Sacramento-San Joaquin Delta
Regional Ecosystem Restoration Implementation Plan

Ecosystem Element Conceptual Model

Riparian Vegetation

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PREFACE

This Conceptual Model is part of a suite of conceptual models which collectively articulate the current scientific understanding of important aspects of the Sacramento-San Joaquin River Delta ecosystem. The conceptual models are designed to aid in the identification and evaluation of ecosystem restoration actions in the Delta. These models are designed to structure scientific information such that it can be used to inform sound public policy.

The Delta Conceptual Models include both ecosystem element models (including process, habitat, and stressor models); and species life history models. The models were prepared by teams of experts using common guidance documents developed to promote consistency in the format and terminology of the models http://www.delta.dfg.ca.gov/erpdeltaplan/science_process.asp .

The Delta Conceptual Models are qualitative models which describe current understanding of how the system works. They are designed and intended to be used by experts to identify and evaluate potential restoration actions. They are not quantitative, numeric computer models that can be "run" to determine the effects of actions. Rather they are designed to facilitate informed discussions regarding expected outcomes resulting from restoration actions and the scientific basis for those expectations. The structure of many of the Delta Conceptual Models can serve as the basis for future development of quantitative models.

Each of the Delta Conceptual Models has been, or is currently being subject to a rigorous scientific peer review process. The peer review status of each model is indicated on the title page of the model.

The Delta Conceptual models will be updated and refined over time as new information is developed, and/or as the models are used and the need for further refinements or clarifications are identified.

Table of Contents

List of Tables

List of Figures

1. Overview

The Sacramento-San Joaquin Delta has immense municipal, agricultural, biological and industrial importance to the economy and livelihood of California and in turn to the United States. Plans to improve conditions in the Delta must address both human and biological communities. The region has been altered extensively over the past 200 years from land conversion to agriculture, fluxes in sedimentation rates, levee construction, and a completely re-plumbed network of waterways and hydrology (Thompson, 1957). Remnant, native riparian and wetland plant communities are almost completely removed and there is some question of whether the natural processes that create and maintain them can be restored (Mount and Twiss, 2005). Restoration implementation will be difficult considering the extent of alteration and complexity of both the natural system and cultural setting. The scientific approach to resolve these issues needs to reflect system complexity and represent the many potential response pathways that lead from proposed alterations. Development of conceptual models to understand these potential pathways is an important first step in understanding restoration implementation (and other management actions) in light of the complexity of the natural system and existing management scheme.

The CALFED program is interested in restoring the Delta ecosystem to the extent possible[1]. Riparian Vegetation (RV[2]) is but one of the natural systems of interest; others include fisheries, wildlife, and other plant communities. The conceptual model presented here deals exclusively with those physical, chemical, and ecological processes relevant to riparian vegetation. Riparian vegetation is important not only for biological conservation of the plant species themselves, but also the other flora and fauna species—and the physical and ecological processes—that depend upon riparian vegetation. Although the restoration of riparian vegetation as a component of a healthy riverine landscape has cultural and economic importance, these aspects are not included in this model.

The conceptual model of riparian vegetation presented here is actually a sub-model of the larger floodplain processes/habitat model (Figure 1)[3]. The RV Sub-model is general by design, and is intended to provide a framework for potential expansion or adaptation to more-refined models of individual species, habitats, and/or entire landscapes. Spatially, we focus specifically on the floodplain or land area beginning at the upper edge of the emergent vegetation zone, then moving up in elevation and inland from the water, ending when non-floodplain areas, open water, or marsh is encountered. Together, the Floodplain model and the RV Sub-model can be used to analyze various "scenarios," ranging from potential restoration or research actions, to water management decisions, to placement of bank protection at a specific Delta levee site. In addition, to highlight key differences in conditions that occur in the Delta, we present here two specific applications of the RV Sub-model that we generalize as a being dominated by tidal processes and another dominated by more riverine processes. We recognize that depending on specific variables (i.e., tide levels, river discharge inputs,

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[1] For the purposes of the Delta regional Management Plan, the Delta is defined as Delta Ecological Management Zone.

[2] By RV we are referring to species composition at the patch and landscape level (alpha-beta diversity), vegetation architecture, and configuration of vegetation patches over the landscape.

[3] By processes/habitat we mean that the Floodplain Model incorporates both the physical and chemical processes that predict the physical habitat for RV.

location, etc.) some areas of the Delta may in actuality exhibit characteristics of both configurations at different times.

The RV Sub-model describes the state of scientific knowledge of various component-linkages including the predictability, understanding, and importance of the linkages. For example, the model allows examination of the effect of groundwater on vegetation, including the predictability of that effect, an indicator of the state of understanding of the effect, and the relative importance of the effect compared to other drivers and linkages.

This narrative report describes how ecosystem drivers (e.g. hydrology, sediment, fire, animals, patch configuration) affect the presence and character of RV in the Delta, and how RV feeds back into other components of the floodplain model. Floodplain Model 1 (Figure 1) illustrates how hydrology (surface water and groundwater) and sediment characteristics form the floodplain—a process we describe here as setting the "physical template" upon which RV establishes (Figures 2 and 3). Outputs from floodplain Model 1 are routed to the RV Sub-model. Specifically, the changes in area of floodplain, sediment regime, inundation regime, and ground water depth are all key inputs to the RV Sub-model. The RV Sub-model, explained in greater detail in Section 3.2 of this narrative, has two general outputs: habitat outcomes (Vegetation Patch and Habitat Mosaic [the pink circle in Figure 1]) and feedback information to Floodplain Models 1 & 2. These feedbacks are described in greater detail later in this narrative.

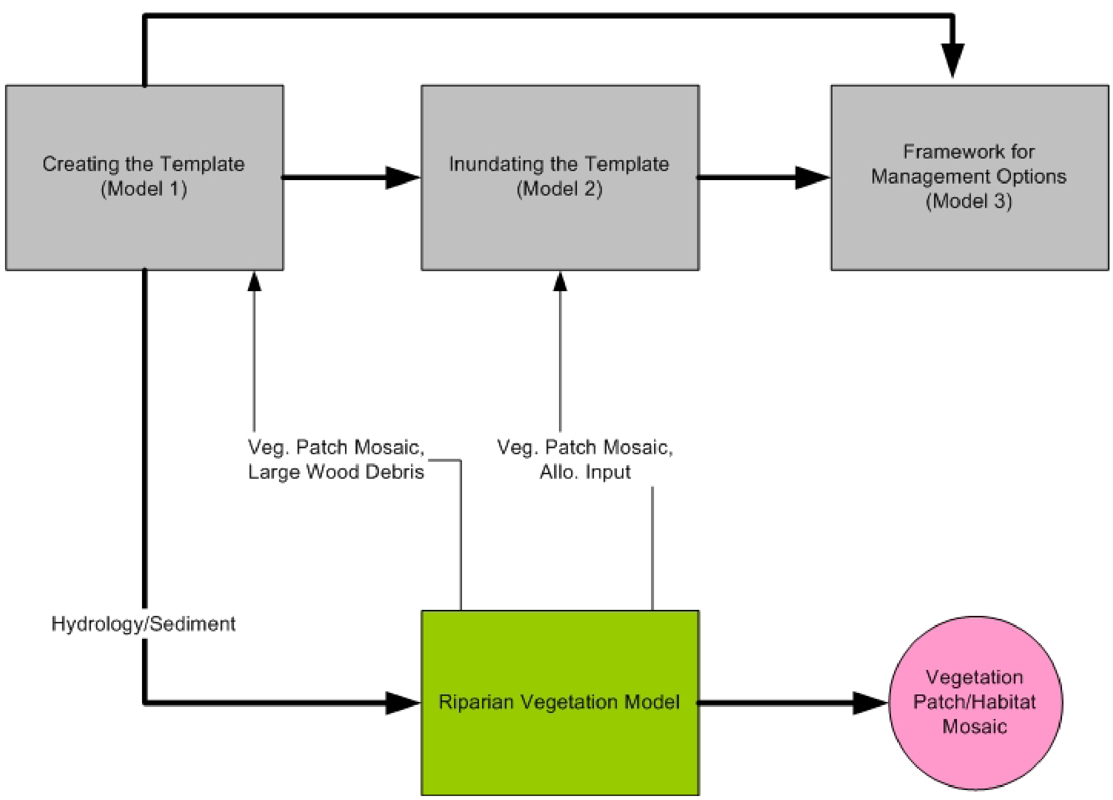

Figure 1: Overview diagram of the Floodplain Model and the RV Sub-model. The RV Sub-model has two main inputs from Model 1, the sediment regime and the hydrologic regime. These inputs set the physical template upon which RV establishes. RV outputs feed back into Floodplain Models 1 & 2 (overall vegetation mosaic of riparian forests, large woody debris and leaf litter/carbon inputs into the aquatic system, hydraulic roughness, etc.) and also drive the formation of the vegetation patch/habitat mosaic. Restoration of the vegetation patch/habitat mosaic is one of the goals of CALFED's DRERIP.

2. Modeling Context

The ecosystems of the Delta (that is, the combination of the ecological landscape and the physical and ecological processes that create and maintain that landscape) are greatly modified from natural conditions. Any conceptual model describing these systems must integrate this reality and allow for impact stressors to be explicitly examined within the model framework. For instance, the hydrogeomorphic processes that form natural levees in the Delta no longer exist in much of the region, and in part this is a result of specific stressors such as Central Valley Project (CVP) and State Water Project (SWP) operations modifying the hydrology (and hence geomorphic processes) and the construction of tall, riprap fortified anthropogenic levees. In addition, land elevations relative to sea level have been lowered because land reclamation (complete in 1930) and agriculture have increased decomposition of organic carbon in the peat soils (Mount and Twiss, 2005; Figure 3). Prescriptions for restoration must adequately address issues pertaining not only to a modified landscape, but also to natural and modified processes.

The physical location where riparian vegetation dominates in the Delta region lies between the freshwater emergent vegetation or tules, up to the areas high on the floodplain that are almost never inundated (Table 1). The higher-elevation edge of the riparian area is not well-defined because flooding height in the Delta is highly variable at the annual and decadal scales. For example, valley oak (*Quercus lobata*) is a valley floor species that is highly associated with floodplain conditions (flooding and shallow groundwater depths). Its population dynamics can be highly influenced by flooding through soil moisture effects on seed viability recruitment, and seedling/sapling survival.

In the Delta, vegetation establishes over two prominent environmental gradients: local elevation and salinity. The elevation gradient is most evident at the small-scale and is best conceptualized by a shoreline/levee cross section where vegetation type changes with elevation. This gradient can also be seen on broader areas with lower topographic relief but enough tidal flux to drive the vegetation inundation and cause species differences with elevation—and even the presence/absence of vegetation (Table 1). The second gradient is the larger-scale salinity gradient across the Delta from Suisun Bay toward upstream reaches. This second gradient fluctuates seasonally and from year to year, depending on freshwater inputs (Warner and Hendrix, 1984; see also CDWR, 2008).

Table 1: Organization of species of dominant plants and their relations to tidal flooding (Adapted from Warner and Hendrix, pg.559 1984).

Increased Flooding/Inundation			Decreased Flooding/Inundation	
Intertidal Zone			Supratidal Zone	
Scirpus californicus	*Scirpus acutus*	*Typha spp.* *Phragmites australis* *Juncus spp.* *Iris pseudacarus*	*Salix spp.* *Cephalanthus occidentalis* *Cornus stolonifera*	*Alnus rhombifolia* *Populus fremontii* *Platanus racemosa* *Juglans hindsii* *Quercus lobata*

The riparian vegetation model assumes the physical drivers are the main first-order control on riparian vegetation. By the physical drivers, we refer to the dynamic inter-relationship between geomorphology and hydrology, including both the land-forming processes and flood water inundation characteristics (including salinity). This is a well established assumption in the literature (NRC 2002, McBride and Strahan 1984, Hupp and Osterkamp 1996, Tabacchi et al. 1998). Secondary controls on vegetation presence and composition include invasive species, periodic fire, and animal population dynamics.

2.1 Historic Riparian Vegetation

According the historical accounts of the region, the lower portions of the rivers that flow into the Delta were surrounded by wide swaths of riparian forests (Thompson, 1961; 1980). Riparian forests in the Lower Delta formed only a relatively narrow band along the high point of the natural levees. On the Sacramento River these forests were quite large in lateral extent (5-6 km), progressively narrowing with distance into the Delta, coincident with the reduced width of the natural levees.

The pre-European settlement species composition is not well known quantitatively; however, Thompson (1961) has summarized the writings of early explorers (mid-1800's) and provides a good description of a target restoration forest composition, structure and spatial location. Terrestrial vegetation consisted broadly of four major plant associations: 1) grassland prairie, 2) Valley oak woodland (*Quercus lobata*), 3) freshwater tule marsh (*Scirpus spp.*), and 4) scrub thickets and riparian forests. These divisions match those of Jepson (1925), Klyver (1931), and Knapp (1965).

The riparian forest overstory was dominated by valley oak (*Quercus lobata)*, California sycamore (*Platanus racemosa)* and Fremont cottonwood (*Populus fremontii)*. Also mentioned yet less abundant were white alder (*Alnus rhombifolia),* Oregon ash *(Fraxinus latifolia),* American dogwood *(Cornus pubescens [C. sericea]),* button willow *(Cephalanthus occidentalis),* California grape (*Vitus californica*) and several true willows including Goodding's black (*Salix gooddingii*), narrow-leaved (*S. exigua*), red (*S. laevigata*), shining (*S. lucida*) and arroyo (*S. lasiolepis*). A more-detailed narrative of Central Valley riparian vegetation, including understory species, can be found in Chapter 16 of the newest version of the *Terrestrial Vegetation of California* (Vaghti and Greco, 2007).

2.2 Current Riparian Vegetation

2.2.1 Native Vegetation

In the Central Valley, less than 5% of the once-broad riparian forests on the valley floor remain (Bay Institute, 1998) and none are entirely unaltered by human use (Sands, 1980; Warner and Hendrix, 1984; Hunter *et al.*, 1999). Using a GIS analysis of the Central Valley, Warner and Hendrix (1984) showed that the remaining riparian vegetation is highly fragmented into small unprotected patches (approximately 15% are in public ownership or managed for biological conservation). Riparian vegetation in the Delta is highly impacted and solutions should not only address the reduction but also fragmentation. Both these impacts are addressed in the RV Sub-model.

Species composition within riparian stands has also been altered. Along many of the tributary rivers into the Delta researchers have documented a loss in cottonwood recruitment because of changed hydrology (Roberts *et al.*, 2002; Stella *et al.*, 2006). This pattern has been well-studied throughout most of the western United States (Johnson *et al.*, 1976; Fenner *et al.*, 1985; Bradley and Smith, 1986; Stromberg and Patten, 1996; Scott *et al.*, 1997; Rood *et al.*, 1999). In addition, sycamore distributions have been reduced. Keeler-Wolf *et al.* (1994) illustrated the continued decline of sycamore in California over the last 100 years; these authors suspected their observations could be partially explained by recruitment problems and drowning caused by elevated summer flows created by flow regulation.

Willow *(Salix)* species grow with other pioneer species on point bars and newly formed lands (McBride and Strahan, 1984; Jones, 1997; Tu, 2000). Later-seral species such as maple, ash, walnut and oak (*Acer, Fraxinus, Juglans* and *Quercus*) develop on older floodplains below an overstory canopy created by pioneer species such as cottonwood and willow (Strahan, 1984; Cepello, 1991; Tu, 2000; Fremier, 2003; Vaghti, 2003)[4]. Comparing research conducted on the Cosumnes River to that completed on the Sacramento River shows that ash species are more-abundant on the Cosumnes, and maple and walnut are more abundant on the Sacramento. It should be noted that maple, although clearly a common species now, was not mentioned by early explorers as summarized by Thompson's work (Fremier, 2003; Vaghti, 2003). All research has described valley oak forests as a later seral stage of riparian forest in the Central Valley (Thompson, 1961 & 1980; Cepello, 1991; Greco, 1999; Tu, 2000; Fremier. 2003; Vaghti, 2003; Williams, 2006). Oak decline is largely attributed to land clearing for agriculture and valley oak riparian forests are much reduced from their historic extent and represent a high conservation priority (SRAC, 1998; Greco *et al.*, 2007). Importantly, low regeneration success of valley oak appears to be limiting species abundance and recovery (Trowbridge *et al.*, 2005).

Understory species (those plants living under the canopy of riparian trees) are also an important component of the riparian ecosystem. The recruitment requirements for individual species in relation to existing site conditions (e.g., open, bare mineral soil versus a dense, shaded overstory with heavy leaf litter) and associated soil moisture availability are understood to be deterministic in the establishment and evolution of understory vegetation through time (Vaghti and Greco, 2007). Additionally, the interaction between understory vegetation and invasive species can inhibit natural patterns of vegetation succession and plant assemblages. Appendix A includes a database of important species physiological tolerances and requirements which can be queried and sorted to support use of the RV Sub-model.

2.2.2 Invasive Species

Invasive, non-native plant species can create serious problems for conservation, restoration and management of riparian areas in the Delta. Ecological consequences from the establishment of invasive species include the alteration of ecosystem processes such as fire frequency (e.g., giant reed, Himalayan blackberry, and tamarisk), nutrient cycling (e.g., Scotch broom,), erosion and sedimentation rates (e.g., giant reed, Brazilian waterweed), and hydrologic regimes (e.g., giant reed, tamarisk). Invasive species typically out-compete native species and are a major conservation concern. With invasions of non-native species, native species diversity frequently declines because of the alteration of community structure, hybridization with native species, and because threatened and endangered plant species are out-competed (Bossard *et al.* 2000, SFEI 1998). Large mono-specific stands of invasive species push out native species and can fundamental alter the system via physical feedbacks and trophic interactions.

[4] By 'seral stage' we are referencing suites of plant species the co-occur consistently over a temporal gradient. Early seral stage refers to those plants adapted to colonize on newly-created lands, e.g. pioneer species such as cottonwood and willows.

The major non-native invasive species that threaten the Delta (see species listed in Appendix A), occur across many riparian community types. In tree and shrub communities located in higher relative elevation[5], invasive species such as yellow star-thistle, poison hemlock, edible fig, and Himalayan blackberry, displace native riparian species, deplete soil moisture, and increase fire hazard (Borman et al. 1992, Hoshovsky 2000, Randall 2000, Serpa 1989). Native shrub and herbaceous communities in lower relative elevation sites are also threatened with invasive species. Outcomes include the reduction of in-stream shading for fish, reptiles, and amphibians (e.g., giant reed [Franklin 1996]); the alteration of community composition (e.g., sweet fennel, [Colvin 1996, Dash and Gliessman 1994, Granath 1992]); and the encroachment of rare plants (e.g., broad-leaved pepperweed [Skinner and Pavlik 1994]). At the lowest relative elevation, major problems for the emergent and aquatic communities because of invasive species include reduction of flow, degradation of waterfowl habitat, alteration of water quality for fish, and the impairment of irrigation systems (e.g., Brazilian waterweed*,* common water hyacinth*,* waterthyme*,* and Eurasian watermilfoil; Aiken et al. 1979, Anderson 1987, Center and Spencer 1981, deWinton and Clayton 1996, Hoffman and Kearns 1997, Langeland 1990, Parsons 1992, Penfound and Earle 1948).

2.3 Processes and Patterns over the Fluvial-Tidal Gradient

2.3.1 Description of the Gradient

The RV model illustrates, in general, the main physical and ecological processes and relationships controlling riparian vegetation in the Delta. Within the Delta, the strengths and direction of these relationships at specific locations varies in response to the degree to which that particular site is dominated by riverine (fluvial) or tidal processes, or a combination of the two (Figures 2 & 3). These two dominant regimes are not entirely distinct, resulting in a great degree of spatial heterogeneity throughout the Delta. To address this heterogeneity, a simplified gradient concept is presented here. The specific location of these areas can change spatially from season to season or over the course of climatic variations that drive ocean and river conditions (see diagram of seasonal changes in hydrology in the Transport model). The gradient is primarily driven by site elevation relative to mean sea level, and is therefore driven by location in the Delta (Figure 3). For this model, we utilize the general convention of the “Lower Delta” and the “Upper Delta” to typify the areas where the combination of conditions described below are applicable. In terms of spatial examples, the Lower Delta can be thought of as the terrestrial regions around the sloughs west and southwest of Lodi, and the Upper Delta being those floodplain lands in the lower Yolo Bypass or lower Cosumnes River. These are just examples, and we acknowledge that areas typified as Lower Delta might also occur in the northeastern part of the Delta, an area generally more-dominated by Upper Delta conditions.

Under our generalization scheme, Upper Delta areas are subject to greater fluvial control, with stronger down-gradient flows of freshwater from adjacent rivers—notably the Sacramento, Cosumnes/Mokelumne, and San Joaquin Rivers—and generally less salinity. In these Upper Delta areas the geomorphic processes and surfaces are more dynamic and are disturbed more frequently. Fluctuations in water stage at individual sites can be as short as the

[5] In this instance, elevation is the floodplain elevation relative to the water surface in the channel, not the absolute elevation.

duration of a winter storm, or extend over the course of a season, as illustrated by the slowly decreasing stage of the declining limb of the late spring snowmelt hydrograph in (Knowles, 2000).

In contrast, areas we generalize as the Lower Delta areas are subject to greater tidal influence. In these areas, the effect of daily tidal cycles dominates (with the exception of when large floods produce strong gradients of freshwater flow through the Delta). The lower channel slopes of this area also result in decreased energy and hence somewhat less potential for physical, geomorphic disturbance.

While this generalized characterization is accurate for pre-disturbance[6] conditions, current operations (i.e., levee maintenance, flood control, water supply management, and agriculture) in the Delta have largely eliminated overbank/levee flooding and changed the salinity regime. Occasional levee breaches do occur and cause major disturbances (Mount and Twiss, 2005) because of the subsided island areas within the levees. However, this type of hydraulic reorganization (island flooding) is not considered a historically normal or common process in the Delta region.

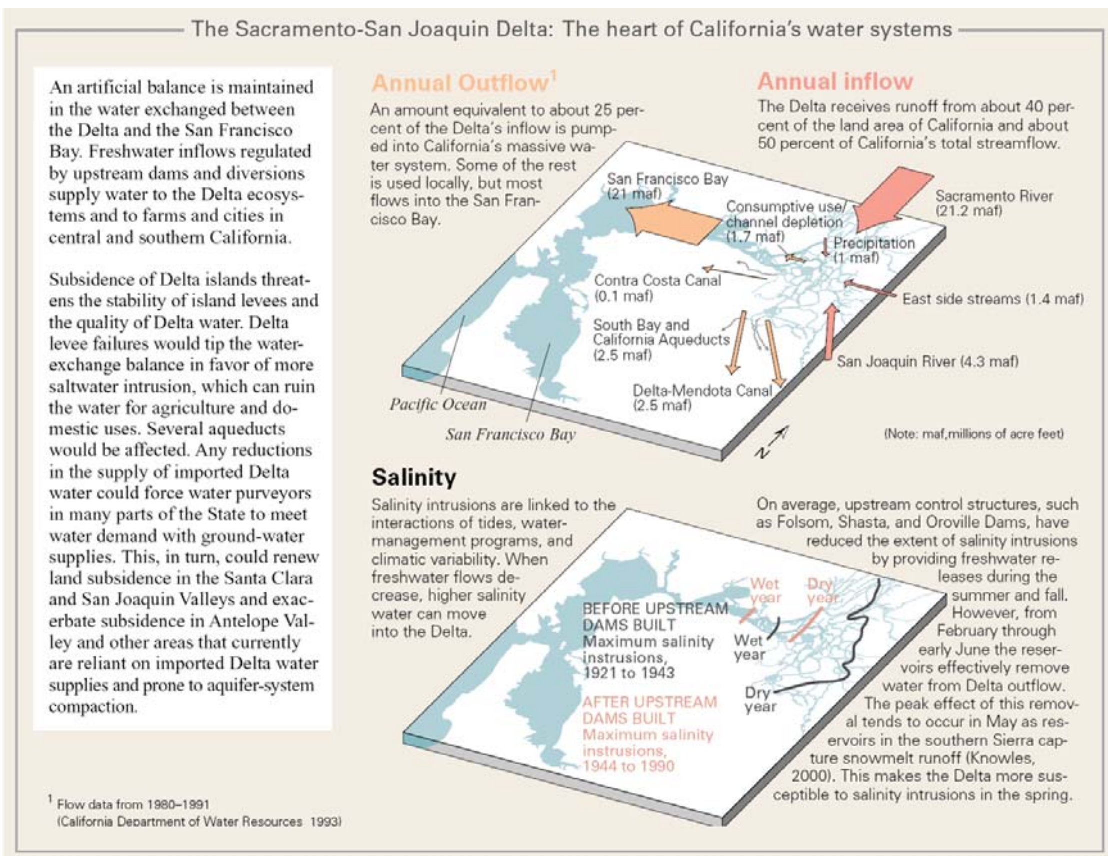

Figure 2: Diagram depicting the annual flow characteristic and salinity of the current Delta. Copied without permission from Ingebritsen, *et al.*, 2000.

[6] When we reference "pre-disturbance conditions", we are referring to the conditions prior to the onset and influence of Euro-American occupation of California.

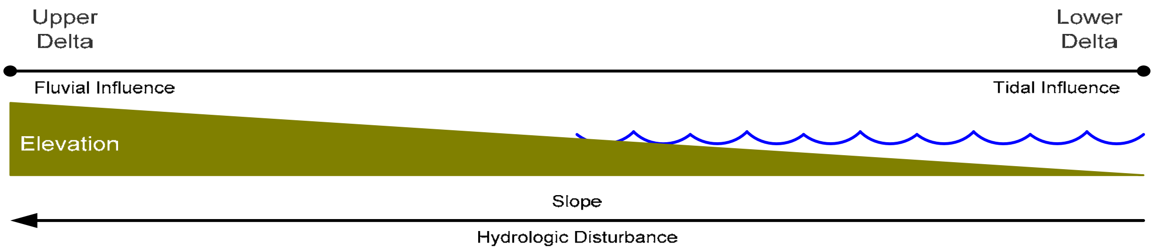

Figure 3: Diagram showing the continuum of physically-defined regions within the Delta system.

2.3.2 River-Centered Model

Vegetation patterns in fluvially-dominated landscapes (i.e., on river floodplains) are driven by the history of hydrologic and geomorphic processes acting at the local and landscape scale—from local processes that affect propagule recruitment, to large-scale processes such as flood water inundation and channel dynamism which cumulatively affect the configuration of vegetation over the landscape (patch size, shape, and number). Our understanding of these physical processes as a first-order control on riparian vegetation is well established (Gregory *et al.*, 1991; Malanson, 1993; Hupp and Osterkamp, 1996; Petts and Amoros, 1996; Naiman and Decamps, 1997; Tabacchi *et al.*, 1998; Bendix and Hupp, 2000; NRC, 2002; Naiman *et al.*, 2005); however, the extent to which these processes change along a river corridor should be specifically evaluated as the river system transitions from fluvially-dominated to tidally-influenced within the "deltaic system".

In the classic riparian vegetation model for fluvial environments, erosion and deposition of landforms over longer periods of time (>10 years) structure the floodplain landscape and more short-term events (< 1 year) such as seasonal flood water inundation[7] influence the local species composition. In this view, new lands created by fluvial disturbance (e.g. lateral river channel movement, overland scour and vegetation removal, and channel avulsion events) create habitat for early seral species. Over time and depending on the degree of changes in the floodplain surface (sedimentation, hydrology), a given plant community may transition toward a community more-dominated by upland species. Chaotic fluvial processes also may rapidly alter the species composition or successional trend. For example, as a point bar forest matures and the river migrates away, a channel avulsion could rapidly change groundwater levels, and hence species composition. In these fluvial environments, dynamism is a relatively frequent component necessary to maintain the breadth of species over time.

2.3.3 Delta-Centered Model

The Delta, where the pre-disturbance flood-prone areas are comprised of the channel margins with relatively low slopes, is generally considered to be more geomorphically stable than the upstream riverine environment. In the Delta, flood events are generally not high-powered and therefore there are fewer land-reworking events. Because of this, historically the anastomosed pattern of channels and islands was generally very stable in terms of both planform and cross-section (Bay Institute, 1998). Unaltered Delta geomorphology is

[7] Inundation patterns include magnitude, duration, frequency, velocity, and timing of flood waters.

characterized by broad, natural levees and islands, rather than by migrating river channels and point bars (Mount and Twiss, 2005; Figure 4). The Delta inundation regime is less characterized by magnitude and velocity and more by frequency and duration. Tidally-influenced stage variations occur daily and vary seasonally. These variations in stage are combined with increases in freshwater inputs during precipitation or snow melt events. Given the relatively low gradients and water velocities in the Delta, sediment transport is largely limited to fine grained sediment, i.e., sand-sized and finer (see Schoellhamer *et al*., 2007). Fine sediments build up slowly on near-bank natural levees and channel migration rates are typically slower with the anastomosing channels of the Delta.

Apart from the lack of channel migration, the current status of the Delta generally does not reflect the historic condition. Commonly, reinforced and heightened levees with relatively steep slopes armored with riprap rise up from Delta waterways. These steep levees offer little opportunity for overbank flows. The process of natural levee building does not currently exist in the Delta; however, the risk of large disturbances through levee breaching has increased because of the combined effects of land subsidence and sea level rise (Mount and Twiss 2005). Land subsidence is the result of extensive land management activities in the Delta (CDWR, 1995), mainly the farming of peat soils.

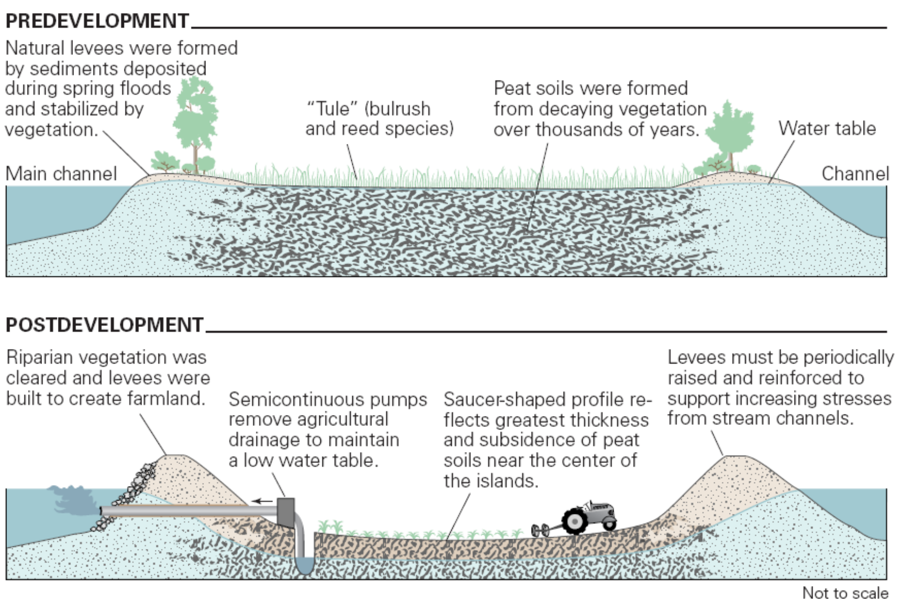

Figure 4: Diagram showing pre- and post-development of the Delta. Copied without permission from Ingebritsen, *et al*., 2000.

In the Upper Delta, species turnover (the transition from late-seral back to early-seral vegetation communities) is more-frequently caused by fluvial disturbances in the form of channel migration, avulsions and overland scour, and less so by longer-term inundation (plant anoxia, resulting for flooding longer than a runoff season). In the Lower Delta, the reverse might be true historically, with relatively-long spring snowmelt flood inundation of larger areas driving vegetative community change rather than rapid geomorphic changes. That is not to say there was not as much hydraulically-induced change in the Delta historically; avulsion events and moving channels occurred in the Delta prior to anthropogenic disturbance, but potentially at a slower rate and probably less frequently than the classic riparian model predicts, with a greater influence of long periods of inundation that drowned RV.

The disturbance of natural processes in the Delta has important implications for management. In the steeper, more fluvially-driven reaches, flow regulation on rivers affects recruitment patterns in riparian areas. It is uncertain if the recruitment patterns in lower, more tidally driven areas have been impacted for the same reason. We suspect that larger scale changes to hydro-geomorphic processes might play a larger role in riparian recruitment and succession. These alterations include the elimination of levee-crest inundation (because levees have been heightened) and the armoring of levees which essentially eliminates any evolution of the anastomosing channel pattern and ultimately "locks in place" the Delta channels and shorelines. Reduced overbank flooding in the Delta also affects sediment deposition, levee-building processes, and ultimately the surface disturbance regime that drives riparian recruitment.

3. Conceptual Models

The processes that drive the formation of riparian vegetation can be classed into four main groups: geomorphology, hydrology, chemistry and ecology. These process are not mutually exclusive, yet can be thought of as independently affecting the presence and trend of riparian vegetation. These categories are described in more detail here with reference to Floodplain Model 1 and the RV Sub-model (Figures 5 and 6, respectively). Because the conceptual model for RV is a sub-model of floodplain processes, it is shown in Figure 5 as a single box. Figure 5 provides the broader context of the interaction between RV and larger, more-complicated floodplain dynamics. Figure 6 depicts the RV Sub-model in greater detail.

3.1 Floodplain Model 1

Floodplain Model 1 (Figure 5) and the RV Sub-model (the green box in Figure 5) are habitat models that together produce a conceptual framework for creating the physical and vegetative floodplain landscape—a setting of the "physical template". This landscape includes physical habitat such as shaded riverine aquatic habitat, perennial open water, and natural shorelines, as well as specific vegetative habitat such as emergent wetland, riparian forest, and inland dune scrub. The direct and cumulative effects of alterations cause by anthropogenic stressors can be assessed using the model to determine potential impacts to RV.

The main inputs into the RV model are the hydrogeomorphic processes that create floodplain features and the hydrology that determines riparian vegetation habitat (recruitment and survival). Groundwater can also influence habitat characteristics on the floodplain, as well as RV recruitment and survival. Herbivory, while probably less important now than under pre-disturbance conditions, can also influence vegetation survival and landscape patterns. Connectivity between propagule source and new habitat site, whether connected by wind, water, or animal, can affect species composition including priority effects (the timing of species dispersal can affect which species gets established) and/or propagule limitation. Likewise, large woody debris (LWD) and floodplain roughness provide a feedback to the formation of floodplain topography.

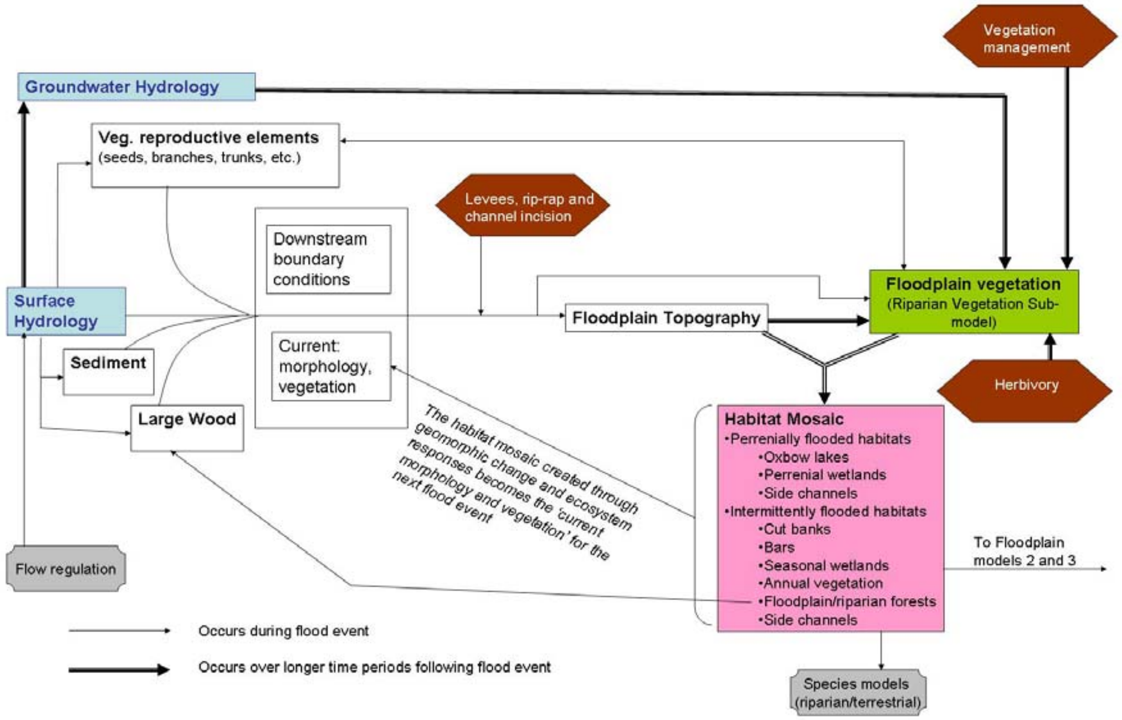

Figure 5. Integrating the RV Sub-model into Floodplain Model 1. The diagram shows how the habitat and processes contained in the RV Sub-model (green box) fit into the overall floodplain dynamics that form and maintain floodplain habitats.

3.2 Riparian Vegetation Sub-Model

The Riparian Vegetation (RV) Sub-model is shown in Figure 6 and 7, focusing on the direct inputs and outputs to the model and the RV Sub-model's relation to processes covered in Floodplain Model 1. The RV Sub-model has been divided into Figures 6 and 7 in order to make visual interpretation easier. There is some overlap between the two figures; however, they should be considered one model. Figure 6 shows general inputs and outputs into the sub-model. Figure 7 provides greater detail of how these factors influence riparian vegetation both at the individual and patch scale, thereby comprising riparian vegetation in the entire Delta. The specific processes by which each factor influences another aspect of the model is shown adjacent to the connecting arrows.

As shown in Figure 7, the RV Sub-model represents the main processes that determine the composition and configuration of riparian plant communities in the Delta. Topography and hydrology drivers are located in hatched boxes that are brown, water chemistry in the blue box, animal caused impacts in the magenta box, climate drivers in the grey box, and ecological drivers in the green box. Fire and disease can significantly affect vegetation; however, in the RV Sub-model these processes are simplified as factors to consider but are not treated as detailed processes with extensive feedbacks. Note that the hydrology and topography drivers are adapted from Floodplain Model 1, and the larger floodplain model essentially drives the key inputs of the RV Sub-model. Anthropogenic stressors are denoted in orange ovals on linkages they potentially affect. Outputs and feedbacks to other models (shown in the pink box; lower right) are a combined product of the Floodplain Model and the RV Sub-model—i.e. the entire floodplain landscape. The following sections of this narrative describe in detail the drivers and linkages. All text in these next sections is specific to the role of the individual drivers and linkages within the model, and should not be mistaken for a broad treatise on the larger fields of study represented by the disciplines of the same name (i.e., hydrology).

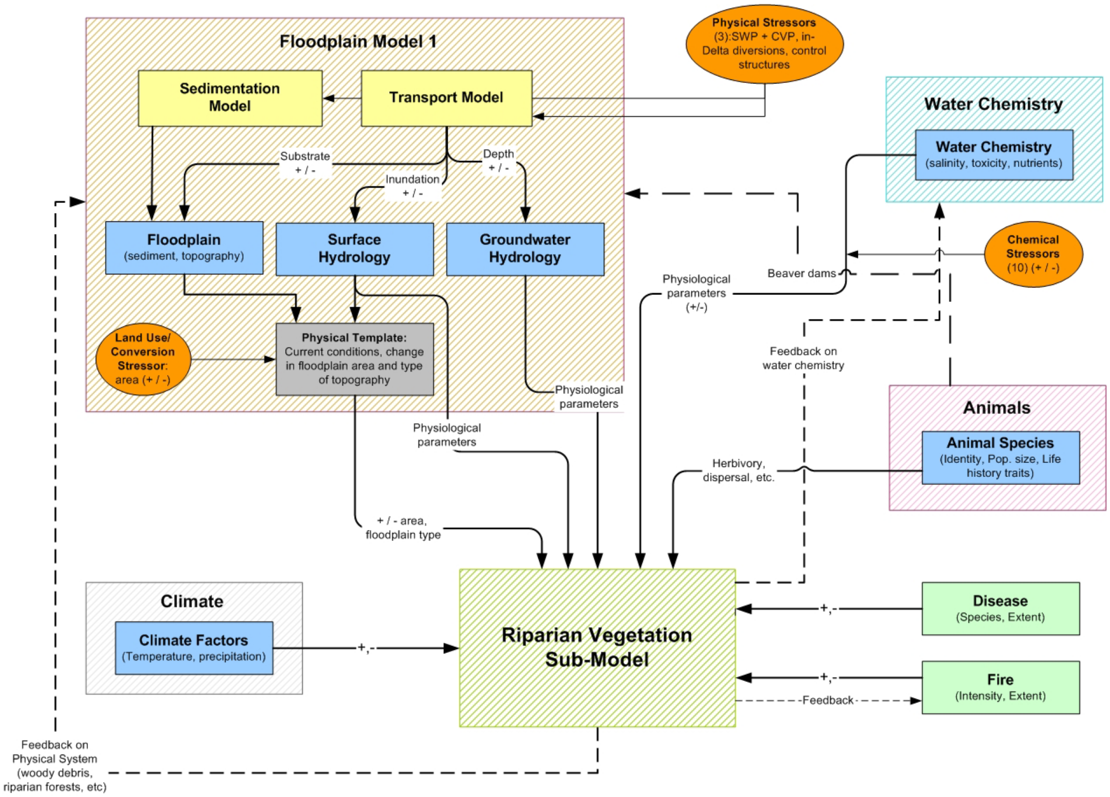

Figure 6. Riparian Vegetation (RV) Sub-model—summary overview. This diagram shows the main drivers of riparian vegetation in the Delta. The brown hatched box represents a reorganization (for clarity in this figure) of the topographic, hydrologic, and anthropogenic drivers and stressors that are fed into the RV Sub-Model from Floodplain Model 1. The drivers and processes from Floodplain Model 1 are depicted in this figure in a conceptually different way to provide an emphasis specific to riparian vegetation.

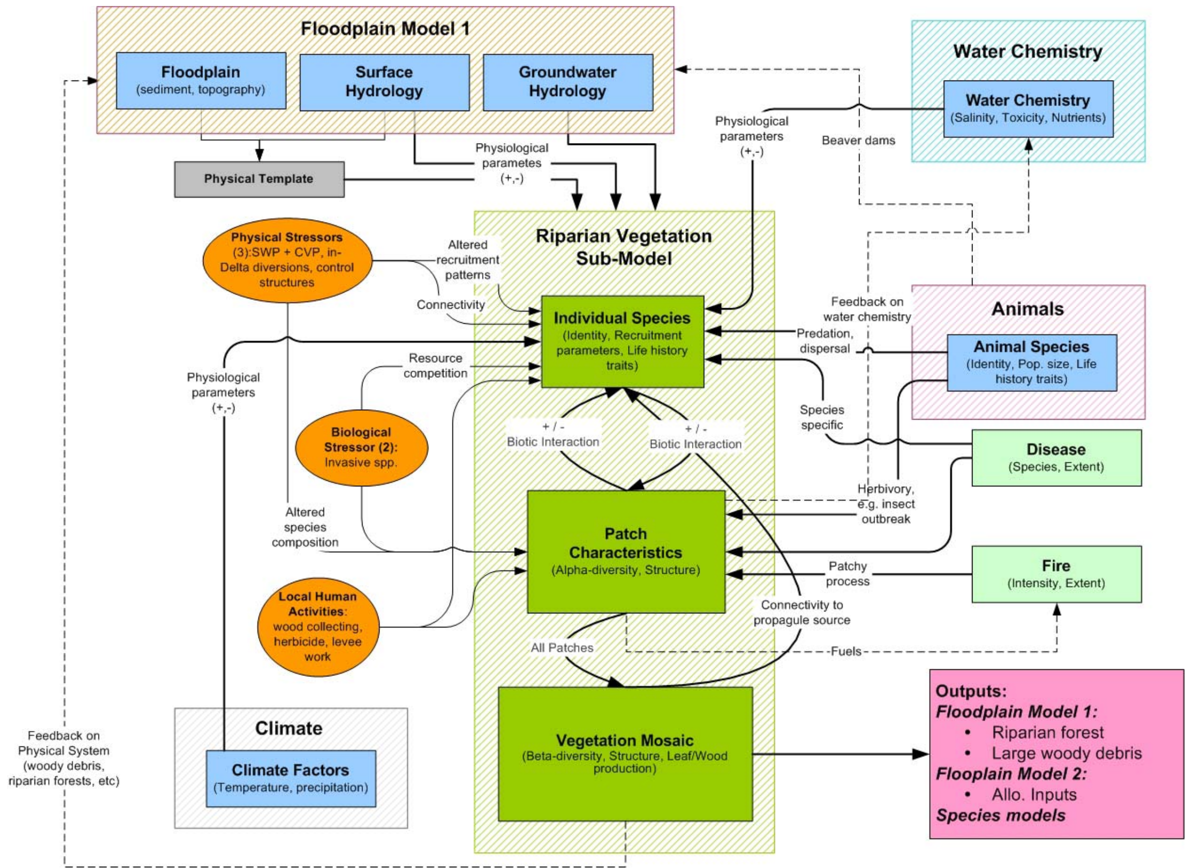

Figure 7. Riparian Vegetation (RV) Sub-model—detailed view. This diagram shows more details of the Riparian Sub-Model. As in Figure 6, the drivers from Floodplain Model 1 are simplified and modified from their original form. The green box illustrates how each driver can effect seedling establishment, patch formation, and finally the vegetation mosaic of the entire landscape.

3.2.1 Geomorphology Factors

Geomorphology refers to the physical processes that drive the creation, alteration, and obliteration of landforms. These processes include channel migration, point bar and natural levee formation, channel avulsions, overland erosion, and others. For the RV Sub-model, geomorphology factors also encompass the physical effects of hydraulic forces on the land such as vegetation removal, as well as the human alteration of floodplain geomorphology such as levee construction, levee removal, channelization, and bank protection. Under various management scenarios the different aerial extents and types of floodplain are important variables for RV. The area and type can change depending on the scenario—a change in land use, an increase in height or length of levees, increased sediment movement, more or less physical disturbance, etc. These changes range in time scale from daily to millennial.

One especially important geomorphic phenomenon occurring in the Delta is land subsidence (Figure 4). Implementing and operating large-scale agricultural development in the Delta involved levee-building to prevent frequent flooding and subsequent draining, clearing and tilling of the marshlands that were once dominated by tules and other marsh vegetation. Reclamation and agriculture have led to subsidence of the land surface on the developed islands in the central and western Delta (Ingebritsen, *et al.*, 2000). Long- term average subsidence rates of 2.5-7.5 cm per year are reported by Rojstaczer and others (1991) and Rojstaczer and Deverel (1993), and through time this has resulted in many of the islands in the central Delta currently at 3 to nearly 8 m below sea level. The dominant cause of land subsidence in the Delta is decomposition[8] of organic carbon in the peat-rich soils (Ingebritsen, *et al.*, 2000) as caused by agricultural practices. These studies also showed that rates of carbon-dioxide production increase with increasing temperature and decrease with increasing soil moisture.

Floodplain (+/- area, type) – The main input to the RV model is an accounting of the area and type of floodplain changed per scenario. Riparian vegetation requires a certain amount of surface water inundation, and some species require specific degrees of substrate scour. As each scenario is routed through the model, questions such as the following can be asked: is there an increase or decrease in the area of floodplain with the necessary amount of inundation for specific RV? Some areas may be inundated more frequently, thereby altering species composition; others could be de-coupled from the waterway and inundated less frequently. Scenarios could change species composition significantly (e.g. wetland to riparian forest or grassland) or more subtly (e.g similar species with varied proportions and/or complete species extirpation). For example, the steepening of shorelines decreases the amount of inundated floodplain by reducing the potential inundation area. In this scenario, there is a loss in area and potential changes to species composition. A more-detailed analysis (by way of applying the model site-specifically) would predict the loss in area as well as the type of floodplain, such as tidal versus fluvial riparian communities. Potentially, the loss of specific species assemblages because of management, climate change, or other factors could result in specific locations or species assemblages targeted for restoration or mitigation.

3.2.2 Hydrology Factors

This class of parameters pinpoints those characteristics of surface water and groundwater hydrology related to plant physiological requirements. While these are closely aligned with some of the required geomorphic processes (i.e. habitat turnover caused by fluvial disturbance), the surface water patterns for plant physiology are distinct and are summarized as inundation duration, frequency, magnitude, timing, and velocity. Each component of the hydrograph affects vegetation recruitment patterns of the various species, e.g. inundation can lead to anoxia of certain plants, frequency and velocity of flow increases the likelihood of recruitment for some species and the timing of flows can impact survival by increasing drought stress.

Surface water (inundation regime) – Riparian vegetation and soils benefit from flooding because of the increase in water availability, exposure of new mineral soils for new germination sites and from the influx of propagules that flood waters bring; however the later process can also bring in invasive species as well. With changes in the surface water inundation regime there will be concomitant changes in floodplain type. The hydrologic and geomorphic repercussions of flooding are integrated and addressed in the Floodplain Model

[8] Before draining for agriculture, island soils were waterlogged and anaerobic (oxygen-poor); organic carbon accumulated faster than it could decompose. Agriculture practices drained the soils and led to aerobic (oxygen-rich) conditions that favor rapid microbial oxidation of the carbon in the peat soil. Field studies (Deverel and Rojstaczer, 1996) determined that most of the carbon loss is emitted as carbon-dioxide gas to the atmosphere and that the increased flux of carbon dioxide gas from the drained peat soils was sufficient to explain most of the carbon loss and measured subsidence.

(Figure 2), and the effects of flooding on propagule sources and timing are incorporated in the 'physiological parameters' arrow between surface hydrology and riparian vegetation in Figures 6 and 7.

Riparian plants are adapted to particular inundation regimes (frequency, duration, magnitude, etc). The recruitment and/or survival zone of each species changes seasonally, annually, and decadally. This linkage requires understanding how the hydrology might change related to the physical template and how these changes might interact with habitat requirements of a particular species. For example, under a specific scenario, there might be more or less land at a certain level of inundation and hence, more or less hydraulic disturbance. That determination must them be routed through the specific requirements of that plant species to determine if the species will benefit or not from the alteration in the scenario.

Groundwater (depth) – Changes in groundwater can have an effect on the physical template. Questions that can be addressed via this parameter include: Does the specific scenario potentially increase or decrease floodplain stability via changes in groundwater depth? Does this change in depth alter the amount and type of floodplain? And if so, in what direction does it change?

3.2.3 Chemistry Factors

Water chemistry is an important driver for RV in the Delta. The timing and extent of salt water intrusion is probably the most important water chemistry driver; however, other water chemistry parameters, such as water contaminants and plant soluble nutrients, can also have significant impacts on vegetation composition. These drivers are governed by the flood and groundwater characteristics outlined above yet.

Salinity – Water salinity effects on plant composition are a function of site location along the salinity gradient. This gradient runs from tidal communities to freshwater riparian plant communities and can have a lasting effect well after the salt water retreat (Warner and Hendrix 1984). The historic limits of this saltwater intrusion have been reduced and its gradient increased by the construction of upstream dams (CDWR 1981). Because of flow regulation (i.e., increased summer flows), salt water levels and extent are less than historical accounts.

In spite of reduced salinity in the Delta following flow regulation, vegetation records obtained from tidal marshes in the San Francisco Bay document increases in salt tolerant plant species in the past century (Byrne *et al*. 2001; Malamud-Roam and Ingram 2004; May 1999). In many cases, these historical changes in marsh vegetation were abrupt and coincided with the mid-twentieth century completion of major reclamation projects in the Central Valley (Shasta Dam, Friant Dam, and the Delta-Mendota and Friant-Kern canals) (Malamud-Roam, *et al.*, 2007). Mount and Twiss (2005) suggest that with the reduction in spring flooding from Central Valley dam operations, the peak salt water intrusion extent occurs in spring rather than historically in late fall. This change in timing of peak salinity could have caused the observed increases in saline tolerant species in the Bay. The extent to which *riparian* vegetation has followed this recession of brackish and salty water and variability in timing is yet unclear. Both the dynamics of salt water intrusion (extent and timing) will affect RV composition in the Delta and the effects will differ among species and scenarios. Appendix A provides a summary of salinity tolerance characteristics for various riparian species in the

Delta, and assessing future trends is possible given knowledge of existing locations of a species and projections of changes in salinity.

Nutrients – Nutrients, primarily nitrogen (N) and phosphorous (P), are important ingredients in all organisms and as such, are required for primary production in any food web. Prior to Euro-American settlement, abundant N and P were likely available to the Delta aquatic food web through the highly productive tidal marshes that covered about 87% of Delta (Atwater and Belknap, 1980). Because of the loss of approximately 95% of the original extent of tidal marsh, nutrient inputs from current tidal marshes are a small percentage of historical levels. Since the 1800's, the energy basis for the Delta aquatic foodweb has shifted from one based on detrital production (contributed from the tidal marshes) to one based on primary production by phytoplankton (Jassby *et al.*, 2003). In the same time period, the primary nutrient source to the Delta aquatic system shifted from tidal marshes to agricultural drainage, and aquatic nutrient levels currently exceed primary production needs in the Delta (Jassby *et al.* 2003). Thus, the Delta is generally considered to not be nutrient-limited.

Currently, excessive nutrient loading from agricultural and urban runoff have led to large, harmful phytoplankton blooms in particular areas of the Delta (Miller *et al*. 2002) and have promoted the growth of some invasive aquatic plants over native species. Invasive aquatic plants, such as water hyacinth (*Eichhornia crassipes*) and Brazilian waterweed (*Egeria densa*), are favored by high nutrient levels and interfere with water conveyance, recreation and boating, and restoration of native emergent wetlands. Excessive growth of weedy aquatic species also depletes dissolved oxygen levels, sometimes leading to fish die-offs, particularly in the south Delta (Lee and Jones-Lee, 2004). Thus based on our current understanding of Delta nutrient dynamics, excessive nutrients are an existing problem in some localities and a potential problem in the overall Delta.

Low-gradient riparian areas are known to effectively filter nutrients, such as N and P, from ground and surface waters (Karr and Schlosser 1978; Lowrance *et al.* 1984; Peterjohn and Correll 1984). This 'filtering function' for N is performed in riparian areas primarily through plant nutrient uptake and incorporation into their biomass, and through denitrification, an anaerobic microbially mediated process (Peterjohn and Correll 1984, Licht 1990). For P, this filtering function involves sediment-bound P that can be captured and sequestered in the slow waters and clay particles associated with riparian vegetation (Cooper and Gilliam 1987; Cooper *et al*. 1987).

The RV Sub-model depicted in Figure 6 shows an arrow from the RV Sub-model to the water chemistry, indicating the nutrient filtering effects riparian vegetation has on water chemistry (and in the Delta, a benefit to water quality). In general, the greater the area of riparian vegetation and its rooting zone that is in contact with groundwater and surface water flowing into the Delta, the more likely it is that N and P will be removed from those waters while passing through the riparian zone (Malanson, 1993; Naiman *et al*., 2005). Of course, for a riparian area to remove excessive nutrients from groundwater and surface water, the riparian zone must be located down-gradient from a source, such as agricultural and/or urban lands, and the ability to remove nutrients is also linked inundation duration of the riparian area and/or rooting zone. Hence, to maximize the nutrient-removal benefits of riparian areas other drivers in the RV Sub-model must also be optimized (i.e., floodplain morphology).

While arrows that link riparian vegetation to water chemistry are not drawn into the more-detailed diagram of the RV Sub-model (Figure 7), the relationship can be conceptualized at the three scales represented in the diagram (individual plant, patch, and landscape mosaic). Thus, the larger the patch of low-gradient, hydrologically-connected riparian vegetation, the greater the water quality benefits. Similarly, the more extensive the distribution of these patches throughout the landscape, the more important their effects.

Contaminants – Excessive levels of organochlorines, toxins left from historical uses of pesticides such as DDT and dieldrin (Lee and Lee-Jones, 2004; Miller *et al*., 2002) exist in the Delta and its tributaries. Other pesticides and herbicides, as well as heavy metals, are also of concern in the Delta (Werner *et al*., 2008). Riparian zones can reduce some contaminant levels in ground or surface water as the water moves towards the channel (Weber *et al*., 2005); but riparian areas and wetlands can have variable effects on toxicity and availability of other contaminants (such as mercury; Alpers *et al*., 2008; Marvin-DiPasquale et al. 2003; Hunerlach et al. 2004). Although contaminants such as DDT, mercury, and PCBs can clearly affect the animals that live in or depend on riparian habitats, water borne contaminants have no known measurable effects on the growth and composition of riparian vegetation. Overall, the interaction between riparian vegetation and contaminants in groundwater and surface water is not considered to be a significant driver of either water quality or riparian structure and diversity. However, the effects of riparian vegetation on contaminants known to be removed, degraded, or sequestered in riparian zones can be incorporated in the Riparian Sub-Model in the same way as described above for nutrients.

3.2.4 Non-Hydrologic Disturbance Factors

Fire – Fire is an important ecological process to consider in landscape management, and is increasingly considered an important ecological process in riparian areas (Dwire and Kauffman, 2003; Pettit and Naiman, 2007). At the patch scale, fire significantly alters species composition. At the landscape scale it can increase complexity of the habitat mosaic by creating patches of variable age and species composition (Agee, 1988). Fire patterns in riparian areas are unique compared to upland areas because of both local and landscape conditions. Relatively-high moisture levels in riparian areas reduce fire frequency and intensity; thus riparian areas can act as refugia for fire sensitive species while adjacent areas burn. Conversely, in drier climatic conditions (season to decadal) riparian areas with high accumulations of dry fuel can act as corridors for fire because of their linear connectivity across the landscape (Agee 1988).

Fire in riparian areas of the Delta has obvious management implications for the ecosystem and adjacent human communities. For example, at different times riparian areas can act as fire buffers or as fire corridors. Fire can also have both desirable and undesirable consequences on riparian vegetation, depending on the original community condition. For example, where remnant riparian vegetation patches are small and rare, fire in the riparian zone could destroy the last few of the remaining patches and clearly would be undesirable. Where native riparian vegetation is more extensive, fire can increase habitat diversity and could therefore be considered a desirable process. In either case, fire can play a significant role in riparian vegetation characteristics locally, over the entire Delta, and even outside the Delta. Fire can increase invasive non-native species, because these species frequently invade openings created through disturbance, such as fire. Additionally, because some non-native species, such as giant reed, can increase the dry fuel load and flammability of an area (Coffman, 2007), some invasive species can disrupt the fire natural regime, increasing the flammability above that of an un-invaded riparian area, and hence increasing the risk of fires growing in size and becoming stand-replacing.

Animals – Animals can affect the composition and structure of riparian vegetation through grazing, engineering (e.g. beaver), seed dispersal and seed scarification (Naiman and Rogers 1997, Naiman et al. 1988). Herbivores, such as deer and beaver, can affect plant growth through browsing. Heavy browsing can reduce overall vegetation cover and in some instances browsing can change the species assemblage of a site to favor the less palatable species, such as coyote brush, over more palatable species such as cottonwood, oak, and willow (Pastor *et al*., 1988; Pastor *et al*., 1993). Light grazing can foster increased plant growth and density (McNaughton, 1979; McNaughton, 1985), particularly if grazing intensity is highest during the dormant period in late summer and fall (Oesterheld and McNaughton, 1991; Painter and Belsky, 1993). Herbivory from deer, beaver, and even mice, can reduce seedling survival rates and has been a problem for riparian restoration projects in the Delta and adjacent lands.[9] Wild turkeys, along with many other bird and rodent species, prefer acorns for food and could deplete the number of acorns available for reproduction (Glusenkamp, 2003) and as mentioned below, act as dispersal agents.

Beaver occur in the Delta and can have significant local effects on riparian plant species composition since they selectively harvest cottonwoods over other hardwoods (Johnston and Naiman 1990a, 1990b; Pollock *et al*., 1995). Beaver dam construction clearly affects local hydrology by inundating areas upstream of the dam and reducing flows downstream. Burrowing animals may also be considered threats to levee integrity (e.g. Bethel Island and Jones tract 2004 Breach; Bay Crossing 2005).

Animals can also act as key dispersal agents for many riparian species in the Delta, including Valley and live oak (*Quercus lobata*, *Q. agrifolia*, and *Q. wislizeni*). Ants, birds, rodents, and chipmunks are all effective seed dispersers in the riparian zone and can provide important linkages among disconnected patches to increase alpha and beta diversity (Naiman et al. 1993). Seeds of invasive exotics, such as Cockelbur (*Xanthium spp*.) and ripgut brome (*Bromus diandrus*) are also distributed by animals. Thus seed and propagule dispersal by animals can increase “genetic” connectivity among patches.

[9] Herbivory has been reported to impact revegetation success at New Hope Tract Phase I mitigation parcel and at various restoration sites in the Cosumnes River Preserve.

In a partial feedback loop, animal populations that live in and affect the structure and composition of riparian vegetation are also affected by the extent and quality of the riparian habitat. The freshwater wetlands, marshes, and riparian areas found in the Delta may serve as critical wintering grounds for migratory birds traveling along the Pacific Flyway. Riparian or wetland dependent bird species include wading birds such as great egret, great blue heron, rails, and a wide variety of waterfowl and shorebirds, including mergansers, western grebes, and killdeer. In addition, passerine species such as sparrows and warblers inhabit dense shrubby vegetation that borders riparian and wetland areas. Several raptor species nest in the riparian zone, some on the ground (Northern harrier), while others such as the white-tailed kite and Swainson's hawk may nest higher up in willows, oaks, or cottonwood stands of riparian forests adjacent to their upland foraging areas. Ground squirrels, hares, voles and other small mammals (commonly living in the riparian zone or in edge habitat nearby) are found throughout the Delta and comprise a large percentage of the diet of birds of prey and carnivores such as barn owls, red-tailed hawks, and coyotes. Additionally, their abandoned burrows can provide habitat for nesting burrowing owls and high water, thermal, and over-wintering refugia for aquatic garter snakes, including the giant garter snake.

Disease - Overall, there are no known diseases likely to importantly affect riparian vegetation and /or riparian function in the Delta. Although no known major disease threatens Delta riparian vegetation, currently unforeseen diseases could occur and have major impacts to plant species composition and structure (e.g. Chestnut blight on Appalachian hardwood forests, Dutch elm disease on Eastern deciduous forests). Two diseases that could impact Delta riparian areas in the coming decades include Pierce's disease and Sudden Oak Death. Pierce's disease infects and kills grape plants in vineyards located in coastal California, southern California and the Central Valley. Sap-sucking insects, such as sharpshooters, act as vectors of the disease-causing bacteria, transporting the bacteria from reservoirs in adjacent vegetation to the vulnerable grape plants. Currently, the disease and three types of insect vectors have been in northern California for at least 100 years but have not become a major issue in the Delta vineyards and are not expected to in the future (Dr. Bruce Kirkpatrick, pers. comm.). However, the glassy-winged sharpshooter is another Pierce's disease vector currently infecting vineyards and orchards in southern California and could become a major threat to vineyards in the Delta in the future. The riparian plant species used by the glassy-winged sharpshooter include many of the important riparian species in the Delta: wild grape (*Vitis californica*), blackberry (*Rubus spp*.), willow (*Salix spp*.), oak (*Quercus spp*.), cottonwood (*Populous spp.*), elderberry (*Sambucus spp*.), and alder (*Alnus spp*.) (PDCP, 2007). Were this sharpshooter to become established in the Delta, its occurrence could indirectly affect management of riparian areas as reducing nearby breeding host plant species is one potential control tactic. Another would likely include spraying insecticides in the riparian area during the spring to kill the insects before they emerge from breeding to infect the grape plants. However, existing regulations disallow destruction of riparian vegetation, so other than effects associated with pesticide applications and landuse change following vineyard failures, no other important impacts to riparian vegetation composition or function are predicted if the Delta becomes infested with the glassy-winged sharpshooter.

The other disease that could possibly alter plant species composition in Delta riparian areas is Sudden Oak Death. However, no cases of Sudden Oak Death have been reported in the Delta (Oak Mapper, 2007). Furthermore, although this disease can infect oak species common to riparian zones in the Delta, e.g. valley oak (*Quercus lobata*), it has not been observed as a serious threat to the survival of these species in the field (Rizzo, 2003).

3.2.5 Climate Factors

Climate factors that directly affect riparian vegetation are changes in rainfall and temperature, including direction, magnitude and timing. The secondary effects of altered climate are through changed hydrology and are discussed in Section 4. Changes in seasonal temperatures will influence species composition by favoring some species over others. Relationships between individual success and changes in climatic variables can be explored using information provided in Appendix A.

3.2.6 Plant Ecology

Successful recruitment of riparian vegetation requires plant reproductive material and "species-appropriate" configurations of certain physiological parameters including substrate, inundation, and water chemistry. Appendix A provides a listing of the species-specific requirements for a variety of parameters, as well as the relative importance of each parameter to individual species.

The connectivity between the recruitment habitat and a seed (or reproductive material) source is a feature of the landscape and includes variables such as hydrological connectedness and/or geographic proximity to existing riparian forest patches. A key question that this addresses is: once the reproductive material is transported, is there appropriate recruitment habitat available? Habitat refers to space for seed germination and the required recruitment parameters. This could be on open substrate or under an existing canopy; the suitable habitat parameters are unique for each species. Habitat is largely determined by the physical template, but the presence of other species also impacts germination success and subsequent survival.

The right combination of physiological parameters and interactions with other species is complex and can change depending on the combination of variables. For example, cottonwood recruitment depends on the timing of flows with seed release and the rate of spring decline in soil moisture/groundwater. In this case, soil type influences the inundation that is necessary for survival—i.e., if there is more porosity, more inundation is required, and indeed, particular soils might inhibit or spur the growth of certain species. An example of this comes from regulated rivers in California, where a constant flow regime favors certain species of alder (*Alnus spp.*) over cottonwood (*Populus spp.*): flow management can alter the composition of riparian forests by altering recruitment, survival and disturbance patterns.

Physiological parameters (surface water, groundwater, and water chemistry) –These three model inputs relate both to seedling establishment and riparian vegetation survival. Changes to the hydrology can directly affect riparian vegetation by altering the patterns of recruitment and survival (favoring one species over another, particularly invasive species) and connectivity between habitat patches. Surface water and groundwater hydrology drive the recruitment and establishment parameters of vegetation somewhat independently of the physical template. These include the recruitment parameters for necessary seedling survival—i.e. the recruitment box, biotic competition and anoxia (Mahoney and Rood, 1998). More specifically, these are related to the timing, magnitude, duration and frequency of flood water inundation. For example, if the scenario increases water inundation (groundwater and surface water), then this will have an effect on the location of seedling establishment and survival (i.e. anoxia). Increased salinity can affect species distributional patterns as well.

Connectivity – Individual seeds or propagules must have a physical connection or pathway to a site with suitable substrate and other conditions for successful recruitment. Elimination of pathways or mechanisms necessary to maintain this connectivity (i.e., extirpation of an animal that formerly dispersed seeds) may result in decreased success or elimination of recruitment. For water-carried propagules or seeds, altered hydrology in the Delta may have adverse effects that are not documented.

Disturbance/Succession –Vegetation patches form on newly deposited or cleared land when recruitment parameters are met. These patches change with time and in riparian systems they tend to change uni-directionally. However, invasive species can confound this pattern. Furthermore, without changes in the opposite direction (e.g. disturbance), the landscape of vegetation patches can become homogeneous and skewed toward later seral vegetation types.

Habitat Mosaic – Some aspects of vegetation are recognized as properties at a landscape level. For example, connectivity between patches is necessary for animal species as well as seed dispersal. In addition, in natural systems, not all patches are in the same successional stage, so management efforts also need to focus on managing for an uneven distribution of forest stages in the system at any given time. The model's outcomes are based on properties of the entire landscape and individual species, including species composition, sources of large woody debris, feedback on the physical system, and the aerial extent and connectivity of vegetation patches.

4. Anthropogenic and Climate Stressors

4.1 Physical Stressors

Physical Stressors in the model include the State Water Project (SWP) and the Central Valley Project (CVP), in-Delta diversions, and various hydrologic/hydraulic control structures. These disturbances have the potential to affect riparian vegetation in the immediate site area by direct removal of floodplain; however, this is a very small aerial extent. Rather, it is the operation of these projects and structures that alter the hydro-geomorphology of the Delta, ultimately affecting the area and type of floodplain in the system. Indirect effects of these physical stressors include potential changes in frequency of recruitment and survival parameters (i.e. changes in hydrology), and altered flow patterns through the Delta could affect seed exchange between patches of riparian vegetation.

Currently most of the Delta is used for agriculture and the remnant riparian vegetation is frequently restricted to a very narrow fringe atop steepened and riprap armored levees. Prior to disturbance, riparian forest probably covered much of the rim of the natural levees and floodplains in the Delta. Another key physical stressor to riparian vegetation in the Delta is the negative feedback caused by the currently small extent of viable floodplain and riparian forest. Because of the small source area, recruitment suffers from decreased propagule source, diminished available substrate, and a vastly reduced available area that has the topography and inundation regime suitable for vegetation establishment. Any increases in riparian vegetation because of restoration, despite how small any one individual project may be, will have a strong positive feedback on the overall coverage and Delta riparian system because the current extent is relatively small.

Additional sources of physical stressors (Gergel *et al*. 2002) that are largely un-quantified for the Delta include human alternation and disturbance from bank trampling for fishing and camping access, direct removal from wood harvesting, levee maintenance work (including vegetation clearing, addition of rock revetment, and topographic modifications) and herbicide application.

4.2 Chemical Stressors

The direct impact of chemicals in the riparian system depends on the toxins; however, higher levels of toxins presumably increase tree and seedling mortality. The extent to which this happens in the Delta appears unknown.

4.3 Biological Stressors

The main biological stressor is invasive species. Certain species (typically non-natives) have the potential to impact riparian vegetation through resource competition (space, light, water and nutrient resources) and indirectly by altering hydrology and geomorphic patterns. Invasive species can displace both seedlings and mature trees at the site, patch or even landscape spatial scale. Species of particular concern in the Delta include riparian pepperweed (*Lepidium latifolium*), giant reed (*Arundo donax*), and others listed in Appendix A.

4.4 Climate Change

Sea level plays a dominant role in affecting vegetation in the Delta. Water surface elevations and associated fluctuations because of tides, meteorological conditions and freshwater inflows drive Delta hydrodynamics. Hydrodynamics, in turn, are a key driver in the availability of suitable habitat for riparian vegetation. Hence, change in sea level has the potential to substantially alter riparian conditions in the Delta. Predicted sea level rise and reduced proportion of precipitation falling as snow because of climate change (see Transport model) will likely alter freshwater outflow and hence change the location of the salinity threshold in the Delta (Chalecki and Gleick, 1999; Gleick and Chalecki, 1999).

The CALFED Independent Science Board (ISB, 2007) prepared a memo for the Delta Blue Ribbon Task Force providing recommendations for which of the many sea level rise (SRL) estimates to use in planning for the future of the Delta. Noteworthy is that the ISB recommends using higher rates of SLR than presented in the Intergovernmental Panel on Climate Change (IPCC) 2007 report. The ISB recommends using a mid-range SLR of 70-100 cm over the next 100 years, with a full range of variability of 50-140 cm. This range is potentially substantial relative to implications of vegetation recruitment and shifts in species composition from changes in salinity[10].

[10] These scenarios can be assessed for riparian vegetation by using Transport model coupled with specific assumptions and species requirements in Appendix A.

5. Two Applications of the Riparian Vegetation Sub-Model

The following sections present two "applications" of the RV Sub-model emphasizing the relative importance, understanding, and predictability rankings for each linkage for two broadly-defined scenarios: one application for those areas or times when riverine/fluvial processes dominate a site (Figure 7) and another application for those areas or times when tidal processes dominate a site (Figure 8). We envision that each these two applications will be the "starting point" for use of the RV Sub-model in evaluating the affects on riparian vegetation from various potential actions in the Delta. Within each application of the model, the importance, understanding, and predictability rankings for each linkage are relative to each other within that application of the model; however, taken as a whole, the two applications of the model can be reviewed together to better-understand some of the important differences that exist between tidal and fluvial areas of the Delta. For instance, surface water hydrology has a stronger control on riparian vegetation than water chemistry in the fluvially-dominated areas of the Delta, and hence the line weights show high and low importance, respectively. In the tidally-dominated areas, groundwater and water chemistry are more-important.

5.1 Fluvially-Controlled Areas

In fluvially-dominated areas of the Delta the surface water hydrology plays a strong role in determining riparian vegetation, both through land forming processes and inundations. In concert, geomorphic processes and surface inundation patterns control how much land is available for colonization and which species are present. The physiological parameters of surface water, groundwater, and water chemistry have a distinct role in determining the species composition of an area. As a generalization, plant species tend to be well organized over a gradient of inundation and time since disturbance. Descriptions of these relationships are clear at a broad level, even predictable over large spatial and temporal scales; however, changes under different scenarios might alter these relationships, and because of the multivariate nature of plant establishment and survival, the location and the area of each species/community under various scenarios is not highly predictable. Table 2 is a summary of the linkages for Figure 8.

Table 3: Summary list of high and low ranking linkages for the RV Sub-model for fluvially-controlled areas. Medium levels of the rankings are not listed.

	Variable
Importance:	(High) Hydro-geomorphology, surface water
	(Low) Water chemistry
Understanding:	(High) Succession/biotic interaction, chemistry feedback, animal feedback
	(Low) Groundwater, biotic feedback on physical system, seed source connectivity, fire
Predictability:	(High) Succession/biotic interaction, water chemistry, all patches, floodplain type, fire
	(Low) Seed source connectivity, micro-scale groundwater conditions, fire feedback, disease, animals

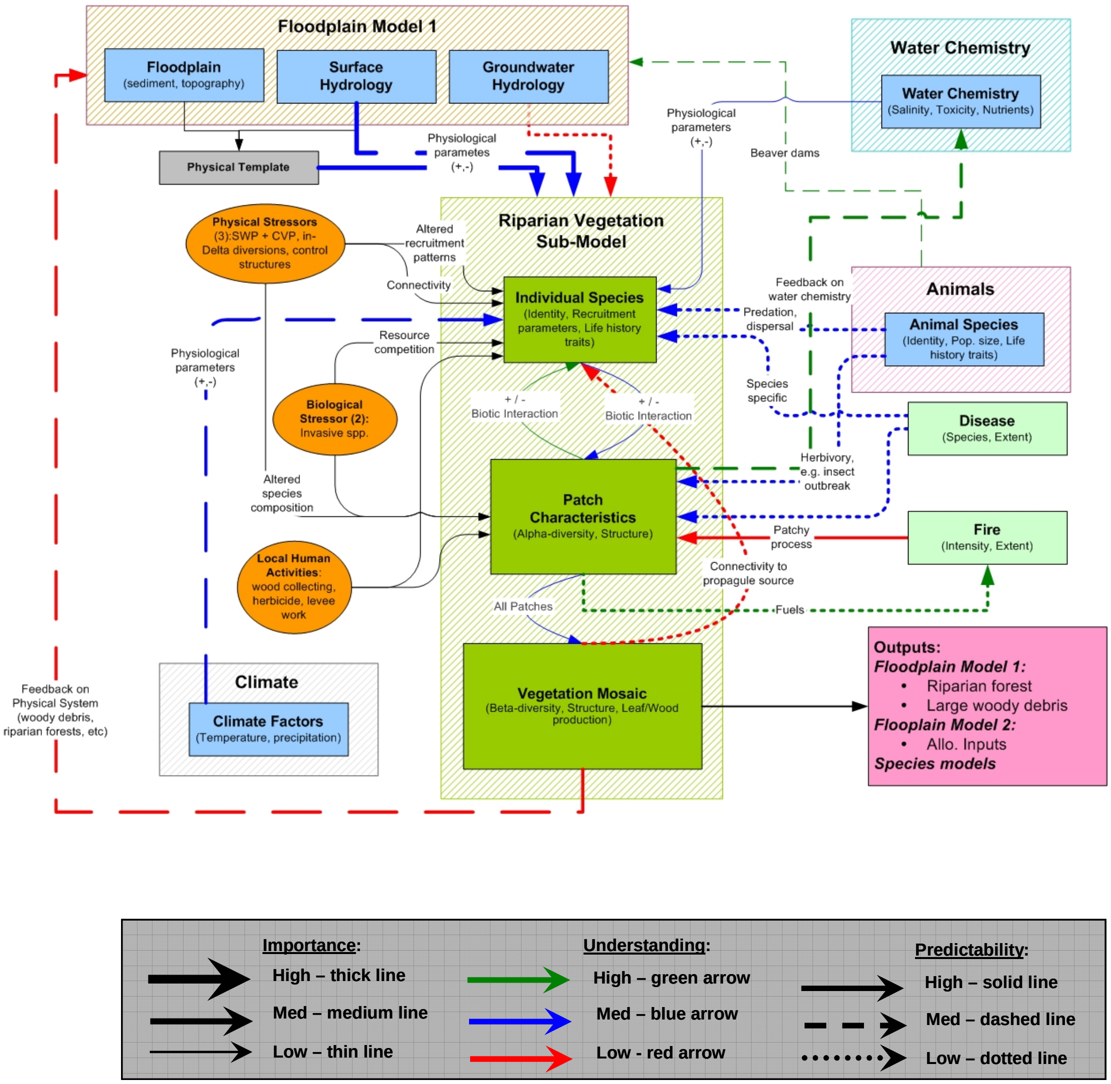

Figure 8: Riparian Vegetation (RV) Sub-model configured to emphasize riverine processes. This diagram emphasizes the important variables—as well as the relative understanding of the process and predictability of the outcome—for situations where riverine processes appear to dominate in the establishment and maintenance of riparian vegetation.

5.2 Tidally-Controlled Areas

Compared to fluvially-controlled areas, floodplain dynamics play a weaker role in the tidally-controlled areas (Figure 9) of the Delta. Salinity controls the recruitment and success of riparian vegetation and is generally well-understood. Less-well understood are the patterns and effects of groundwater depths, connectivity, and biotic feedbacks on the physical system on riparian vegetation. Surface water and groundwater hydrology have a strong influence on riparian vegetation; however, our understanding of groundwater is complicated because of unknown levels of local pumping, irregular levee construction, and is therefore relatively low. Biotic interactions are important because resource competition as well as the compatibility between site conditions and species' physiological parameters determines a patches' species composition. Seed-source connectivity between remnant stands and new habitat in the Delta presumably is less important because the area is hydraulically well-connected. However, the level of connectivity will depend on species identity and has low predictive power[11]. Groundwater in tidally-controlled areas of the Delta is particularly important in understanding riparian vegetation, while it is unknown how significant connectivity and biotic feedbacks are in controlling patch formation and species composition. Groundwater in the Delta is difficult to predict; however, its effect on riparian vegetation is probably quite predictable: higher water tables could lead to drowning of riparian vegetation, but probably helps in seedling establishment. Table 3 is a summary of the linkages for Figure 9.

Table 4: Summary list of high and low ranking linkages for the RV Sub-model for tidally-controlled areas. Medium levels of the rankings are not listed.

	Variable
Importance:	(High) Surfacewater, groundwater, succession/biotic interaction
	(Low) Connectivity to seed source, animal feeback,
Understanding:	(High) Water chemistry, chemistry feedback, animal feedback
	(Low) Groundwater, connectivity to seed source, biotic feedback on physical system, fire
Predictability:	(High) Groundwater, all patches, fire
	(Low) Connectivity to seed source, fire feedback, disease, animals

[11] For example, as mentioned earlier, the role of altered flow patterns in the Delta are thought to be a potentially important, but unknown, stressor on seed-source connectivity.

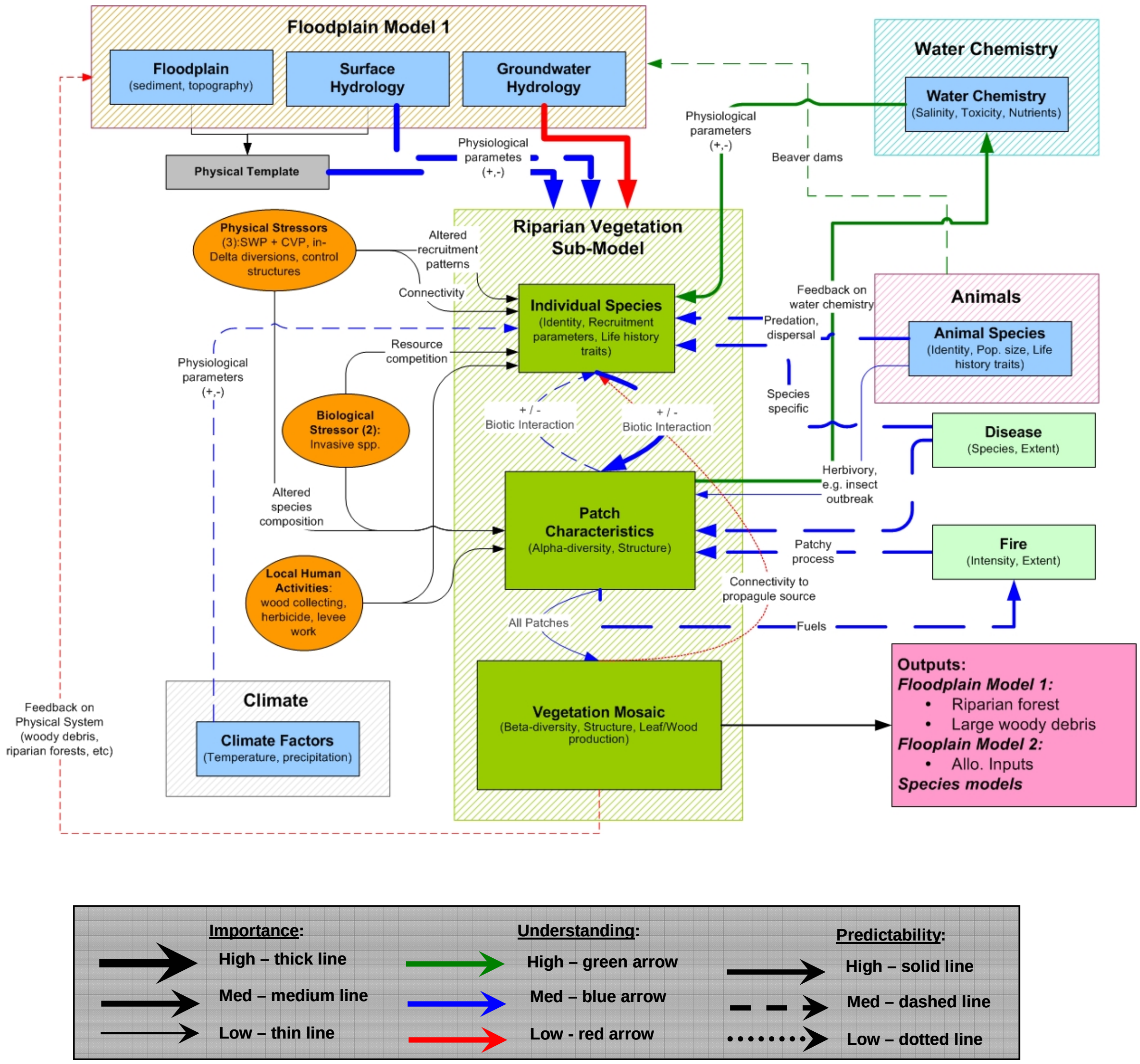

Figure 9: Riparian Vegetation (RV) Sub-model configured to emphasize tidal processes. This diagram emphasizes the important variables—as well as the relative understanding of the process and predictability of the outcome—for situations where tidal processes appear to dominate in the establishment and maintenance of riparian vegetation.

6. References

Agee, J. K. 1988. Successional dynamics in forest riparian zones. pp. 31-43 In: Streamside Management: Riparian Wildlife and Forestry Interactions. Univ. of Wash. Institute of Forest Resources Contr. 59.

Aiken, S.G., P.R. Newroth, and I. Wile. 1979. The biology of Canadian weeds. Canadian J. Plant Science. 59:201-215.

Alpers C, Eagles-Smith C, Foe C, Klasing S, Marvin-DiPasquale M, Slotton D, and Winham-Myers L. 2008. Mercury conceptual model. Sacramento (CA): Delta Regional Ecosystem Restoration Implementation Plan.

Anderson, L.W. 1987. Hydrilla (Hydrilla verticillata). Exotic Pest Profile No. 11. California Department of Food and Agriculture.

Atwater, B.F. and D.F. Belknap. 1980. Tidal-wetland deposits of the Sacramento-San Joaquin Delta, California. In M.E. Field, A.H. Bouma, I.P. Colburn, R.G. Dourglas, and J.C. Ingle, eds. Quaternary Depositional Environments of the Pacific Coast: Pacific Coast Paleogeography Symposium 4. Proceedings of the Society of Economic Paleontologists and Mineralogists, Los Angeles, CA.

Bay Crossing 2005. "Cutting off water supplies to California homes and farms". July 2005 issue, Alameda, CA.

Bay Institute. 1998. From the Sierra to the Sea: The Ecological History of the San Francisco Bay-Delta Watershed. The Bay Institute, San Francisco.

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

Borman, M.M., D.E. Johnson, and W.C. Krueger. 1992. Soil moisture extraction by vegetation in Mediterranean/maritime climatic region. Agronomy J. 84:897-904.

Bossard, C.C., J.M. Randall, and M.C. Hoshovsky, editors. 2000. Invasive Plants of California Wildlands. University of California Press.

Bradley, C. E., and D. G. Smith. 1986. Plains cottonwood recruitment and survival on a prairie meandering river floodplain, Milk River, southern Alberta and Northern Montana. Canadian Journal of Botany 64:1433-1442.

Byrne R, Ingram BL, Starratt S, Malamud-Roam F, Collins JN, Conrad ME. 2001. Carbon-isotope, diatom and pollen evidence for late Holocene salinity change in a brackish marsh in the San Francisco Estuary. Quaternary Research. 55:66-76.

CDWR (California Department of Water Resources). 1995. Delta levees: California Department of Water Resources. Sacramento, CA.

CDWR (California Department of Water Resources). 1981. Delta water supply and quality. In: The future of the Delta. California Department of Water Resources and University Extension, University of California, Davis, Sacramento, CA.

CDWR (California Department of Water Resources). 2008. Boundary Conditions conceptual model. Sacramento (CA): Delta Regional Ecosystem Restoration Implementation Plan.

Center, T.A. and N. Spencer. 1981. The phenology and growth of water hyacinth (Eichhornia crassipes (Mart.) Solms) in a eutrophic north-central Florida lake. Aquatic Botany. 10:1-32.

Cepello, S. A. 1991. Riparian vegetation distribution along the middle Sacramento River in relation to flood frequency. Masters thesis. California State University, Chico, Chico, CA.

Chalecki, E. L., and P. H. Gleick. 1999. A framework of ordered climate effects on water resources: a comprehensive bibliography. Journal of American Water Resources Association 35:1657-1665.

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

Colvin, W.I. 1996. Fennel (Foeniculum vulgare) removal from Santa Cruz Island, California: managing successional processes to favor native over nonnative species. Senior thesis, Board of Environmental Studies. University of California, Santa Cruz, CA.

Cooper, J. R. and J. W. Gilliam. 1987. Phosphorous redistribution from cultivated fields into riparian areas. Soil Science Society of America Journal 51:1600–1604.

Cooper, J. R. and J. W. Gilliam, R. B. Daniels, W.P. Robarge. 1987. Riparian areas as filters for agricultural sediment. Soil Science Society of America Journal 51:416–420.

Dash, B.A. and S.R. Gliessman. 1994. Nonnative species eradication and native species enhancement: fennel on Santa Cruz Island. In Fourth California Island Symposium: Update on the Status of Resources. W. Halvorson and G. Maender, editors. Santa Barbara Museum of Natural History. Santa Barbara, CA. pp. 505-512.

Deverel, S.J., and Rojstaczer, S.A. 1996. Subsidence of agricultural lands in the Sacramento-San Joaquin Delta, California: Role of aqueous and gaseous carbon fluxes. Water Resources Research, v. 32, p. 2359-2367.

de Winton, M.D. and J.S. Clayton. 1996. The impact of invasive submerged weed species on seedbanks in lake sediments. Aquatic Botany. 53(1-2):31-45.

Dwire, K. A., and J. B. Kauffman. 2003. Fire and riparian ecosystems in landscapes of the western USA. Forest Ecology and Management 178:61-74.

Fenner, P., W. W. Brady, and D. R. Patten. 1985. Effects of regulated waterflows on regeneration of Fremont cottonwood. Journal of Range Management 38:135-138.

Franklin, B.B. 1996. Eradication/control of the exotic pest plants tamarisk and Arundo in the Santa Ynez River drainage. USDA-FS-PSW, Washington, DC.

Fremier, A. K. 2003. Floodplain age modeling techniques to analyze channel migration and vegetation patch dynamics on the Sacramento River, CA. Masters of Arts. University of California, Davis, CA.

Gergel, S., M. Turner, J. Miller, J. Melack, and E. Stanley. 2002. Landscape indicators of human impacts to riverine systems. Aquatic Sciences. V. 64. p. 118-128.

Gleick, P. H., and E. L. Chalecki. 1999. The impacts of climate changes for water resources of the Colorado and Sacramento-San Joaquin River Basins. Journal of American Water Resources Association 35:1429-1441.

Gluesenkamp, Daniel. 2003. "California's latest population explosion: Introduced turkeys" The Ardeid 2003: 6-7.

Granath, T. 1992. Fennel on Santa Cruz Island. Year II. Senior thesis, Board of Environmental Studies. University of California, Santa Cruz, CA.

Greco, S. E. 1999. Monitoring Riparian Landscape Change and Modeling Habitat Dynamics of the Yellow-billed Cuckoo on the Sacramento River, California. PhD Dissertation. University of California, Davis, Davis.

Greco, S. E., A. K. Fremier, R. E. Plant, and E. W. Larsen. 2007. A tool for tracking floodplain age land surface patterns on a large meandering river with applications for ecological planning and restoration design. Landscape and Urban Planning.

Gregory, S. V., F. J. Swanson, W. A. McKee, and K. W. Cummins. 1991. An Ecosystem Perspective of Riparian Zones. BioScience 41:540-551.
Hoffman, J. and W. Kearns. 1997. Eurasian water-milfoil (Myriophyllum spicatum). In Wisconsin manual of Control Recommendations for Ecologically Sensitive Plants. State of Wisconsin. Madison, WI.
Hoshovsky, M.C. 2000. Rubus discolor. In Invasive Plants of California Wildlands. Carla C. Bossard, John M. Randall, Marc C. Hoshovsky, editors. University of California Press.
Hunerlach, M.P., Alpers, C.N., Marvin-DiPasquale, M., Taylor, H.E., and De Wild, J.F. 2004. Geochemistry of mercury and other trace elements in fluvial tailings upstream of Daguerre Point Dam, Yuba River, California, August 2001: U.S. Geological Survey Scientific Investigations Report 2004-5165, 66 p.
Hunter, J. C., K. B. Willett, M. C. McCoy, J. F. Quinn, and K. E. Keller. 1999. Prospects for preservation and restoration of riparian forests in the Sacramento Valley, California, USA. Environmental Management 24:65-75.
Hupp, C. R., and W. R. Osterkamp. 1996. Riparian vegetation and fluvial geomorphic processes. Geomorphology 14:277-295.
Ingebritsen SE, Ikehara ME, Galloway DL, Jones DR. 2000. Delta subsidence in California: the sinking heart of the state. U.S. Geological Survey FS-005-00. 4 p.
ISB (CALFED Independent Science Board). 2007. Memo to Michael Healey (Lead Scientist CALFED Bay-Delta Program) from Jeffrey Mount (Chair, CALFED Independent Science Board) regarding Sea Level Rise and Delta planning. September4, 2007.
Jassby, A.D., J. E. Cloern, and A.B. Muller-Solger. 2003. Phytoplankton fuels Delta foodweb. California Agriculture. 57(4):104-109.
Jepson, W. 1925 Manual of the flowering plants of California. University of California Press, Berkeley, California, USA.
Johnson, W. C., R. L. Burgess, and W. R. Keammerer. 1976. Forest overstory vegetation and environment of the Missouri River floodplain in North Dakota. Ecological Monographs 46:59-84.
Johnston, C. A. and R. J. Naiman. 1990a. Aquatic patch creation in relation to beaver population trends. Ecology 71:1617–1621.
Johnston, C. A. and R. J. Naiman. 1990b. Browse selection by beaver: Effects on riparian forest composition. Canadian Journal of Forest Research 20:1036–1043.
Jones, W. M. 1997. Spatial patterns of woody plant regeneration in two California Central Valley floodplain forests. Master thesis. University of Montana, Missoula, MT.
Karr, J. R. and I. J. Schlosser. 1978. water resources and the land-water interface. Science 201:229–134.
Keeler-Wolf, T., K. Lewis, C. Roye. 1994. The definition and location of sycamore alluvial woodland in California. Natural Heritage Division, Department of Fish & Game, Sacramento. Prepared for Department of Water Resources.
Klyver, J. 1931. Major plant communities in a transect of the Sierra Nevada Mountains of California. Ecology 12:1-17.
Knapp, R. 1965. Die Vegetation con Nord- un Mittelamerika und de Hawaii-Inseln. Gustave Fisher-Verlag, Stuttgart, Germany.
Knowles, N. 2000. Natural and human influences on freshwater flows and salinity in the San Francisco Bay-Delta estuary and watershed. Interagency Ecological Program for the Sacramento-San Joaquin Estuary Newsletter 13:5-23.

Langeland, K. 1990. Hydrilla: a continuing problem in Florida waters. Florida Cooperative Extension Circular No. 884. Miami, FL.
Lee, G.F., and A. Jones-Lee. 2004. Overview of Sacramento – San Joaquin River Delta waters quality issues. Prepared for the Delta Keepers. 148 pages. Accessed on the world wide web on November 14, 2007 at:http://deltavision.ca.gov/docs/Status_and_Trends/Selected%20References/Water%20Quality%20Management%20and%20Discharges/Overview%20of%20Sacramento-San%20Joaquin%20River%20Delta%20-%20Water%20Quality%20Issues.pdf
Licht, L. A. 1990. Poplar Tree Buffer Stirps Grown in Riparian Zones. Ph.D. dissertation, University of Iowa, Iowa City.
Lowrance, R. Todd, R., Fail, Jr., J. Hendrickson, Jr., O., Leonard, R., Asmussen, L. 1984. Riparian forests as nutrient filters in agricultural watersheds. BioScience 34-374–377.
Mahoney, J.M. and S.B. Rood, 1998. Streamflow requirements for cottonwood seedling recruitment:An integrative model. Wetlands. 18:634-645.
Malamud-Roam, F., M. Dettinger, B. L. Ingram, M. K. Hughes, and J. L. Florsheim. 2007. Holocene Climates and Connections between the San Francisco Bay Estuary and its Watershed. San Francisco Estuary and Watershed Science. Vol. 5, Issue 1 (February 2007). Article 3. http://repositories.cdlib.org/jmie/sfews/vol5/iss1/art 3
Malamud-Roam F, and L. Ingram. 2004. Late Holocene δ13C and pollen records of paleosalinity from tidal marshes in the San Francisco estuary. Quaternary Research. 62:134-145.
Malanson, G. P. 1993. Riparian Landscapes. Cambridge University Press, Cambridge.
Marvin-DiPasquale, M., Agee, J., Bouse, R., and Jaffe, B., 2003, Microbial cycling of mercury in contaminated pelagic and wetland sediments of San Pablo Bay, California: Environmental Geology, 43(3):260-267.
May, MD. 1999. Vegetation and salinity changes over the last 2000 years at two islands in the northern San Francisco Estuary, California. [M.A. Thesis]. Available from U.C. Berkeley.
McBride, J. R., and J. Strahan. 1984. Establishment and survival of woody riparian species on gravel bars of an intermittent stream. American Midland Naturalist 112:235-245.
McNaughton, S. J. 1979. Grazing as an optimization process: grass-ungulate relationships in the Serengeti ecosystem. American Naturalist 113:691-703.
McNaughton, S. J. 1985. Ecology of a grazing ecosystem: the Serengeti. Ecological Monographs 55:259-294.
Miller, J. M. Miller, K. Larsen. 2002. Identification of causes of algal toxicity in Sacramento –San Joaquin Delta. Central Valley Regional Water Quality Control Board, Sacramento, CA. 29 pp.
Mount, J. F., and R. Twiss. 2005. Subsidence, sea level rise and seismicity in the Sacramento-San Joaquin Delta. San Francisco Estuary & Watershed Science 3.
Naiman, R. J., J. S. Bechtold, D. Drake, J. J. Latterell, T. C. O'Keefe, and E. A. Balian. 2005. Origins, patterns, and importance of heterogeneity in riparian systems.in C. G. J. G. Lovett, M.G. Turner, and K.C. Weathers, editor. Ecosystem Function in Heterogeneous Landscapes. Springer-Verlag, New York.
Naiman, R. J. and H. DeCamps. 1997. The ecology of interfaces: Riparian zones. Annual Review of Ecology and Systematics 28: 621–258.

Naiman, R. J. and K. H. Rogers. 1997. Large animals and the maintenance of system level characteristics in river corridors. BioScience 47: 521–529.

Naiman, R. J., H. Décamps, and M. Pollock. 1993. The role of riparian corridors in maintaining regional biodiversity. Ecological Applications 3:209–212.

Naiman, R. J., H. Decamps, M.E. McClain. 2005. Riparian: Ecology, Conservation, and Management of Streamside Communities. Elsevier Academic Press.

Naiman, R, J., C.A. Johnston, and J.C. Kelley. 1988. Alteration of North American streams by beaver. BioScience. 38:753-762.

NRC. 2002. Riparian Areas: functions and strategies for management. National Research Council. National Academy Press, Washington, D.C.

Oak Mapper 2007. Monitoring Sudden Oak Death with web GIS. Accessed on the world wide web on November 14, 2007 at: http://kellylab.berkeley.edu/SODmonitoring/Gmaps/indexr.htm

Oesterheld, M., and S. J. McNaughton. 1991. Effect of stress and time for recovery on the amount of compensatory growth after grazing. Oecologia 85:305-313.

Painter, E. L., and A. J. Belsky. 1993. Application of herbivore optimization theory to rangelands of the western United States. Ecological Applications 3:2-9.

Parsons, W.T. 1992. Noxious Weeds of Australia. Inkata Press, Melbourne, Australia.

Pastor, J., R.J. Naiman, B. Dewey, and P. McInnes. 1988. Moose, microbes, and the boreal forest. BioScience 38:770-777.

Pastor, J., B. Dewey, R.J. Naiman, P.F. McInnes, and Y. Cohen. 1993. Moose browsing and soil fertility in the boreal forests of Isle Royale National Park. Ecology 74:467–480.

PDCP: Pierce's Disease Control Program. 2007. State Ruling, section 3658, Article 3: Plants. Accessed on the world wide web at http://pi.cdfa.ca.gov/pqm/manual/454.htm#gwhostlist on November14, 2007.

Penfound, W. and T. Earle. 1948. The biology of the water hyacinth. Ecological Monographs. 18:447-472.

Peterjohn, W. T. and D. L. Correll. 1984. Nutrient dynamics in an agricultural watershed: Observations on the role of the riparian forest. Ecology 65:1466–1475.

Pettit, N., and R. Naiman. (2007) Fire in the Riparian Zone: Characteristics and Ecological Consequences. *Ecosystems*. 10:673-687.

Petts, G. E., and C. Amoros. 1996. The fluvial hydrosystem.in G. E. Petts and C. Amoros, editors. Fluvial hydrosystems. Chapman & Hall, New York, US.

Pollock, M.M., R.J. Naiman, H.E. Erickson, C.A. Johnston, J. Pastor, and G. Pinay. 1995. Beaver as engineers: Influences on biotic and abiotic characteristics of drainage basins. Pages 117–126 in C.G. Jones and J. H. Lawton, Eds. Linking species and ecosystems. Chapman and Hall: New York.

Randall, J.M. 2000. Ficus carica. In Invasive Plants of California Wildlands. Carla C. Bossard, John M. Randall, Marc C. Hoshovsky, editors. University of California Press.

Rizzo, D. M. 2003. Sudden Oak Death: Host plants in forest ecosystems in California and Oregon. Sudden Oak Death Online Symposium. www.apsnet.org/online/SOD (website of The American Phytopathological Society).

Roberts, M. D., D. E. Peterson, D. E. Jukkola, and V. L. Snowden. 2002. A Pilot Investigation of Cottonwood Recruitment on the Sacramento River. The Nature Conservancy, Sacramento River Project, Chico, CA.

Rojstaczer, S.A., and Deverel, S.J. 1993. Time dependence of atmospheric carbon inputs from drainage of organic soils. Geophysical Research Letters. v. 20, p. 1383–1386.
Rojstaczer, S.A., Hamon, R.E., Deverel, S.J., and Massey, C.A. 1991. Evaluation of selected data to assess the causes of subsidence in the Sacramento-San Joaquin Delta, California. U.S. Geological Survey Open-File Report 91-193. 16 p.
Rood, S. B., K. Taboulchanas, C.E. Bradley and A.R. Kalischuk. 1999. Influence of flow regulation on channel dynamics and riparian cottonwoods along the Bow River, Alberta. Rivers 7:33-48.
Sands, A., editor. 1980. Riparian Forests in California, Their Ecology and Conservation. University of California Press, Berkeley, CA.
Scott, M. L., G. T. Auble, and J. M. Friedman. 1997. Flood dependency of cottonwood establishment along the Missouri River, Montana, USA. Ecological Applications 7:677-690.
SFEI (San Francisco Estuary Institute). 1998. Introduced Tidal Marsh Plants in the San Francisco Estuary. Regional distribution and priorities for control. San Francisco Estuary Institute, Oakland, CA.
Schoellhamer D, Wright S, Drexler J, and Stacy M. 2007. Sedimentation conceptual model. Sacramento, (CA): Delta Regional Ecosystem Restoration Implementation Plan.
Serpa, L. 1989. Letter to Terri Thomas, Area Manager for The Nature Conservancy Preserve. Tiburon, CA.
Skinner, M.W. and B.M. Pavlik. 1994. Inventory of Rare and Endangered Vascular Plants of California. Special Publication No. 1. 5th Edition. California Native Plant Society. Sacramento, CA.
SRAC. 1998. Sacramento River Conservation Area Handbook. Sacramento River Advisory Council, Sacramento, CA.
Stella, J. C., J. J. Battles, B. K. Orr, and J. R. McBride. 2006. Synchrony of Seed Dispersal, Hydrology and Local Climate in a Semi-arid River Reach in California. Ecosystems 9:1200-1214.
Strahan, J. 1984. Regeneration of riparian forests of the Central Valley. Pages 58-67 in R. E. Warner and K. M. Hendrix, editors. California Riparian Ecosystems. University of California Press, Berkeley, CA.
Stromberg, J. C., and D. T. Patten. 1996. Instream flow and cottonwood growth in the eastern Sierra Nevada of California, USA. Regulated Rivers-Research & Management 12:1-12.
Tabacchi, E., D. L. Correll, R. Hauer, G. Pinay, A. M. Planty-Tabacchi, and R. C. Wissmar. 1998. Development, maintenance and role of riparian vegetation in the river landscape. Freshwater Biology 40:497-516.
Thompson, J. 1957. The settlement geography of the Sacramento-San Joaquin Delta, California. Ph.D. Dissertation. Stanford University, Palo Alto, CA.
Thompson, K. 1961. Riparian forests of the Sacramento Valley, California. Annals of the Association of Geographers 51:294-315.
Thompson, K. 1980. Riparian forests of the Sacramento Valley, California. Pages 35-38 in A. Sands, editor. Riparian Forests in California. The Regents of the University of California, Davis, CA.
Trowbridge, W. B., S. Kalmanovitz, and M. W. Schwartz. 2005. Growth of Valley Oak (Quercus Lobata Nee) in Four Floodplain Environments in the Central Valley of California. Plant Ecology V176:157-164.

Tu, I. M. 2000. Vegetation patterns and processes of natural regeneration in periodically flooded riparian forests in the Central Valley of California. Doctoral dissertation. University of California, Davis, CA.

Vaghti, M. G. 2003. Riparian Vegetation Classification in Relation to Environmental Gradients, Sacramento River California. Masters of Science. University of California, Davis, Davis, CA.

Vaghti, M. G., and S. E. Greco. 2007. Riparian Vegetation of the Great Valley. Pages 425-455 in M. G. Barbour and T. Keeler-Wolf, editors. Terrestrial Vegetation of California. California Native Plant Society, Sacramento, CA.

Warner, R. E., and K. M. Hendrix, editors. 1984. California riparian systems: ecology, conservation and productive management. University of California Press, Berkeley, CA.

Weber, F.A., A. Voegelin and R. Kretzschmar. 2005. Colloid-facilitated Transport of Contaminants over Redox Cycles in Temporary Flooded Riparian Wetland Soils. Geophysical Research Abstracts, Vol. 7.

Werner I, Anderson S, Larsen K, and Oram J. 2008. Chemical stressors conceptual model. Sacramento (CA): Delta Regional Ecosystem Restoration Implementation Plan.

Williams, A. 2006. Modeling the Spatial Distributions of Riparian Plant Species on the Middle Sacramento River, California, with Conservation Applications. Masters of Arts. University of California, Davis, CA.

Scientific Name	Common Name	Growth Form	Evergreen	Foliage Porosity in Summer	Foliage Porosity in Winter	Shade Tolerance	Root Depth, Minimum (inches)	Height (at 20 years or max., in ft.)	Height (when mature, or avg for herbs, in ft.)	Precip. (Min; inches)	Precip. (Max; inches)	Temperature Minimum (F)	California Wetland Indicator Status	Anaerobic (flood) Tolerance	Drought Tolerance	Moisture Use	Growth Rates	Hedge (herbivory) Tolerance	Fruit/Seed Period	Sexual Reproductive Spread Rate	Vegetative Spread Rate	Adapted to Fine Textured Soils	Adapted to Medium Textured Soils	Adapted to Coarse Textured Soils	Nitrogen Fixation	Fertility Requirement	C:N Ratio	CaCO3 Tolerance	pH (Min)	pH (Max)	Salinity Tolerance	Impact (IPC)	Invasiveness (IPC)	Protection status (e.g. CNPS lists, federel or state listed)	Comments
NATIVE WOODY SPECIES																																			
Acer negundo	boxelder	Tree	No	Dense	Porous	Intermediate	40	35	60	17	60	-43	FACW	None	High	Medium	Rapid	None	Summer to Fall		Slow	Yes	Yes	Yes	None	Medium	High	High	5.2	7	Medium	NA	NA		
Alnus rhombifolia	white alder	Tree	No	Moderate	Porous	Tolerant	12	50	75	50	125	-23	FACW	Low	None	High	Rapid	Medium	Summer		None	Yes	Yes	Yes	Low	Low	High	None	6	7.5	None	NA	NA		
Baccharis pilularis	coyote brush	Subshrub, Shrub	Yes	Dense	Moderate	Intolerant	20	10	10	12	30	22	None	None	High	Low	Moderate	High	Fall		Moderate	No	Yes	Yes	None	Low	High	High	6	8.5	High	NA	NA		
Baccharis salicifolia	mule fat	Shrub	No	Porous	Porous	Intolerant	12	10	10	10	18	-3	FACW-	Low	Low	Medium	Rapid	Low	Summer-Fall		None	Yes	Yes	Yes	None	Low	High	High	7	8.5	High	NA	NA		
Cephalanthus occidentalis	common buttonbush	Tree, Shrub	No	Moderate	Porous	Tolerant	14	20	20	28	65	-33	OBL	High	Medium	High	Moderate	None	Spring-Winter		None	Yes	Yes	Yes	None	Low	Medium	Medium	5.3	8.5	Low	NA	NA		
Fraxinus latifolia	Oregon ash	Tree, Shrub	No	Dense	Porous	Intermediate	24	35	70	20	110	7	FACW	Medium	Low	Medium	Moderate	Low	Summer		None	Yes	Yes	Yes	None	Medium	High	Low	5	7	None	NA	NA		
Juglans hindsii (based on Juglans major in USDA)	western walnut	Tree	No	Moderate	Porous	Intolerant	40	50					FAC	Low	Medium		Slow	None	Fall to winter	Slow	None	No	Yes	Yes	No		High	Low	6	7	None	NA	NA		
Platanus racemosa	California sycamore	Tree	No	Moderate	Porous	Intolerant	36	20	75	14	20	7	FACW	Medium	Medium	Medium	Slow	None	Fall		None	No	Yes	Yes	None	Low	High	Medium	5.8	7.3	None	NA	NA		
Populus fremontii	Fremont cottonwood	Tree	No	Moderate	Porous	Intolerant	32	50	90	20	26	-13	FACW	Medium	Medium	High	Rapid	None	Spring		None	Yes	Yes	Yes	None	Medium	High	Medium	6	8	Low	NA	NA		
Quercus agrifolia	northern California live oak	Tree, Shrub	Yes	Dense	Dense	Intolerant	36	25	70	20	60	7		None	Medium	Medium	Slow	None	Summer-Fall		None	No	Yes	Yes		Low	High	Low	5.5	7.5	None	NA	NA		
Quercus lobata	valley oak	Tree	No	Dense	Porous	Intolerant	42	35	100	16	40	7	FAC*	None	Medium	Medium	Rapid	None	Summer-Fall		None	No	Yes	Yes	None	Medium	High	None	4.5	7.5	None	NA	NA		
Salix exigua	narrow-leaved willow	Tree, Shrub	No	Dense	Porous	Intermediate	20	10	10	20	30	-38	OBL	High	Medium	High	Rapid	Medium	Summer-Spring		Moderate	No	Yes	Yes	None	Low	Medium	High	6	8.5	Low	NA	NA		
Salix gooddingii	Goodding's black willow	Tree	No	Dense	Moderate	Intolerant	28	40	40	12	55	-23	OBL	High	Medium	High	Rapid	None	Spring		Slow (sprouts from stems, branches)	No	Yes	Yes	None	Medium	High	Low	5.7	7.4	None	NA	NA		
Salix laevigata	red willow	Tree, Shrub	No	Dense	Dense	Intolerant		25	15	33	60		FACW?	High	Low/None	High	Rapid	Low?	June-July		Slow (sprouts from stems, branches)	Yes	Yes		None	Medium	High	tolerant of sub-alkaline soils (UC Jepson)	6	8	High/Moderate	NA	NA		
Salix lasiolepis	arroyo willow	Tree, Shrub	No	Dense	Dense	Intolerant	26	35	35	35	60	7	FACW	High	None	High	Moderate	Medium			Slow (sprouts from stems, branches)	Yes	Yes	Yes	None	Medium	High	Low	5.5	7.5	None	NA	NA		Data is for the "Rogue" cultivar.
Salix lucida	shining willow	Tree, Shrub	No	Dense	Moderate	Intermediate	10	13	13	30	60	-43	FACW, FACW+	Medium	Low	High	Rapid	Low	Spring-Summer		Slow (sprouts from stems, branches)	Yes	Yes	No	None	Medium	High	Medium	5.8	7.2	None	NA	NA		
Sambucus mexicana	blue elderberry	Shrub	No	Moderate		Intermediate	12	23	23	10	60	-38	FAC	Medium	High	Low	Rapid	Low	Summer-Fall		Moderate	No	Yes	Yes	None	Low		Medium	4.9	7.5	None	NA	NA		Listed under *Sambucus nigra* L. ssp. *cerulea*
Toxicodendron diversilobum	poison-oak	Perennial shrub/vine	No	Low	Moderate	High		10	3				None						June to September													NA	NA		
Vitis californica	California grape	Perennial vine	No	Dense	Porous	Tolerant		30	15				FACW	Low: prefers well drained soils	Medium	Medium	Rapid (several feet per year)	High	September-October			Yes	Yes	Yes	None			High	tolerates acid soils (about 4.5?)	Prefers calcareous soils (~8.5?)		NA	NA		
NATIVE HERBACEOUS																																			
Atriplex lentiformis	Quailbush	perennial shrub/subshrub	Yes	Low	Low	Intolerant	20	8	4	4	20	7	FAC	High	High	Low		High				No	Yes	No	None	Medium		High	7	10	High	NA	NA		The "Casa" cultivar has no anaerobic tolerance, medium moisture use, min precip of 6, and temp min of -8 (F).
Carex barbarae	Santa Barbara sedge	Perennial	Yes	Moderate	High	Tolerant	6	3	1.5				FACW	Moderate	High	Medium/High	High	Moderate				Yes	Yes		None							NA	NA		Lots of rhizomes, good for bank stabilization; important to native Americans
Artemsia douglasiana	mugwort	Perennail forb	No	Moderate	High	Tolerant		4	1.5				FACW		Medium High	Medium/High	High	Moderate-High	July-December													NA	NA		
Euthamia occidentalis	western goldenrod	Perennail forb	No	Moderate	High	Intolerant	10	6	3.5	16	32	-28	OBL	Low	Medium	Medium	Moderate	None	Summer to Fall		slow	Yes	Yes	Yes	None	Medium	Medium	Medium	4.5	7	None	NA	NA		
Juncus mexicanus	Mexican rush	Perennial	No	High	High	Intolerant	8	0.8	0.6	8	20	-18	FACW	High	Low	Medium	Moderate	None	Summer		Rapid	Yes	Yes	No	None	Medium	Medium	Medium	6.2	8.2	High	NA	NA		
Leymus triticoides	beardless wildrye	Perennial	No	High	High	Intolerant	10	3	2	7	60	-33	FAC+	High	High	High	High	None	Summer		Rapid	Yes	Yes	No	None	Medium	Medium	High	6	9	High	NA	NA		
Heliotropium curassavicum	salt heliotrope	Perennial forb				Intolerant	10			10	24	-28	OBL	Low	Medium	Medium		None				Yes	Yes	No	None	Low		None	6.5	8.5	High	NA	NA		
Scirpus acutus	hardstem bulrush	Perennial graminoid		Dense	Moderate	Intolerant	14	9.8	7	12	60	-38	OBL	High	Medium	High	Moderate	None	Spring to Fall	Moderate	Moderate	Yes	Yes	No	None	Medium		Medium	5.2	8.5	Low	NA	NA		Listed as *Schoenoplectus acutus* var. *acutus*
Distichlis spicata	inland saltgrass	Perennial graminoid		Porous	Porous	Intolerant	2	1.15	1	5	70	-35	FACW	High	Medium	Medium	Slow	None	Summer to Fall	Slow	Moderate	Yes	Yes	No	None	Medium	High	High	6.4	10.5	High	NA	NA		
Scirpus californicus	California bulrush	Perennial graminoid		Dense	Porous	Intolerant	14	6.6	6	40	60	17	OBL	High	Low	High	Moderate	None	Spring to Fall	Rapid	Rapid	Yes	Yes	No	None	Medium	Medium	Medium	4	9	Low	NA	NA		Listed as *Schoenoplectus californicus*
Sporobolus airoides	alkali sacaton	Perennial graminoid		Moderate	Porous	Intolerant	16	3	2.5	5	13	-38	FAC+	None	High	Low	Moderate	None	Summer to Fall	Slow	None	Yes	Yes	Yes	None	Medium	Medium	High	6.6	9	High	NA	NA		
Typha angustifolia	narrowleaf cattail	Perennial forb		Moderate	Porous	Intolerant	10	4.9	4	30	60	-33	OBL	High	Low	High	Rapid	None	Spring to Summer	Rapid	Rapid	Yes	Yes	Yes	None	Medium	Medium	Low	3.7	8.5	Medium	NA	NA		
Typha latifolia	broadleaf cattail	Perennial forb		Porous	Porous	Intermediate	14	5	4	60	200	-36	OBL	High	None	High	Rapid	None	Summer to Fall	Moderate	Rapid	Yes	Yes	Yes	None	Medium	High	Medium	5.5	7.5	Low	NA	NA		
THREATENED AND ENDANGERED SPECIES																																			
Cordylanthus palmatus	palmate-bracted bird's-beak	Annual forb, hemi-parasitic	No	Low	Low		deep	1	0.5				OBL	High	High				Summer through fall	lots of seeds in seed bank		Yes	Yes		No			High	7.0?	8.5?	High	NA	NA	Fed: Endangered, State: Endangered	Limited to saline, alkali soils that are seasonally flooded, host plant includes Distichlis: USUALLY ON PESCADERO SILTY CLAY WHICH IS ALKALINE, WITH DISTICHLIS, FRANKENIA, ETC. 5-155M.
Holocarpha macradenia (4)	Santa Cruz tarplant	Annual forb	No	Moderate	High	Low		1.5	0.75				None					High	July to December	Low	None											NA	NA	Fed: Threatened, State: Endangered	Low elevation terraces and coastal prairies; LIGHT, SANDY SOIL OR SANDY CLAY; OFTEN WITH NONNATIVES. 10-260M
Erysimum capitatum ssp. angustatum	Contra Costa wallflower	Biennial/perennial forb	No	Moderate	High																											NA	NA	Fed: Endangered, State: Endangered	STABILIZED DUNES OF SAND AND CLAY NEAR ANTIOCH ALONG THE SAN JOAQUIN RIVER. 3-20M
Oenothera deltoides ssp. howellii	Antioch Dunes evening-primrose	Short-lived perennial forb	No	High	High	Low		3.3	1.5				None		High																	NA	NA	Fed: Endangered, State: Endangered	REMNANT RIVER BLUFFS AND SAND DUNES EAST OF ANTIOCH. 0-30M.
INVASIVE SPECIES (WOODY and HERBACEOUS)																																			
Arundo Donax	Giant reed	Shrub, graminoid	No	Dense	Moderate	Intermediate	24		9	35	65	7	FACU-, FACW	Medium	Low	High	Rapid	None			Rapid	Yes	Yes	No		Medium	High	Low	4.8	7	None	A	B		
Centaurea maculosa (2)	Spotted knapweed	Biennial forb/herb	No; dies back in late fall	Moderate	Porous/absent	Low	sturdy long tap-root	3	1.5				None		Moderate		High	Moderate; herbivory reduces flowering	June-October	High	Moderate, from lateral roots											A	B		Likely to be changed to Centaurea biebersteinii in next Jepson
Centaurea solstitialis (2)	Yellow star-thistle	winter annual forb/herb	No; dies back in late fall	Moderate	Porous/absent	Low	72 (average)	5	2.5				None		High	Low/moderate	High	Moderate; herbivory reduces flowering	July-December	High	None											A	B		
Lepidium latifolium	Broadleaved pepperweed												FACW																			A	A		
Lythrum salicaria (2)	Purple loosestrife	subshrub, perennial forb	No; dies back in late fall	Dense	Porous/absent	Intermediate	6	7	7				OBL	High			Rapid		June-September	High	Low-Moderate	Yes	Yes		No				5.5	7.5		A	A		Expanded root crown up to 1.5 feet diameter; Stem bits can take root if conditions just right
Rubus discolor	Himalayan blackberry	vine, shrub	No										FACW																			A	A		
Tamarix parviflora (2)	Smallflower tamarisk	shrub/small tree	No	Low	Moderate		180 (average)	24		Low			FAC	High	High	High	High Up to 10 -13 feet per year		March to May	High	Moderate (root sprouts, stem fragments)	Yes	Yes		No	Low	High		acid tolerant (~4.5)	prefers alkaline soils (~8.5 or more?)	High	A	A		
Tamarix ramosissima (2)	Saltcedar tamarisk	shrub/small tree	No	Low	Moderate		180 (average)	15		Low			FAC	High	High	High	High Up to 10 -13 feet per year		April to August	High	Moderate (root sprouts, stem fragments)	Yes	Yes		No	Low	High		acid tolerant (~4.5)	prefers alkaline soils (~8.5 or more?)	High	A	A		
Conium maculatum (2)	Poison hemlock	Biennial forb/herb	No	Dense	Low	Moderate	tap root	9	6				FACW	Moderate	Moderate		High	Low (generally not consumed; toxic)	Late summer to winter	High	None	Yes	Yes		No							B	B		
Foeniculum vulgare (2)	Sweet fennel	Perennial forb	No	Dense	Low	Moderate	tap root	9	6				FACU	Moderate	Moderate	Medium	High	High	Summer to Fall	High	Moderate (root crown and root fragments)	Yes	Yes	Yes	No	Low	High					A	B		
Egeria densa (3)	Brazilian waterweed	Submerged aquatic perennial		Dense		High (grows best under low light)	Roots slender, can be buried 8" in substrate	Floating matts in water				Die with prolonged near-freezing temperatures	OBL	High	None	High	High	High	July through November	Low (seeds inviable in western US)	HIGH	NA	NA	NA	No	Highly susceptible to iron deficiency			acid tolerant (~5)	alkaline tolerant (~8.5)	High	A	A		
Eichhornia crassipes (3)	Water hyacinth	Aquatic perennial forb		Dense		High	Floating roots	Floating matts in and up to 2' above water				Grow best in warm water	OBL	High	None	High	Extremely High	High	July to November	High	Very High	Yes			No	Grows fastest in nutrient rich waters			3.5	8	salinity <1.6%	A	A		
Ludwigia peploides (3)	Creeping water primrose	Aquatic perennial forb		Dense		High	Floating roots	Floating matts in and up to 0.5' above water					OBL	High	None	High	High	High		Low	High	Yes			No	Low					High	A	B		
Myriophyllum spicatum (3)	Eurasian watermilfoil	Aquatic perennial forb		Dense		High	Floating roots	Floats in matts at and just below water surface					OBL	High	Can grow along shore	High	High	High			Very High	Yes			No	Low			5.4	11	High	A	B		
Cytisus scoparius	Scotch broom	Perennial shrub	No	Dense	Moderate	Intolerant	16	7		30	60	-13	None	None	High	Low	Rapid	Low	Spring to Summer	Rapid	None	Yes	Yes	Yes	YES	Medium	Low	Medium	5.5	7	Low	A	B		
Ficus carica	edible fig	Perennial shrub/tree	No	Dense	Low	Moderate		30				hard freezes cause die-back	None	Low	Moderate	Medium	Moderate	High	3x per year	Rapid	Rapid (root/branch sprouts)	Yes	Yes	Yes	No				6	7		B	A		
Hydrilla verticillata	Florida elodea/ waterthyme	Submerged aquatic perennial	No	Dense	Low	High	0.2 to 0.5	Floats in matts at and just below water surface				50°F for growth; turions survive short near freezing temperatures	OBL	High	None	High	Rapid	High		Low	Rapid (by fragments, stolons, turions and tubers)	Yes	Yes	Does not grow as well in sand							Moderate	A	B		Plants die back in winter, but develop overwintering tubers in the soil substrate

Source (unless otherwise noted): USDA, NRCS. 2002. The PLANTS Database, Version 3.5 (http://plants.usda.gov). National Plant Data Center, Baton Rouge, LA 70874-4490 USA.
1 Jepson manual
2 DiTomasi and Healy 2007
3 DiTomasi and Healy 2003
4 Holl and Hayes 2006

Wetland Indicator Status

OBL	Obligate Wetland. Occur almost always (estimated probability >99%) under natural conditions in wetlands
FACW	Facultative Wetland. Usually occur in wetlands (estimated probability 67%-99%), but occasionally found in non-wetlands
FAC	Facultative. Equally likely to occur in wetlands or non-wetlands (estimated probability 34%-66%)
FACU	Facultative Upland. Usually occur in non-wetlands (estimated probability 67%-99%), but occasionally found in wetlands (estimated probability 1%-33%
UPL	Obligate Upland. Occur in wetlands in another region, but occur almost always (estimated probability >99%) under natural conditions in non-wetlands in the region specifie
+	Indicates a frequency toward the higher end of the category (more frequently found in wetlands
-	Indicates a frequency toward the lower end of the category (less frequently found in wetlands

Nitrogen Fixation: What is the amount of nitrogen fixed by this plant relative to other species? (None, Low, Moderate, High, Unknown (blank)
Adapted to Soils: Can this plant establish and grow in coarse/fine/medium textured soils? (yes/no
Anaerobic Tolerance: What is the plant's relative tolerance of anaerobic conditions of the growth medium? (None, Low, Medium, High
CaCO3 Tolerance: What is the plant's relative tolerance of calcium carbonate in the growth medium? (None, Low, Medium, High, Unknown (blank)
Drought Tolerance: What is the relative tolerance of the plant to drought conditions compared to other plants in the same region? (None, Low, Medium, High
Fertility Requirement: What are the relative fertility requirements needed for the growth of this plant? (Low, Medium, High
Hedge Tolerance: What is the tolerance to hedging by livestock or wildlife? (None, Low, Medium, High, Unknown (blank)
Moisture Use: What are this plant's relative moisture requirements for growth? (Low, Medium, High
pH, Minimum: Minimum pH under which this plant can maintain good growth
pH, Maximum: Maximum pH under which this plant can maintain good growth
Precipitation, Minimum: Minimum precipitation required by plant for good growth in inches
Precipitation, Maximum: Maximum precipitation tolerated by plant for good growth in inches
Root Depth, Minimum (inches): Minimum depth of soil required for good growth in inches
Salinity Tolerance: What is the plant's tolerance to saline soil conditions? (None, Low, Medium, High
Shade Tolerance: What is the relative tolerance for this plant to grow in shade conditions? (Intolerant, Indeterminate, Tolerant
Temperature, Minimum (°F): Minimum temperature under which the plant will survive in degrees F