.7 mph and a low vegetation-weighting regime.

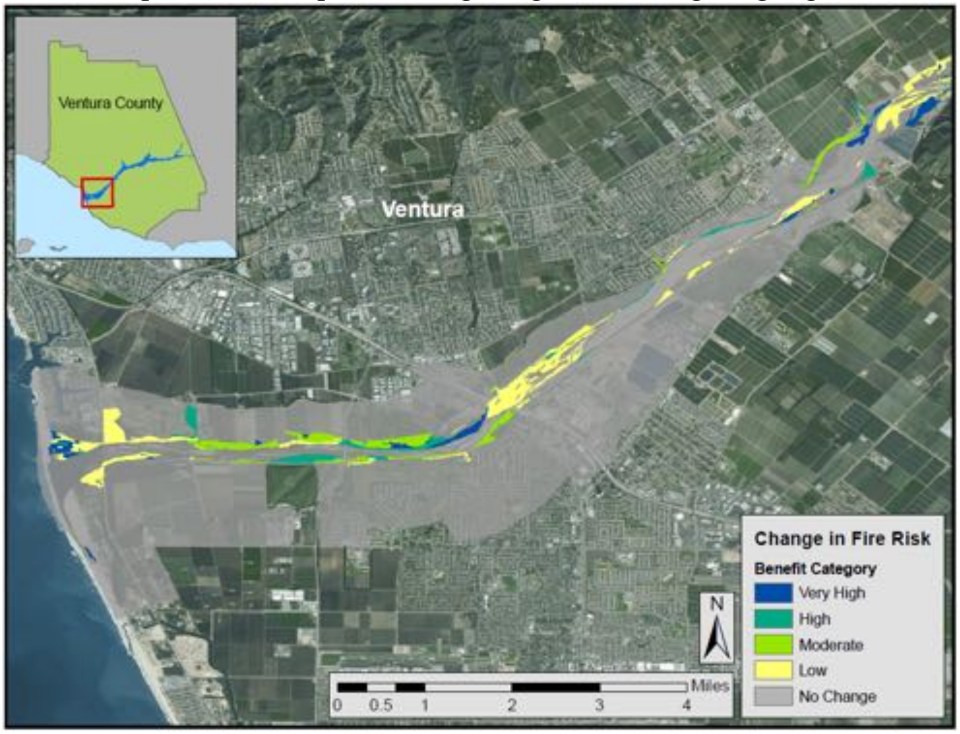


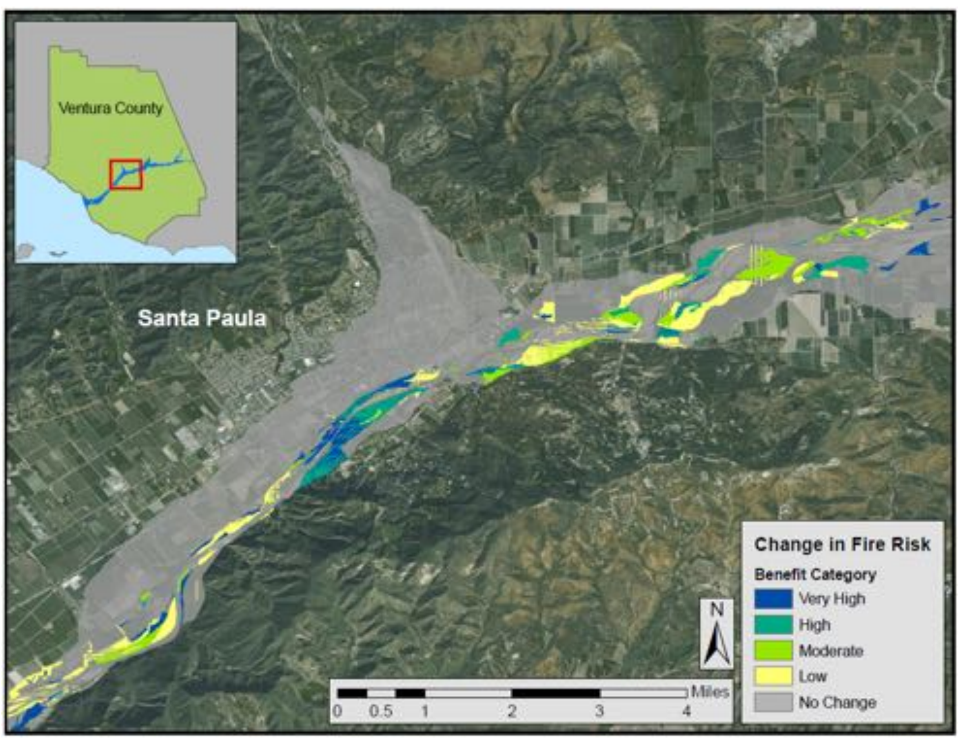


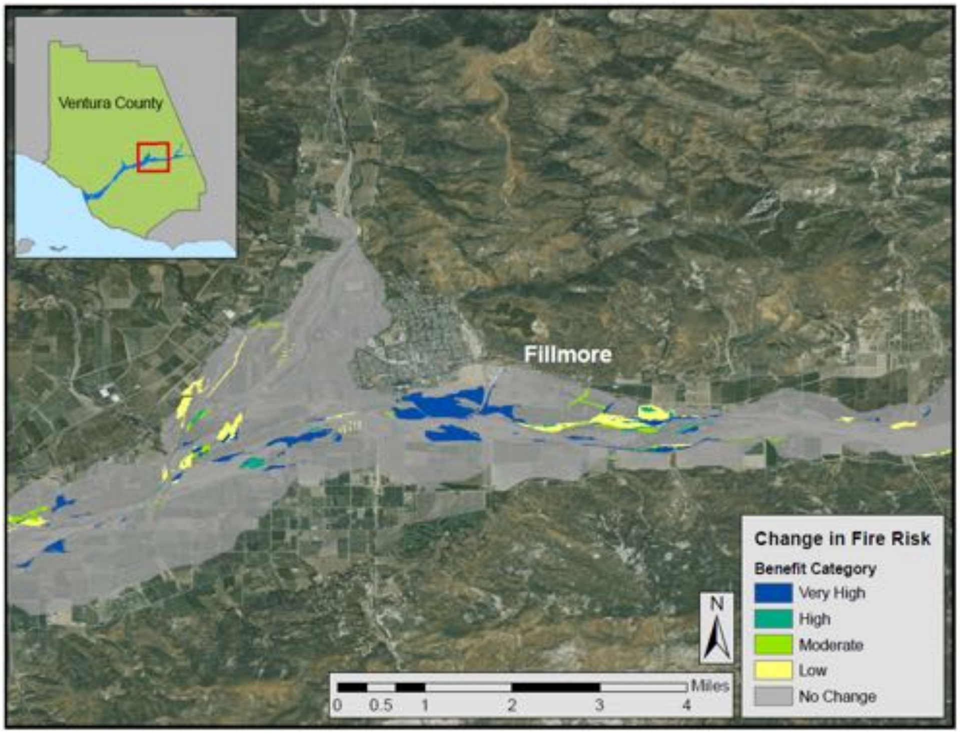

Ventura County
Fillmore
Change in Fire Risk
Benefit Category
Very High
High
Moderate
Low
No Change
N
Miles
0
0.5
1
2
3
4

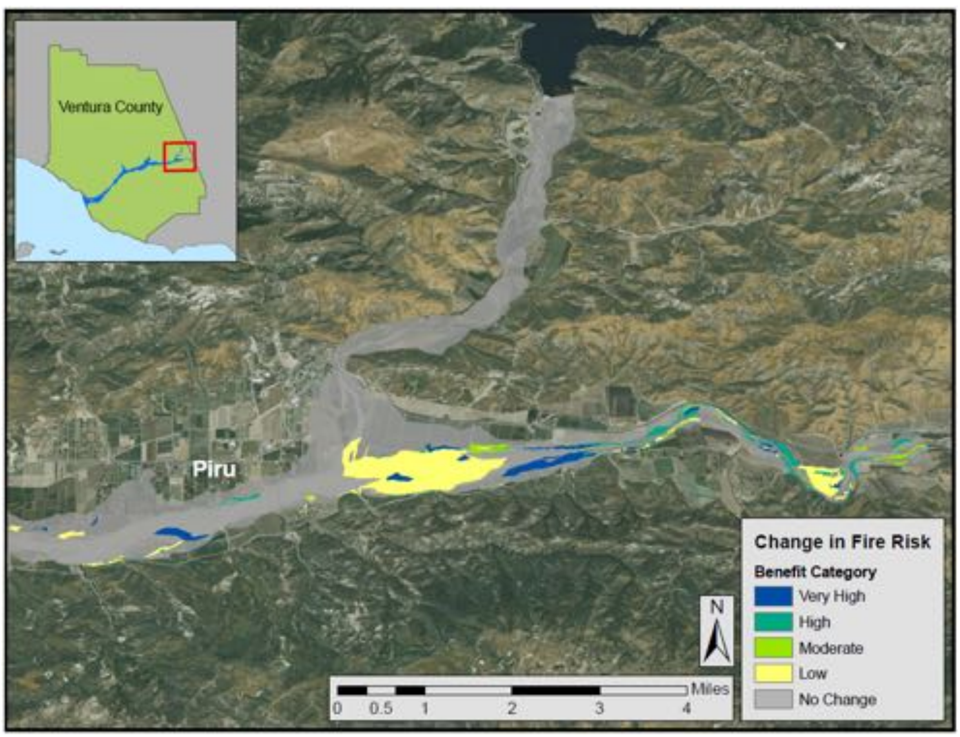

Ventura County
Piru
Change in Fire Risk
Benefit Category
Very High
High
Moderate
Low
No Change
N
Miles
0
0.5
1
2
3
4

Situation 2. Situation 2 represents a moderate fire risk assessment, with a low wind speed of 6.7 mph and a high vegetation-weighting regime

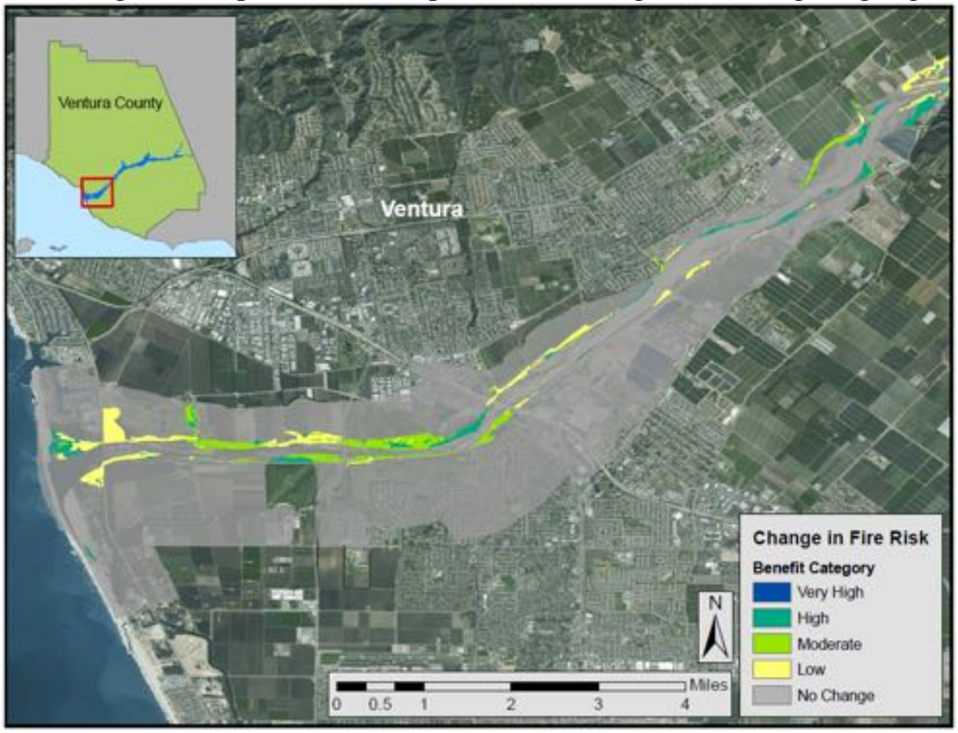


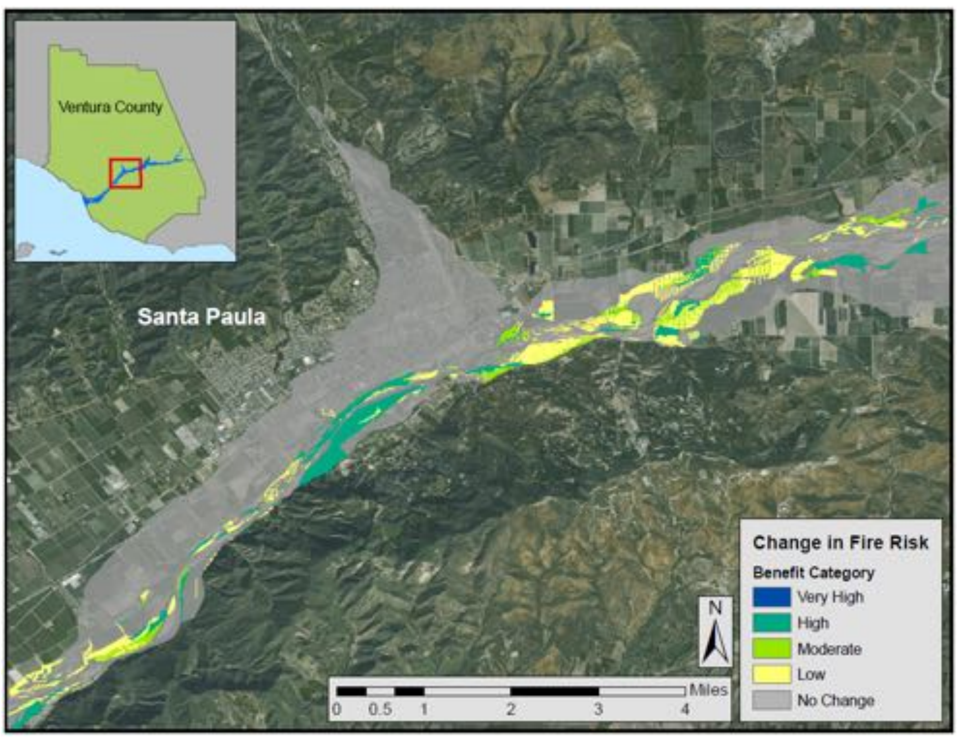


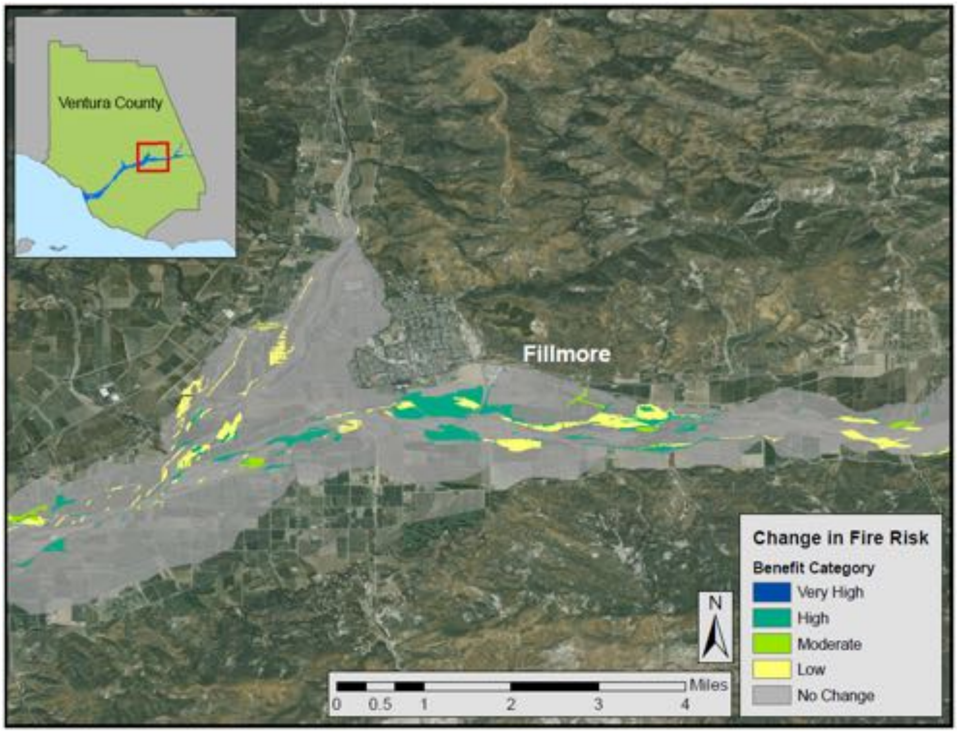

Ventura County
Fillmore
Change in Fire Risk
Benefit Category
Very High
High
Moderate
Low
No Change
N
0 0.5 1 2 3 4
Miles

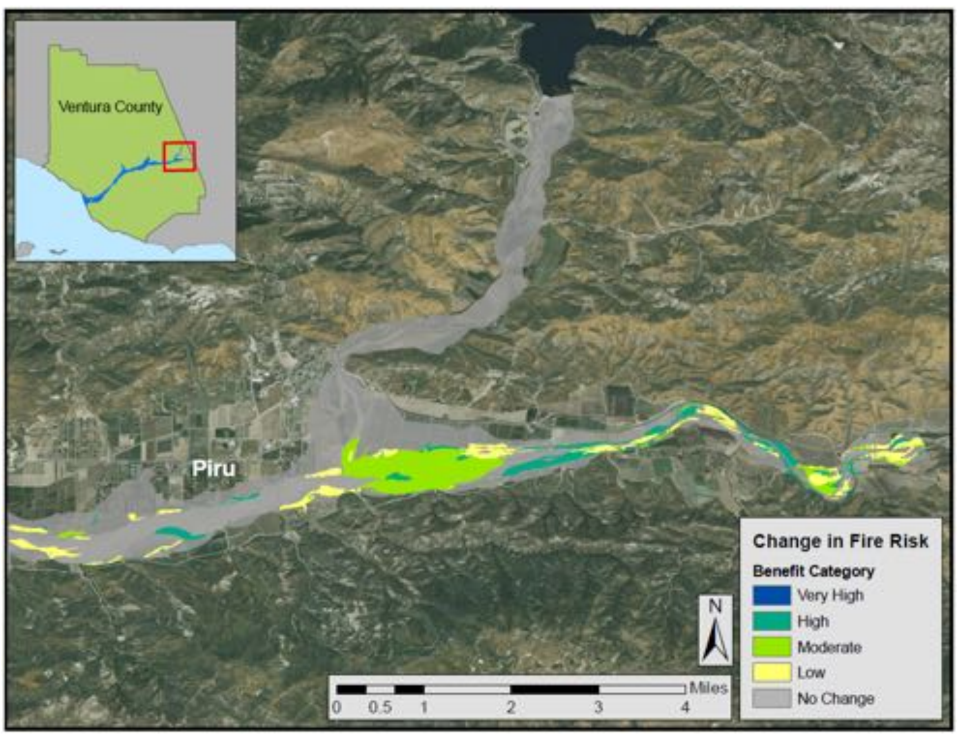

Ventura County
Piru
Change in Fire Risk
Benefit Category
Very High
High
Moderate
Low
No Change
N
0 0.5 1 2 3 4
Miles

Situation 3. Situation 3 represents secondary moderate fire risk assessment, with a high wind speed of 21.4 mph and a low vegetation-weighting regime.

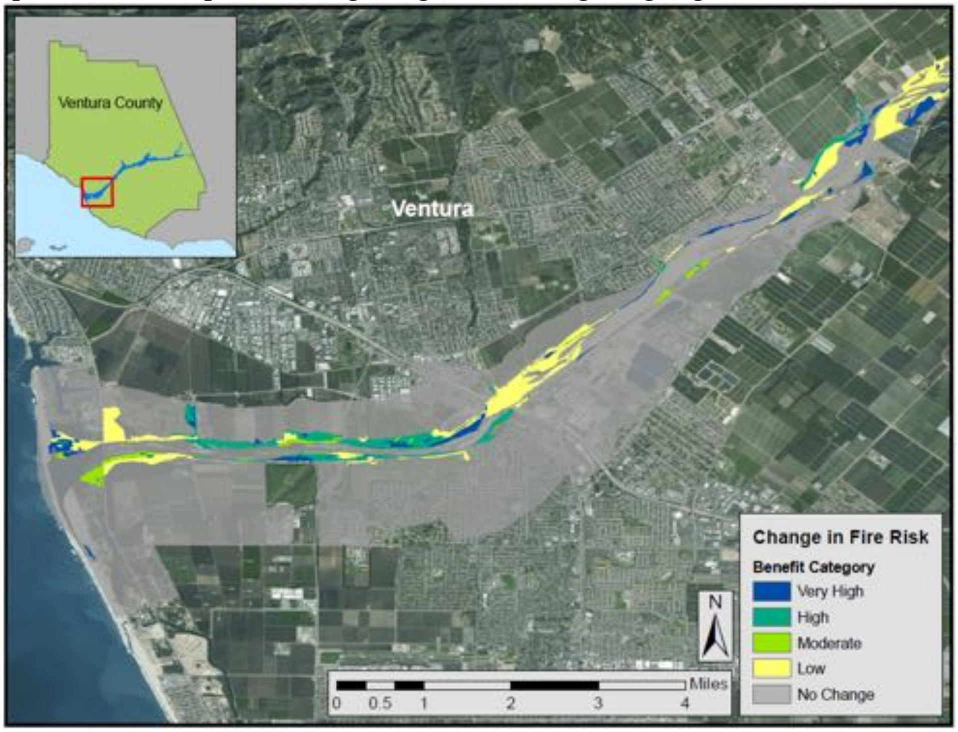


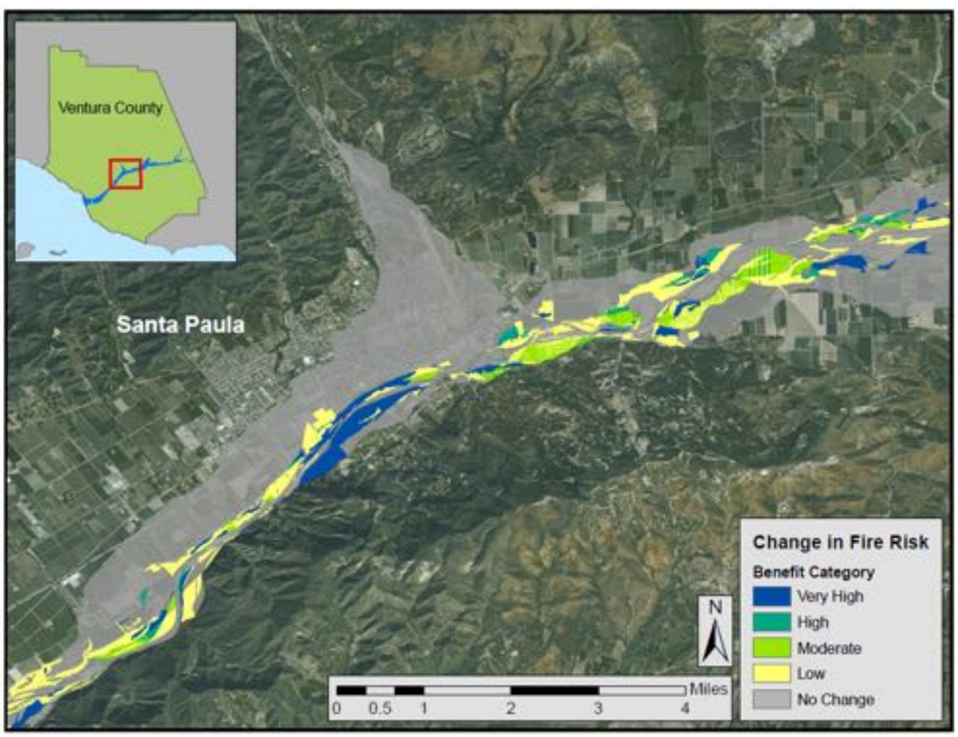


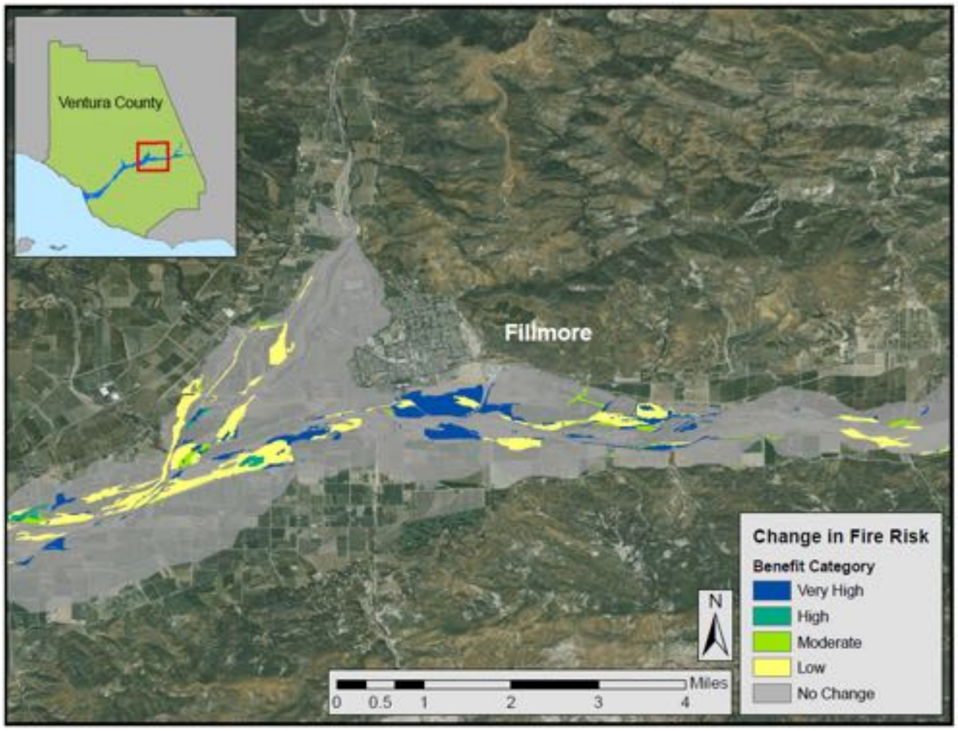

Ventura County
Fillmore
Change in Fire Risk
Benefit Category
Very High
High
Moderate
Low
No Change
N
0 0.5 1 2 3 4 Miles

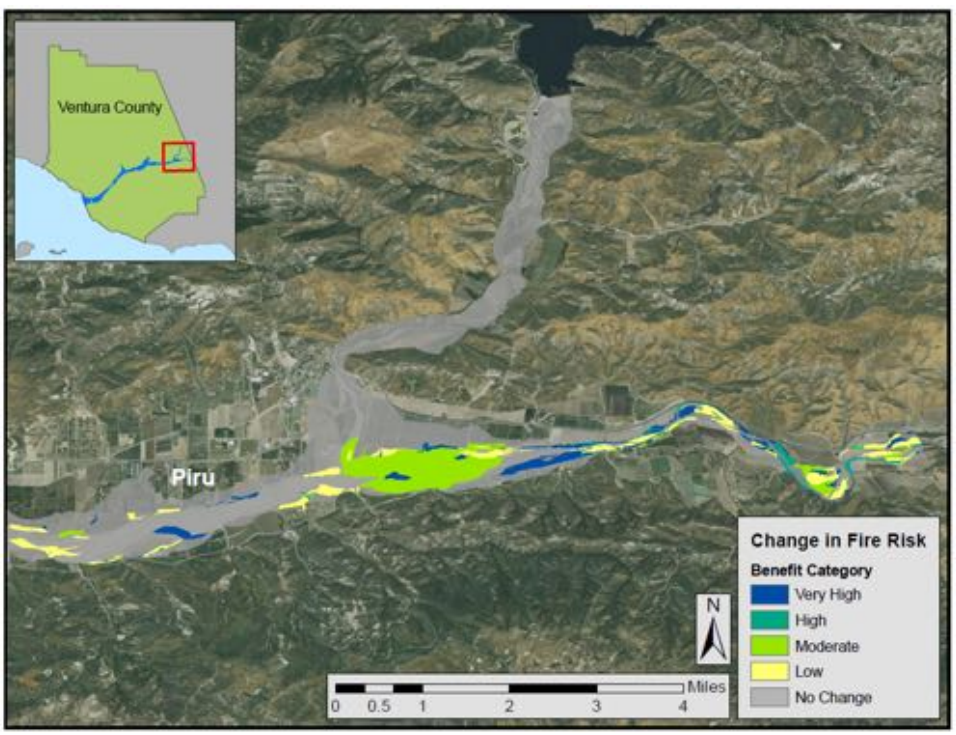

Ventura County
Piru
Change in Fire Risk
Benefit Category
Very High
High
Moderate
Low
No Change
N
0 0.5 1 2 3 4 Miles

Situation 4. Situation 4 represents the worst-case scenario for fire risk with a high wind speed of 21.4 mph and a high vegetation-weighting regime.

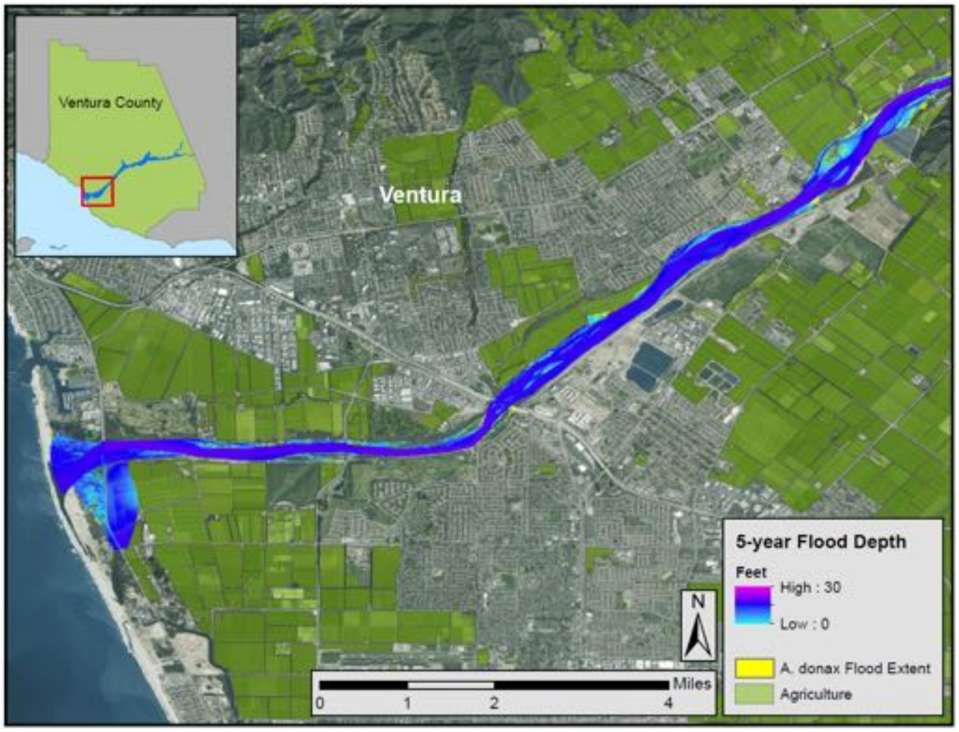


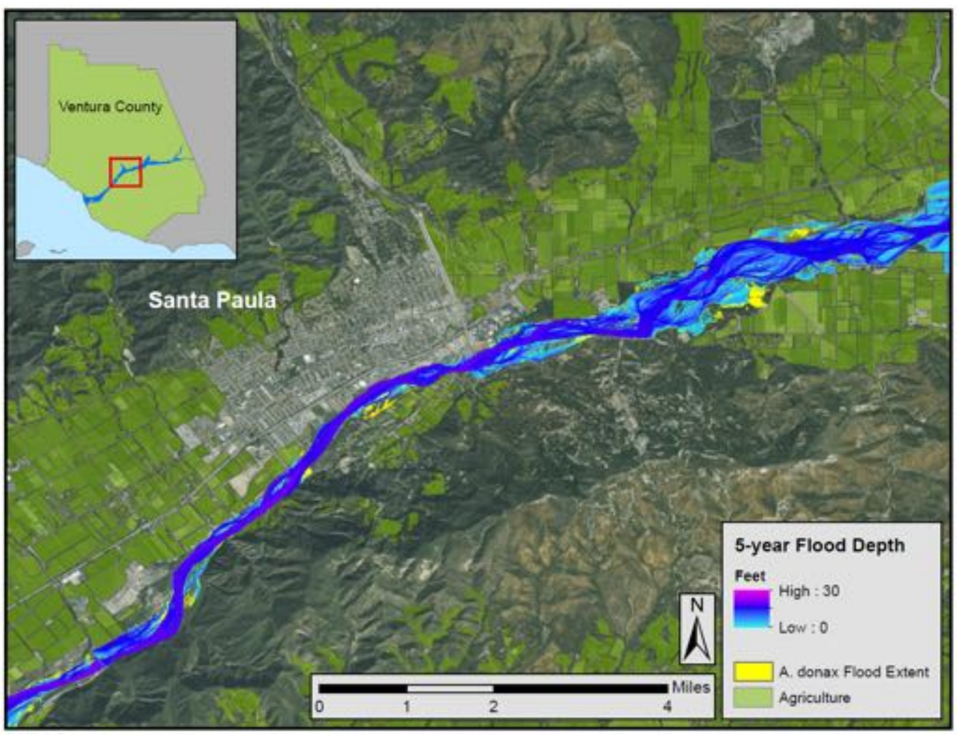


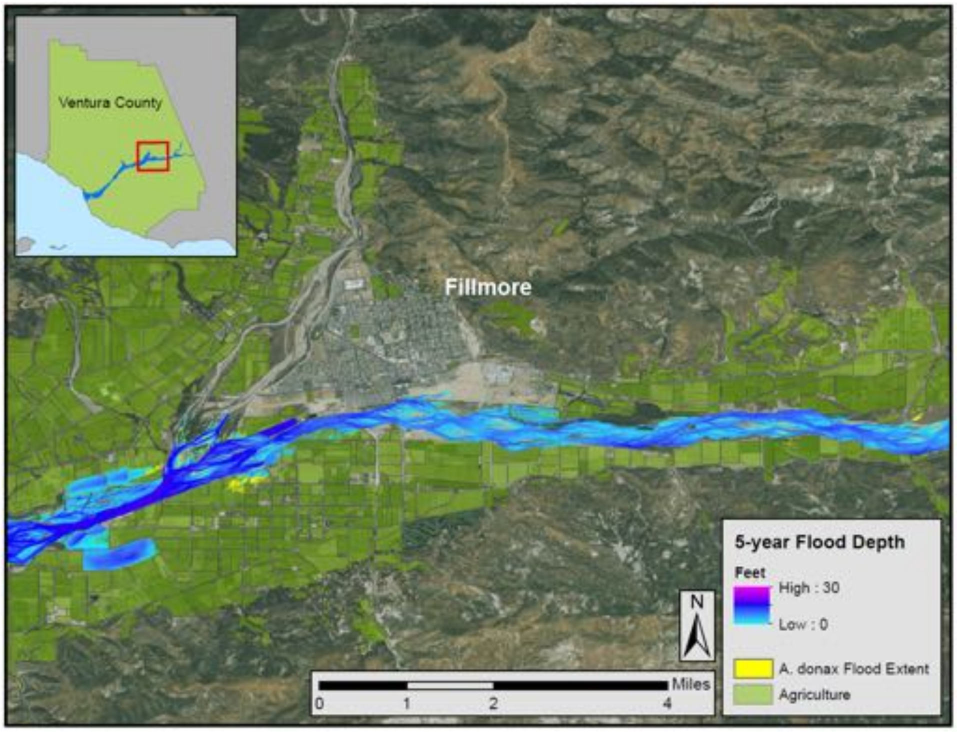

Ventura County
Fillmore
Change in Fire Risk
Benefit Category
Very High
High
Moderate
Low
No Change
N
Miles
0
0.5
1
2
3
4

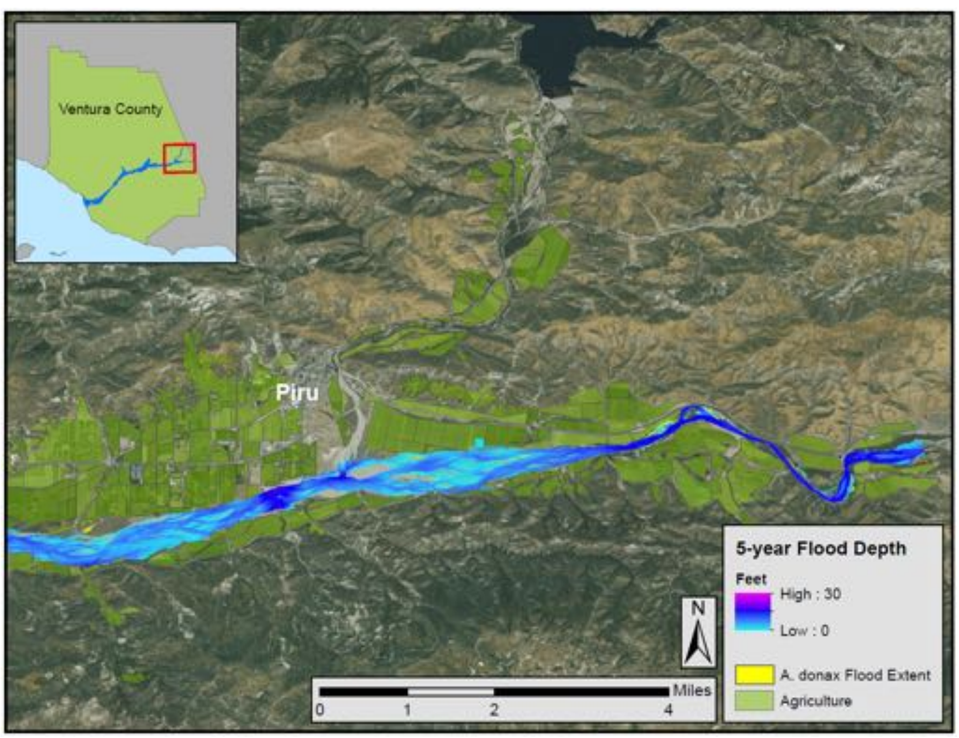

Ventura County
Piru
Change in Fire Risk
Benefit Category
Very High
High
Moderate
Low
No Change
N
Miles
0
0.5
1
2
3
4

Appendix C: Hydrology flood mapping

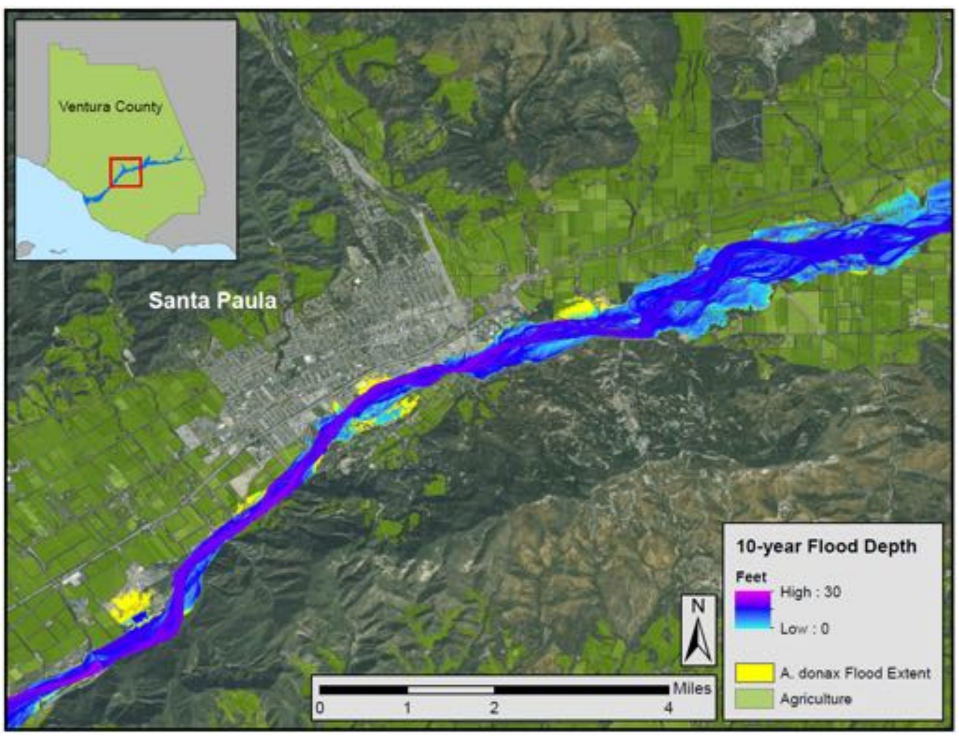


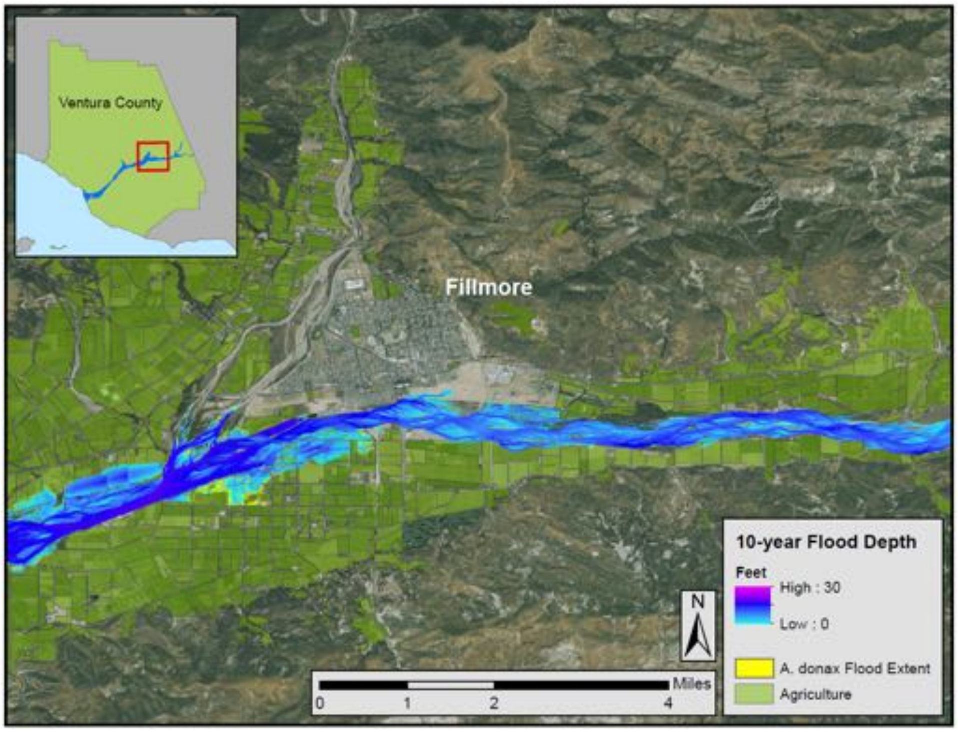


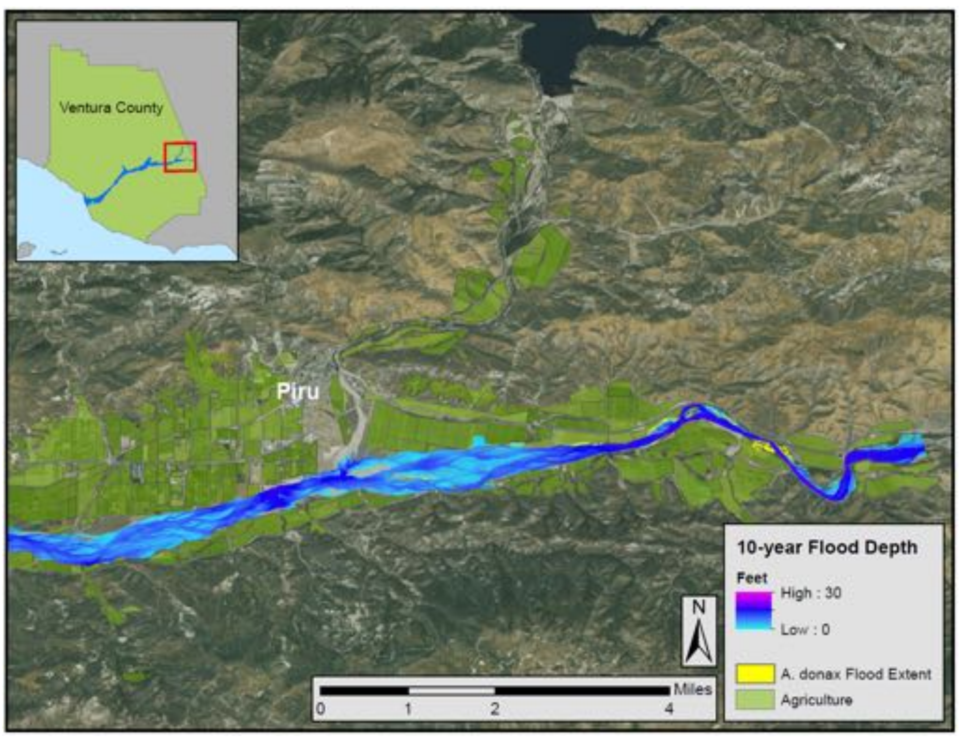

Ventura County
Fillmore
5-year Flood Depth
Feet
High : 30
Low : 0
N
A. donax Flood Extent
Agriculture
Miles
0
1
2
4


Ventura County
Piru
5-year Flood Depth
Feet
High : 30
Low : 0
N
A. donax Flood Extent
Agriculture
Miles
0
1
2
4


Ventura County
Ventura
10-year Flood Depth
Feet
High : 30
Low : 0
A. donax Flood Extent
Agriculture
N
Miles
0
1
2
4


Ventura County
Santa Paula
10-year Flood Depth
Feet
High : 30
Low : 0
A. donax Flood Extent
Agriculture
N
Miles
0
1
2
4

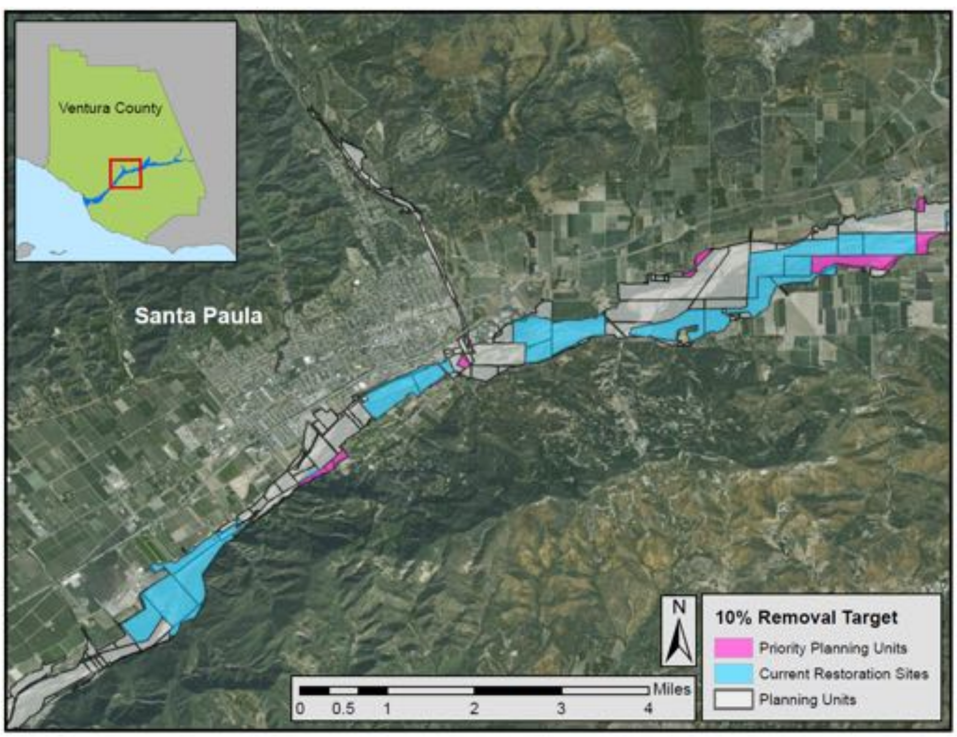

Ventura County
Fillmore
10-year Flood Depth
Feet
High : 30
Low : 0
A. donax Flood Extent
Agriculture
N
Miles
0
1
2
4

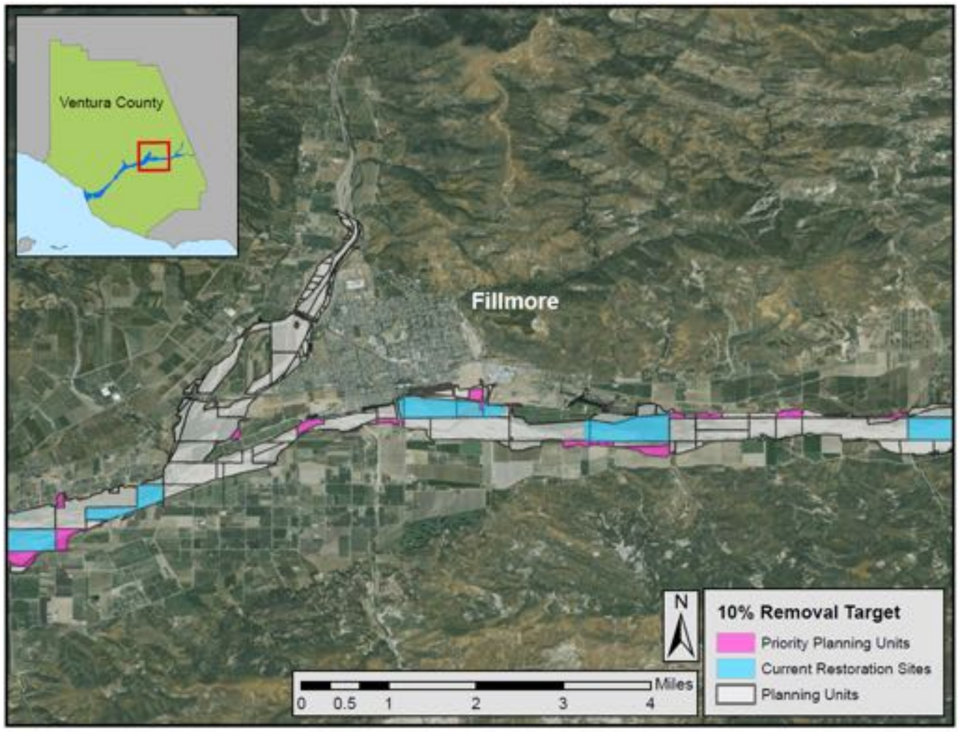

Ventura County
Piru
10-year Flood Depth
Feet
High : 30
Low : 0
A. donax Flood Extent
Agriculture
N
Miles
0
1
2
4

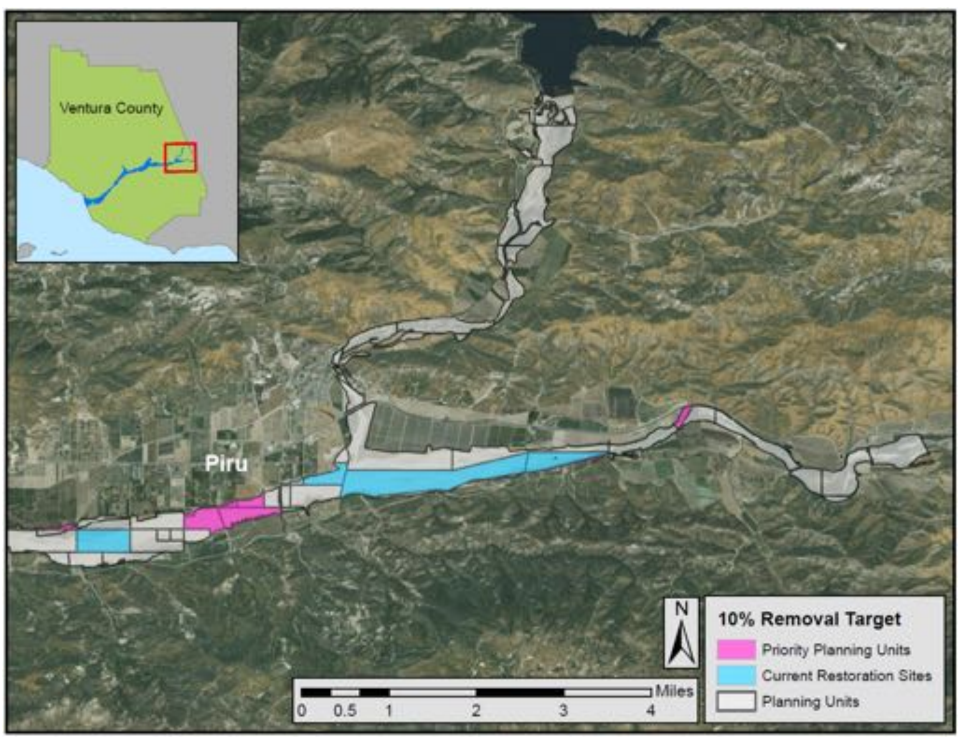
Appendix D: Priority areas for ecological value

Priority areas selected for *A. donax* removal given a specified removal target (percent of current acres).

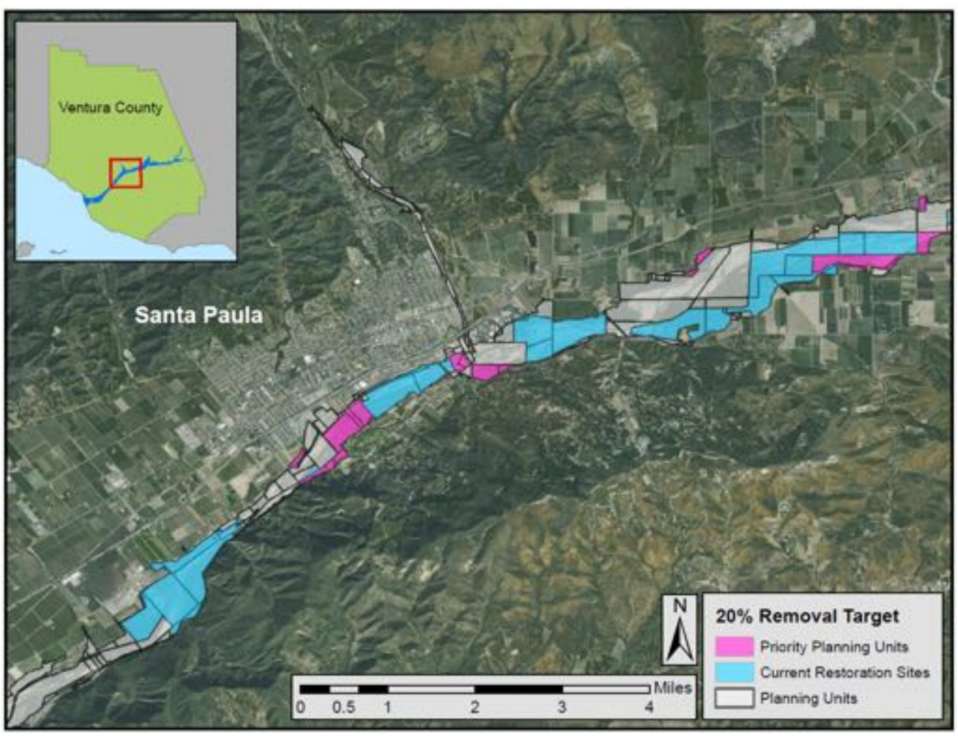
10% removal target. Planning units selected to achieve a 10% removal target. (4 maps total)

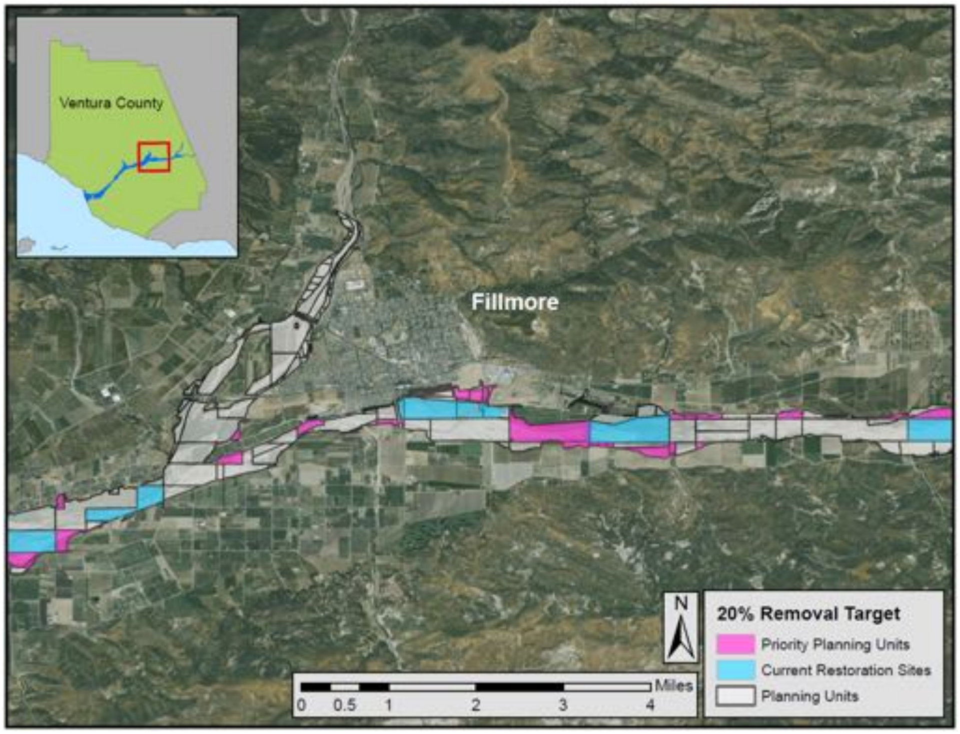


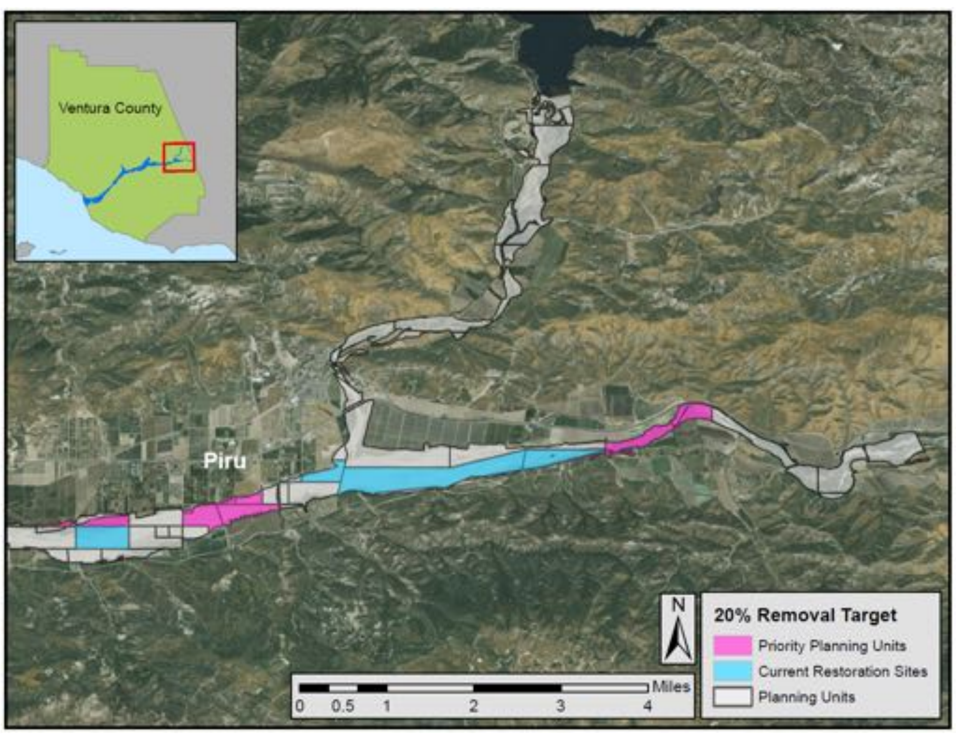

Ventura County
Fillmore
N
10% Removal Target
Priority Planning Units
Current Restoration Sites
Planning Units
Miles
0 0.5 1 2 3 4


Ventura County
Piru
N
10% Removal Target
Priority Planning Units
Current Restoration Sites
Planning Units
Miles
0 0.5 1 2 3 4

15% removal target. Planning units selected to achieve a 15% removal target (4 maps total).




Ventura County
Fillmore
N
20% Removal Target
Priority Planning Units
Current Restoration Sites
Planning Units
Miles
0 0.5 1 2 3 4


Ventura County
Piru
N
20% Removal Target
Priority Planning Units
Current Restoration Sites
Planning Units
Miles
0 0.5 1 2 3 4