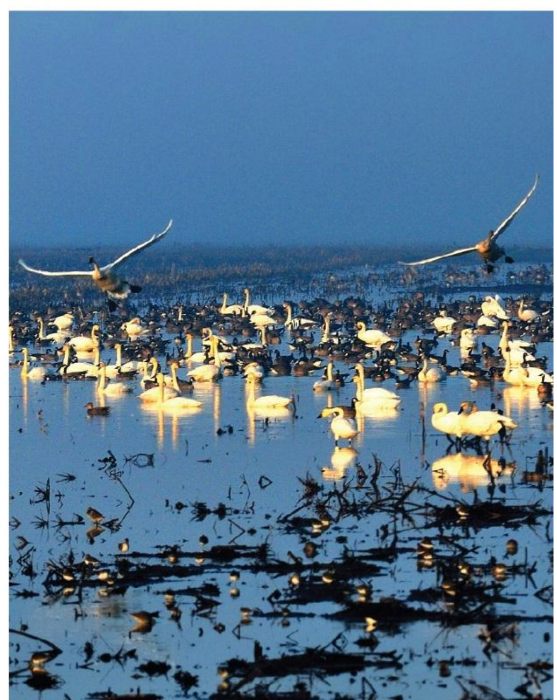
CHAPTER 4

Protect, Restore, and Enhance



ABOUT THIS CHAPTER

This chapter describes the Sacramento-San Joaquin Delta (Delta) ecosystem and the factors that affect and too often degrade it. It proposes policies and recommendations for restoring the Delta ecosystem organized into five core strategies to achieve the coequal goals of the Delta Reform Act:

- Create more natural functional flows
- Restore habitat
- Improve water quality to protect the ecosystem
- Prevent introduction of and manage nonnative species impacts
- Improve hatcheries and harvest management

These core strategies form the basis of the five policies and nine recommendations found at the end of the chapter.

RELEVANT LEGISLATION

The coequal goals for the Delta (Water Code section 85054) are relevant to ecosystem restoration:

> *"Coequal goals" means the two goals of providing a more reliable water supply for California and protecting, restoring, and enhancing the Delta ecosystem. The coequal goals shall be achieved in a manner that protects and enhances the unique cultural, recreational, natural resource, and agricultural values of the Delta as an evolving place.*

Eight objectives in Water Code section 85020 are inherent in the coequal goals. Section 85020(a), (c), and (e) are relevant to this chapter:

> *85020 The policy of the State of California is to achieve the following objectives that the Legislature declares are inherent in the coequal goals for management of the Delta:*
>
> > *(a) Manage the Delta's water and environmental resources and the water resources of the state over the long term.*
> >
> > *(c) Restore the Delta ecosystem, including its fisheries and wildlife, as the heart of a healthy estuary and wetland ecosystem.*
> >
> > *(e) Improve water quality to protect human health and the environment consistent with achieving water quality objectives in the Delta.*

The coequal goals and inherent objectives seek broad protection of the Delta. Achievement of these broad goals and objectives requires implementation of specific strategies. Water Code sections 85022 and 85302 provide direction on the implementation of specific measures to promote the coequal goals and inherent objectives related to the Delta ecosystem restoration.

> *85022(d)(5) Develop new or improved aquatic and terrestrial habitat and protect existing habitats to advance the goal of restoring and enhancing the Delta ecosystem.*
>
> > *(6) Improve water quality to protect human health and the environment consistent with achieving water quality objectives in the Delta.*

85302(c) The Delta Plan shall include measures that promote all of the following characteristics of a healthy Delta ecosystem.

> *(1) Viable populations of native resident and migratory species.*
>
> *(2) Functional corridors for migratory species.*
>
> *(3) Diverse and biologically appropriate habitats and ecosystem processes.*
>
> *(4) Reduced threats and stresses on the Delta ecosystem.*
>
> *(5) Conditions conducive to meeting or exceeding the goals in existing species recovery plans and state and federal goals with respect to doubling salmon populations.*

85302(d) The Delta Plan shall include measures to promote a more reliable water supply that address all of the following:

> *(1) Meeting the needs for reasonable and beneficial uses of water.*
>
> *(3) Improving water quality to protect human health and the environment.*

85302(e) The following subgoals and strategies for restoring a healthy ecosystem shall be included in the Delta Plan.

> *(1) Restore large areas of interconnected habitats within the Delta and its watershed by 2100.*
>
> *(2) Establish migratory corridors for fish, birds, and other animals along selected Delta river channels.*
>
> *(3) Promote self-sustaining, diverse populations of native and valued species by reducing the risk of take and harm from invasive species.*
>
> *(4) Restore Delta flows and channels to support a healthy estuary and other ecosystems.*
>
> *(5) Improve water quality to meet drinking water, agriculture, and ecosystem long-term goals.*
>
> *(6) Restore habitat necessary to avoid a net loss of migratory bird habitat and, where feasible, increase migratory bird habitat to promote viable populations of migratory birds.*

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CHAPTER 4

Protect, Restore, and Enhance the Delta Ecosystem

In the Delta Reform Act, the goal of protecting, restoring, and enhancing the Delta ecosystem is coequal to the goal of providing a more reliable water supply for California. Both must be accomplished while protecting and enhancing the unique cultural, recreational, natural resource, and agricultural values of the Delta as an evolving place.

Some past land and water uses have put these goals in conflict. For example, reliable water supplies have been associated with artificially stabilized flows and a complex human-made system of infrastructure that includes dams, levees, and channelized rivers and sloughs. Yet healthy rivers and estuaries, and the native species that live in them depend on naturally variable water flows and a dynamic landscape. Many native species also depend on wetlands that have been drained for farming and other human uses.

Despite these conflicts, the Delta Stewardship Council (Council) must work to achieve the goal of protecting, restoring, and enhancing the Delta ecosystem. Inherent in that goal is the objective to "restore the Delta ecosystem, including its fisheries and wildlife, as the heart of a healthy estuary and wetland ecosystem" (Water Code section 85020(c)). (See sidebar, What Does It Mean to Achieve the Goal of Protecting, Restoring, and Enhancing the Delta Ecosystem?)

The Council envisions a future in which the Delta ecosystem has the following characteristics:

- Native species, including algae and other plants, invertebrates, fish, birds, and other wildlife, are self-sustaining and persistent.
- The tidal channels and bays in the Delta and Suisun Marsh connect with freshwater creeks, upland grasslands, and woodlands.
- The Sacramento and San Joaquin rivers and other Delta tributaries include reaches where streams are free to meander and connect seasonally to functional floodplains.
- Habitats for resident and rearing migratory fish, birds, and upland wildlife are connected by migratory corridors, including areas with high-quality cover and feeding opportunities.
- More natural variations in water flows and conditions make aquatic habitats, tidal marshes, and floodplains more dynamic, encourage survival of native species, and resist invasions by weeds and animal pests.
- The ecosystem is resilient enough to absorb and adapt to current and future effects of multiple stressors without significant declines in ecosystem services.
- The Delta will provide more reliable water supplies, in part because survival of its wildlife, fish, and plants do not require extraordinary regulatory protection.
- Californians recognize and celebrate the Delta's unique natural resource values through wildlife observation, angling, waterfowl hunting, and other outdoor recreation.

This future Delta will differ from the Delta that greeted the first Californians and will probably be different from the current ecosystem. Not every species or natural area now found in the Delta may persist through the changes ahead, including climate change, but Californians' use and management of the Delta will be directed and coordinated to sustain conditions that make species' survival more likely while maintaining the many other benefits provided by the Delta ecosystem.

WHAT DOES IT MEAN TO ACHIEVE THE GOAL OF PROTECTING, RESTORING, AND ENHANCING THE DELTA ECOSYSTEM?

Achieving the coequal goal of ecosystem protection, restoration, and enhancement means successfully establishing a resilient, functioning estuary and surrounding terrestrial landscape capable of supporting viable populations of native resident and migratory species with diverse and biologically appropriate habitats, functional corridors, and ecosystem processes.

For this purpose, the term "restoration" is defined in Water Code section 85066 as follows:

> *"the application of ecological principles to restore a degraded or fragmented ecosystem and return it to a condition in which its biological and structural components achieve a close approximation of its natural potential, taking into consideration the physical changes that have occurred in the past and the future impact of climate change and sea level rise."*

Restoration actions may include restoring interconnected habitats within the Delta and its watershed, restoring more natural Delta flows, or improving ecosystem water quality.

"Protection" means preventing harm to the ecosystem, which could include preventing the conversion of existing habitat, the degradation of water quality, irretrievable conversion of lands suitable for restoration, or the spread of invasive nonnative species.

"Enhancement" means improving existing desirable habitat and natural processes. Enhancement might include flooding the Yolo Bypass more often to support native species, or to expand or better connect existing habitat areas. Enhancement includes many fish and wildlife management practices, such as managing wetlands for waterfowl production or shorebird habitat, installing fish screens to reduce entrainment of fish at water diversions, or removing barriers that block migration of fish to upstream spawning habitats.

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A Restored Delta Ecosystem Is Key to a Reliable Water Supply

Delta water supplies can be more reliable only when the Delta ecosystem is restored. The water projects that rely on the Delta were developed without contemporary understanding of the Delta's ecology or anticipation of the value that Californians now place on a healthy environment. As the effects of the projects on the Delta ecosystem became apparent, a series of adjustments in their operation has been put in place. Each adjustment affected the water diversions, altering volume and timing to reduce damage, but without fully mitigating harm to the Delta ecosystem. The perilous condition of salmon, delta smelt, and other species remains a key limit on project operations. Only as these populations recover will water project operations become more flexible and reliable.

To restore the Delta ecosystem, Californians will need to use water management facilities in new ways. Reservoirs will need to hold and release water for ecosystem purposes as well as for water users. Storage and the development of alternative supplies will be needed to help reduce reliance on the Delta and improve regional self-reliance. Multipurpose bypasses and levees will need to provide habitat while also controlling flooding. Channels and water controls will need to be able to deliver water for habitats as well as for farms and cities. Modern water diversions will need to protect fish while providing reliable water supplies. For these reasons, restoring the Delta ecosystem will require new investment in water facilities and alternative supplies, not just regulation of water project operations or restoration of habitats for fish and wildlife. Other actions undertaken to protect the ecosystem can also benefit water users; for example, vigilance in preventing invasive species introduction can avoid future costs to manage mussel infestations in pipelines or other water structures. Tradeoffs may be necessary as we better match demands to the supply available, consistent with ecosystem protection, and match our expectations about the ecosystem to the changing climate.

A restored Delta ecosystem is also important to the Delta's future as an attractive place to live, work, and recreate. Water flows are important not just to water exporters, fish, and aquatic environments, but also to the Delta's municipal, industrial, and agricultural waters users, who will need consideration as system changes are planned and implemented. Restoration actions will require careful design so they are attuned to local needs: locating habitats to minimize conflicts with existing and planned uses; working with farmers by promoting wildlife-friendly farming; providing buffers between wildlife areas and farms; working with landowners regarding how to manage restored wildlife populations on or near their lands; and improving opportunities for outdoor recreation, including boating, angling, and hunting, that are enjoyed by residents and also attract visitors. Integrating habitat improvements when levees are rebuilt or flood channels are improved can draw new sources of funds to strengthen the Delta flood control system. In essence, a systems approach that recognizes tradeoffs and the value of balance will be necessary for California to achieve the coequal goals.

The Delta Ecosystem, Past and Present

In the Delta, the Central Valley's great rivers—the Sacramento from the north and San Joaquin from the south—join the Cosumnes, Mokelumne, and Calaveras here in a vast and complex estuary influenced by tides and river currents (see Figure 4-1).

Before the early 1800s, the rivers flowed through approximately 400,000 acres of tidal wetlands and other aquatic habitats that connected with several hundred thousand acres of nontidal wetlands and riparian forest. Flows of the Delta's rivers and tidal channels varied by season and year-to-year, sometimes pouring from the Sierra in great floods whose fresh waters overflowed wetlands and floodplains, and at other times declining as droughts shriveled rivers and brackish tidewaters pushed inland. To the west, the rivers joined to discharge through marsh-fringed Suisun Bay to the Carquinez Straight, San Francisco Bay, and the Pacific Ocean.

The Delta's historical landscape also varied from north to south (see Figure 4-2). In the north Delta, flood basins occurred where the Sacramento River intertwined with tidal channels. A vast area of freshwater wetlands dominated by tules transitioned into tidal wetlands. Shallow perennial ponds and lakes, broad riparian forests along natural levees, and seasonal wetlands at the upland edge were also common. The central Delta was characterized by large, tidal islands that flooded during spring tides (or more frequently) intersected by networks of branching tidal channels. Channel banks were low and covered by the willows, grasses, sedges, shrubs, and ferns that also grew in island interiors. The south Delta contained a complex network of channels formed predominantly by riverine processes. The floodplain comprised emergent wetlands, perennial and seasonal ponds, willow thickets, and seasonal wetlands. Driftwood and other woody debris filled some channels, likely from riparian forest along the San Joaquin River's natural levees.

Historical records show a rich and complex Delta with habitats supporting diverse and abundant native plants and animals (Grossinger et al. 2010, Whipple et al. 2010, Whipple 2011). Some fish, including smelt, schooled in the open waters of the western Delta's bays and channels, moving east when brackish water intruded from San Francisco Bay. Other resident wildlife and plants also prospered: rails in tidal and tule marshes, giant garter snakes in freshwater wetlands and ponds, and riparian brush rabbits and wood rats in willow thickets and riparian forests. Each fall, salmon and steelhead, drawn by the swelling Sacramento and San Joaquin rivers, migrated inland from the ocean and navigated upstream to spawning areas in their tributaries. As river flows receded, their young, emerging from these tributaries' spawning gravel, would return downstream and shelter in driftwood-lined eddies or undercut riverbanks and feed in Delta sloughs, marshes, and floodplains before returning to the sea. Waterfowl, cranes, and shorebirds migrated through the Delta along a north-south route that stretched from the Arctic to Mexico or beyond. Songbirds followed a similar path through riparian woodlands that connected from the Sacramento Valley through the Delta to the San Joaquin Valley.

To immigrants arriving in the nineteenth century, the Delta and Central Valley appeared a wild and dangerous place that had to be "reclaimed" to support the agricultural way of life they had inherited from their ancestors. The rapid transformation of the historical Delta over 160 years involved many changes. Over 1,000 miles of levees were constructed to drain wetlands and protect islands from damaging floods. Channels were cut between sloughs or through islands to ease navigation and encourage drainage without regard to effects on the estuary. Forests were cut and land leveled for farming (Hanak et al. 2011). This transformation produced the rich agricultural economy and rural culture of the Delta described in Chapter 5. But it came at a cost: loss of the original estuarine ecosystem and its species, and native people.

Comparison of Historical (early 1800s) and Modern Delta Waterways

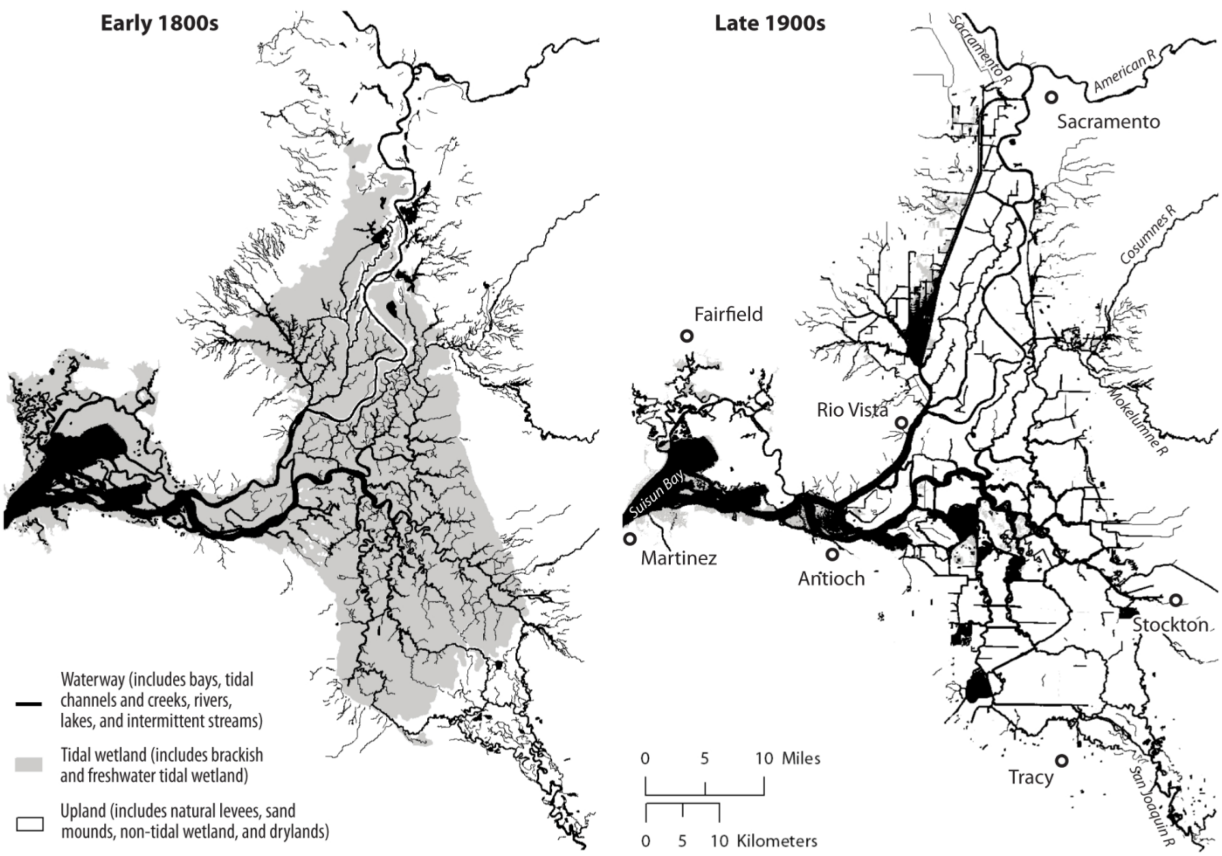
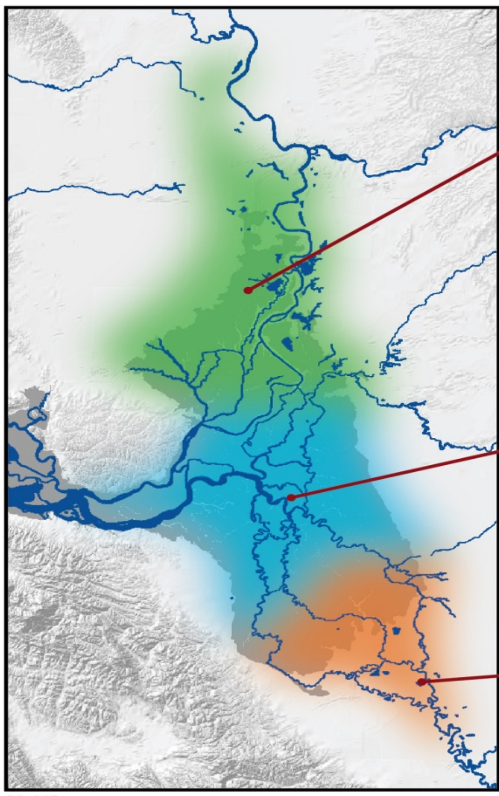


Figure 4-1 The map at left shows the complexity of early 1800s Delta hydrography (black) within tidal wetland (gray). The modern hydrography at right shows major differences such as channel widening, meander cuts, cross levees, and loss of within-island channel networks and tidal wetland.

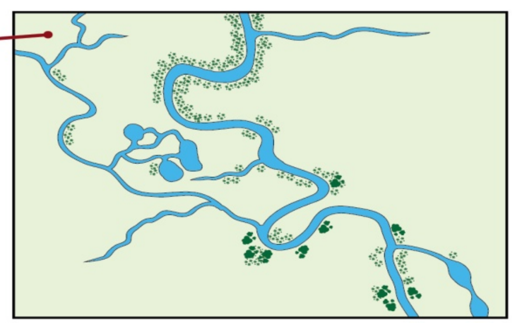
Source: San Francisco Estuary Institute 2012

Primary Landscapes in the Historical Delta



Flood Basins: Sacramento River floods into adjacent low wetland basins, with riparian forest along the river's natural levees.

Tidal Islands: Large tidal channels define islands with freshwater wetlands and numerous small tidal channels.



Distributary Rivers: San Joaquin River branches merge into tidal wetlands within a floodplain with a wide mix of habitats.

Figure 4-2

The historical Delta can be divided into three primary landscapes: flood basins in the north Delta, tidal islands in the central Delta, and distributary rivers (rivers with multiple branches flowing away from main channels) in the south Delta. Transitions between these landscapes occurred gradually, across broad areas. Though these landscapes held many habitat types in common, characteristics and spatial patterns varied greatly—these large-scale patterns are what helped define the landscapes, which in turn provided different functions for native species. Understanding these major landscape types is a valuable framework for evaluating current and future restoration strategies in the Delta, providing a baseline between the current landscapes and the long-established historical patterns.

Source: Whipple 2011

Nearly all the rivers historically flowing to the Delta were dammed, creating Shasta, Folsom, Millerton, and Oroville lakes and other impoundments described in Chapter 3. These dams, together with levees constructed to prevent flooding, blocked access to spawning areas and other habitats critical to salmon, splittail, and other fish. The once pronounced seasonal and year-to-year variability of river flows has given way to more stable, artificially regulated conditions. The formerly complex Delta sloughs have been replaced by a simplified grid of straightened channels, cuts, and often rock-lined rivers fixed in space and time, and used for water conveyance and shipping. Pumps to divert water for irrigation or municipal use south or west of the Delta further disrupted the estuary (see Figure 4-3).

Ecosystem restoration cannot restore the historical Delta. Its alteration is too complete to reverse and could not occur without damage to other beneficial uses of its water and land. The Delta Reform Act recognizes these limitations and defines restoration as a "...close approximation of its natural potential..." (Water Code section 85066).

Ecosystem Stressors

Many factors stress the Delta's ecosystem (Baxter et al. 2010). Stressors are actions or factors, whether caused by humans or nature, that negatively affect the ecosystem processes and functions. Stressors include altered flows, habitat loss, entrainment in Delta diversions, degraded water quality, harmful nonnative species, migration barriers, and impacts from hatcheries. Reducing one stressor, or even several stressors, is unlikely to solve all environmental problems in the Delta (Delta ISB 2011, see Appendix I). Many restoration projects fail because multiple stressors have been insufficiently considered (Palmer et al. 2005). Because of uncertainty over cause and effect, ecosystem restoration must address as many stressors as possible through adaptive management, as described in Chapter 2 and Appendix C.

Organizing stressors into categories, such as those developed by the Delta Independent Science Board (ISB), helps resource managers to think about, assess, and manage them. (See sidebar, Stressor Categories to Help with Management Options.) Ecosystem stressors and their effects can be categorized by what causes them (sources of stress) or by what can be done about them. The Delta Plan's ecosystem restoration strategies address the following current stressors:

- Delta flows
- Habitat
- Ecosystem water quality
- Nonnative species
- Hatcheries and harvest management

STRESSOR CATEGORIES TO HELP WITH MANAGEMENT OPTIONS

The Delta ISB developed categories that put Delta stressors into broad context to help assess management options (for example, what can be done about them) (Delta ISB 2011). Management options are stressor reduction, elimination, or mitigation. When this is not possible, adaptation to stressors must be promoted. The Delta ISB has proposed the following categories:

- **Current stressors** result from ongoing human activities that at least in some cases can be eliminated (for example, fish entrainment at water diversions and pollution from point sources).
- **Legacy stressors** result from past actions that cannot be undone, but their impact can sometimes be reduced or mitigated (for example, mercury pollution from historical gold mining and past introductions of nonnative species).
- **Globally determined stressors** result from large-scale human activities or natural processes that cannot be eliminated or mitigated within the purview of the Delta Plan and require larger-scale planning and adaptation (for example, global climate change and human population growth).
- **Anticipated future stressors** require preparation (for example, future land subsidence, urban expansion, and new invasions by nonnative species).

These categories have some overlap; for example, a globally determined stressor such as sea level rise also can be an anticipated future stressor.

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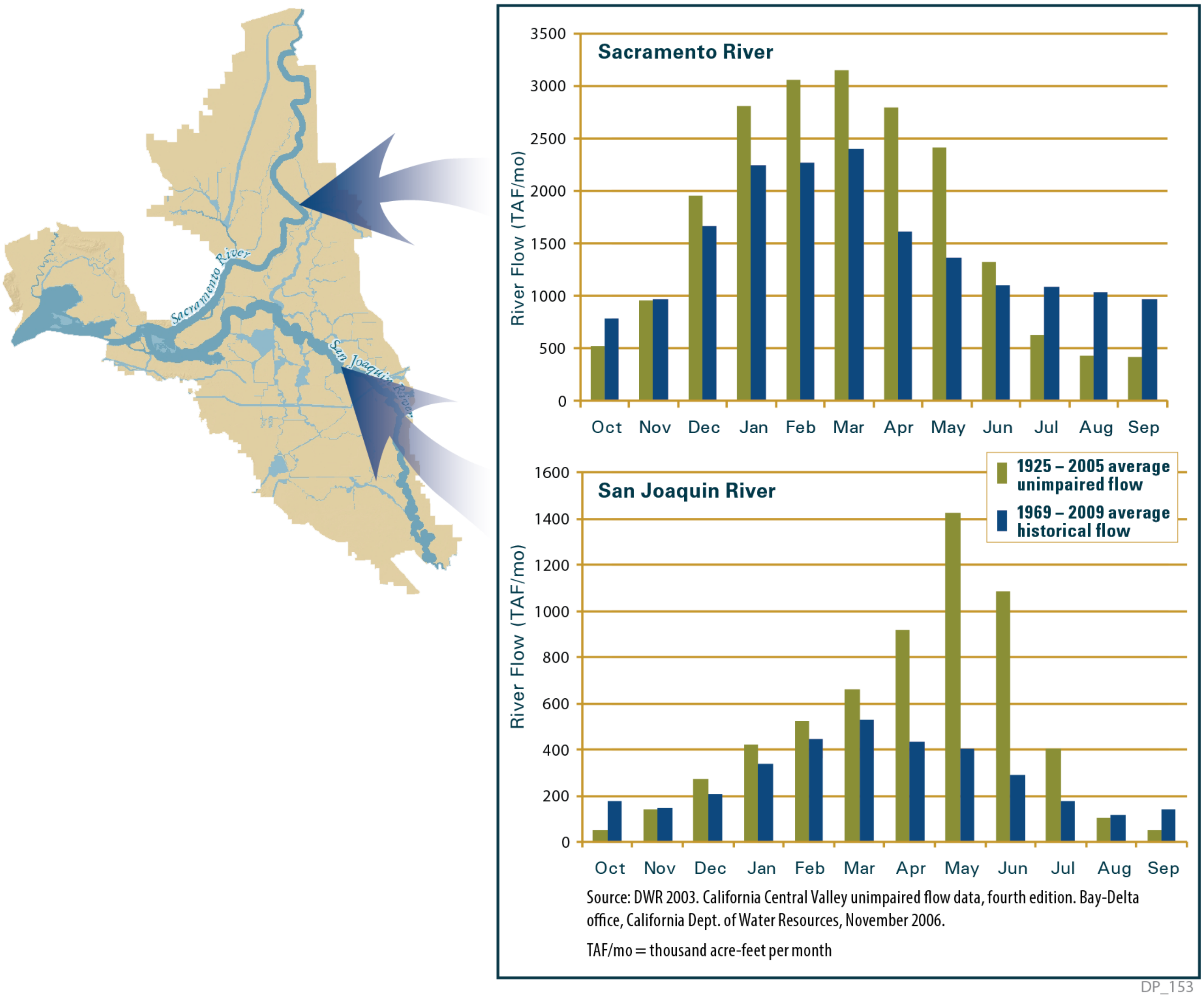
Changes in Historical Flows Challenge Delta Ecology



Source: DWR 2003. California Central Valley unimpaired flow data, fourth edition. Bay-Delta office, California Dept. of Water Resources, November 2006.

TAF/mo = thousand acre-feet per month

Figure 4-3

Habitat for native species has been shaped in the past by natural cycles of river flows.* Since the 1960s, our water system, with its upstream reservoirs, diversions, and other management facilities, has changed these patterns in two ways. First, seasonal flows are much less variable and encourage nonnative fish and vegetation, which can crowd out native species that thrive in a more varied environment. Second, peak flows now come at lower magnitudes and occur earlier on the San Joaquin; this shift affects water temperatures, salinity, and access to habitat, causing stress on native species.

** Natural flow is runoff that would have occurred had the landscape and waterways remained unaltered. Our best estimate of natural Delta inflow is "unimpaired flow," the flow that would be expected if reservoirs were removed but the contemporary watershed and valley land uses remained. However, natural and unimpaired Delta inflow are not the same, and the difference between them could be substantial at times.*

Climate Change

Climate change will cause major stresses on the Delta ecosystem. Rising sea level could inundate freshwater marshes and other freshwater aquatic habitats, potentially with brackish water, reducing habitat for native plants, fish, and wildlife. In addition to rising sea level, the amount of ideal low-salinity habitat for native fish such as the delta smelt will be affected by changes in runoff timing and intensity, which will also affect erosion and sedimentation patterns, again altering fish habitat. Increased water temperature will negatively affect smelt, salmon, and other coldwater-dependent fish, and will likely increase the range of invasive species (Healey et al. 2008, Villamanga and Murphy 2010). In terrestrial habitats, warming could create soil moisture deficits, change plant community composition, and even disrupt timing between pollinators and plants (California Natural Resource Agency 2009). Overall climate change will exacerbate current challenges to the protection and restoration of Delta ecosystems.

Ecosystem Restoration

Restoration of the Delta ecosystem does not mean a return to predevelopment conditions with only its native plants and animals. That is beyond human ability. Instead, restoration seeks to return areas to a close approximation of their natural potential, including re-establishing natural habitat and ecosystem functions, as feasible, within the context of the current configuration of the Delta, the current biological communities, and the permanent modifications to Delta land forms and hydrology. Successful ecosystem restoration rehabilitates key elements—the living and nonliving features such as soils, elevation, waterways, species, populations, and habitats—and the structure and processes that connect them. This section summarizes the principles of and considerations for ecosystem restoration in the Delta.

Much work has been done to develop ecological principles specific to the Delta. (See sidebar, Delta Ecological Principles.) Restoration projects that adhere to these principles are more likely to achieve their goals and objectives.

The Delta Reform Act's definition of restoration recognizes that the ecosystem will be dynamic, changing in response to restoration actions and future climate change (Healey et al. 2008, Delta ISB 2011). The desired future condition is an evolving ecosystem that supports communities of both native and nonnative species, and continues to provide value such as clean water, flood storage, or recreational fishing. A dynamic, restored Delta ecosystem can be a natural complement to the Delta as an "evolving place" described in Chapter 5.

To increase the likelihood of ecosystem restoration success, plans and actions must incorporate the principles of adaptive management (see Chapter 2 and Appendix C for a detailed discussion). This begins with a clear, practical vision of what will be achieved for the ecosystem, together with human need for water supply reliability and flood risk reduction. Additional examples are provided in the sidebar, Current Delta Ecosystem Restoration Efforts.

DELTA ECOLOGICAL PRINCIPLES

The following are ecological principles for the Delta adapted from those developed for the Delta Vision Blue Ribbon Task Force by former CALFED Lead Scientist Michael Healey (2007a, 2007b) and for the Bay Delta Conservation Plan (BDCP) Steering Committee by the BDCP Independent Science Advisors (2007).

Principle 1: Humans are part of the Delta ecosystem. Human activities over the past 160 years have produced a Delta ecosystem that is different from the historical ecosystem, and will remain so even as human-induced stressors are modified.

Management implications: Strategic management of human activities, and uses of the landscape and water in the Delta will be integral to the successful protection, restoration, and enhancement of the Delta ecosystem.

Principle 2: The Delta ecosystem is part of larger ecosystems. The Delta ecosystem affects and is affected by surrounding ecosystems. High year-to-year variability in precipitation and river flows are, in part, caused by climate patterns that span the entire Pacific Ocean. In addition, many animals that use the Delta do so for only part of their life cycles, spending other parts upstream in the rivers, in the ocean, or as far as away as South America and northern Canada.

Management implication: Management of the Delta cannot occur independently of structures and events upstream and in the ocean, in regional and state economies, or in the wider governance context.

Principle 3: The Delta ecosystem is a mosaic of smaller terrestrial and aquatic ecosystems. These ecosystems interact in important ways (for example, exchange of material, energy, and species). This landscape mosaic determines overall performance of the ecosystem. The size, shape, arrangement, and connections within the mosaic are critical to the way the Delta functions.

Management implication: Management plans and decisions need to be informed by a landscape perspective that recognizes interrelationships among patterns of land and water use, patch size, location and connectivity, and species success. The landscape perspective needs to be developed at several physical and temporal scales.

Principle 4: The Delta ecosystem is naturally dynamic. This includes disturbances and extreme events such as very wet and very dry years. Changes in one part of the Delta may have far-reaching effects in space and time.

Management implication: The Delta cannot be managed as a homogenous or static system.

Principle 5: Native Delta species are adapted to a naturally dynamic Delta ecosystem. The natural Delta is dynamic and variable, and the organisms living there are adapted to that variability.

Management implication: In order to successfully protect, restore, and enhance the Delta, management needs to include actions that mimic, to some extent, the historical natural variability.

Principle 6: Each native Delta species has particular tolerances for habitat variables such as temperature, dissolved oxygen, salinity, turbidity, and toxic substances. Species distributions may shift if conditions change and exceed these tolerances. Increase of air and water temperature by even 2 degrees may make the Delta uninhabitable for some local species and also make it potentially inhabitable for species from warmer regions.

Management implication: Loss of some species from the ecosystem may be inevitable. For local species, refugia may have to be located in cooler regions if extinction is to be prevented. Additional actions may be necessary to alleviate a potential increase in nonnative invasive species.

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CURRENT DELTA ECOSYSTEM RESTORATION EFFORTS

Several significant ecosystem restoration planning and implementation efforts are worth noting:

- The draft Ecosystem Restoration Program (ERP) Conservation Strategy was released by the California Department of Fish and Wildlife (DFW) in 2011 (DFG 2011) to update the CALFED ERP plans from 2000. DFW collaborates with its federal fish agency partners, the U.S. Fish and Wildlife Service and National Marine Fisheries Service, to implement the ERP, including providing grants for Delta and Suisun Marsh restoration research and implementation.
- DFW and the California Department of Water Resources (DWR) are continuing to implement and plan for ecosystem restoration projects begun under the CALFED Bay-Delta Program located in Suisun Marsh, at Dutch Slough, at Cache Slough, in the Yolo Bypass, and at the Cosumnes Preserve's North Delta project.
- The *Suisun Marsh Habitat Management, Preservation, and Restoration Plan* is a comprehensive approach to restoring 5,000 to 7,000 acres of tidal wetlands and maintaining managed wetlands and their functions consistent with the CALFED program, the Suisun Marsh Preservation Agreement, applicable species recovery plans, and other interagency goals.
- The Bay Delta Conservation Plan (BDCP) is an overarching approach to large-scale ecosystem restoration now in the planning process (see sidebar, Bay Delta Conservation Plan and Delta Ecosystem Restoration).
- Several Habitat Conservation Plans (HCP) and Natural Community Conservation Plans (NCCP) for parts of the Delta are in place or under development in the Delta. These plans' purpose is to minimize and mitigate the impact of authorized incidental take of the endangered or rare species and their habitats. Completed HCPs and NCCPs in the Delta include the San Joaquin HCP and East Contra Costa County HCP/NCCP. The BDCP, Yolo County HCP/NCCP, South Sacramento HCP, and Solano Multispecies HCP are under development.
- The State Water Resources Control Board (SWRCB) is updating its Bay-Delta Water Quality Control Plan (Bay-Delta Plan). The first phase focuses on objectives to protect water quality for south Delta agriculture and San Joaquin River flow objectives to protect fish and wildlife. The second phase focuses on other changes to its Bay-Delta Plan to protect fish and wildlife, including Delta outflow objectives, Sacramento River flow objectives, export/inflow objectives, Delta Cross Channel Gate closure objectives, Suisun Marsh objectives, potential new reverse flow objectives for Old and Middle rivers, potential new floodplain habitat flow objectives, potential changes to the monitoring and special studies program, other potential changes to the program of implementation, and issues identified through the BDCP process. As part of the SWRCB's review of its Bay-Delta Plan, it will consider information developed as part of its 2010 staff technical report *Development of Flow Criteria for the Sacramento–San Joaquin Delta Ecosystem* (SWRCB 2010) along with information about other factors, such as coldwater pool requirements and other water uses.
- In 2009, the Legislature established the Sacramento–San Joaquin Delta Conservancy (Delta Conservancy) as a primary State agency to implement ecosystem restoration in the Delta, along with supporting efforts that advance environmental protection and the economic well-being of Delta residents. The Delta Conservancy adopted a strategic plan to guide its planning and implementation efforts in March 2012.
- DWR's Delta Levees Special Flood Control Projects program provides funding to local agencies in the Delta for habitat projects linked to flood management improvements. Similarly, DWR's *2012 Central Valley Flood Protection Plan* proposes new or enhanced flood bypasses, levee setbacks, and fish passage improvements that provide both flood risk reduction and habitat. This effort is discussed in more detail in Chapter 7.

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Delta Flows

The Delta is the upstream portion of the San Francisco Estuary, where ecosystems dominated by the Central Valley's rivers transition to the more ocean-influenced ecosystem of the downstream portions of the estuary. Water flow is a "master variable," driving the ecological health of rivers and their ability to support valued environmental services (Poff et al. 1997, Postel and Richter 2003). In estuaries, the interaction of river flows and ocean tides produces a salinity gradient from fresh water to brackish and salty water. River flows and ocean tides also deposit and erode sediment to shape the estuarine landscape and its habitats. Estuarine species are adapted to the complex natural flow, salinity, and sediment dynamics in their native estuaries.

Delta flows can be divided into three categories: (1) river and floodplain flows, (2) in-Delta net channel flows, and (3) net Delta outflows (SWRCB 2010). Each category has different ecological effects. (See sidebar, Flow Is More than Just Volume.)

BAY DELTA CONSERVATION PLAN AND DELTA ECOSYSTEM RESTORATION

The parties seeking permits pursuant to the Bay Delta Conservation Plan (BDCP) are attempting to formulate a 50-year plan that, if successful, would ultimately contribute to the recovery of priority species, restoration of a more naturally functioning Delta ecosystem, and establishment of a secure and reliable water supply from the Delta for human use.

As discussed in the Chapter 3 sidebar, BDCP and Water Supply Reliability, the BDCP is a planning process intended to result in the issuance of permits from the California Department of Fish and Wildlife (DFW) under the Natural Community Conservation Planning Act and from the U.S. Fish and Wildlife Service and the National Marine Fisheries Service pursuant to Section 10 of the federal Endangered Species Act (ESA). In addition, the Bureau of Reclamation will use the information developed from this process to obtain incidental take authorization through an ESA Section 7 process. The BDCP proposes to contribute to the restoration of the health of the Delta's ecological systems by contributing to a more natural flow pattern than existing conditions within the Delta and by implementing a comprehensive restoration program.

As currently proposed, the BDCP takes an approach to supporting landscape-level processes by creating a reserve system consisting of a mosaic of natural communities that would be adaptable to changing conditions (including sea level rise) to sustain populations of covered species and maintain or increase native biodiversity (BDCP 2012). The proposal considers protection of at least 31,000 acres of existing natural communities, and restoration or creation of at least 72,809 acres of natural communities, including at least 65,000 acres of tidally influenced natural communities. In addition, the BDCP is intended to improve the Delta ecosystem by taking actions such as:

- Protecting and improving habitat linkages to promote the movement of native species
- Accommodating future sea level rise by providing transitional areas that allow future upslope establishment of tidal wetlands
- Allowing natural flooding to promote the regeneration of vegetation and related ecosystem processes
- Connecting rivers and their floodplains to recharge groundwater, provide fish spawning and rearing habitat, and increase food supply
- Managing the distribution and abundance of nonnative predators to reduce predation on native special-status species

Examples of elements of the BDCP strategy to support natural communities include:

- Controlling invasive nonnative plant species
- Restoring or creating 5,000 acres of riparian forest
- Restoring corridors of riparian vegetation along 20 miles of channel margin
- Restoring 2,000 acres of grassland
- Protecting at least 20,000 acres of cultivated land to support suitable habitat for native species

The BDCP also plans to propose comprehensive programs for monitoring, research, and adaptive management.

If the process is successful and DFW approves the BDCP as a natural community conservation plan pursuant to Chapter 10 (commencing with Section 2800) of Division 3 of the Fish and Game Code, and determines that the BDCP meets the requirements of this section, and the BDCP has been approved as a habitat conservation plan pursuant to the federal ESA (16 United States Code section 1531 et seq.), the Council shall incorporate the BDCP into the Delta Plan (Water Code section 85320(e)). The Council has a potential appellate role regarding the inclusion of the BDCP in the Delta Plan.

As of this publication, the final public draft of the BDCP and the related environmental impact report/environment impact statement are expected to be released in late 2013. The Council is a Responsible Agency for California Environmental Quality Act purposes.

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1. **River and floodplain flows.** The Sacramento and San Joaquin rivers and their tributaries provide fresh water into the Delta. Along the margins of the Delta, these rivers seasonally inundate floodplains. Inundated floodplains stimulate the food web by enhancing plant growth, triggering aquatic invertebrate production, exporting food that becomes available to animals downstream, and providing spawning and rearing habitat on the floodplain for fish such as salmon and splittail. In recent decades, floodplains like the Yolo Bypass are flooded primarily by very high flows that flood the Yolo Basin about one year in three. Floodplain restoration could re-establish topographic connections that flood the bypass more often and at lower flows.

2. **In-Delta net channel flows.** Delta flows are primarily driven by tides affected by the moon's cycles, river inflows, in-Delta agricultural diversions, and water exports through the Central Valley Project (CVP) and the State Water Project (SWP). Averaging these influences in any Delta channel over about 1 day gives the "net flow." Locations near the CVP and SWP export pumps, such as parts of Old River and Middle River in the south Delta, experience net "reverse" flows when export pumping by the water projects exceeds these channels' normal downstream flows. The average flow in these channels actually runs backward at times, which affects the Delta's aquatic ecosystems both directly and indirectly (see Figure 4-4). Reverse flow in the southern Delta is associated with increased entrainment of some fish species (Grimaldo et al. 2009) and disruption of migration cues for migratory fish (see the Migratory Corridors for Native Species section for more detail). Reverse and otherwise altered flows caused by upstream reservoir operations, the constraints of artificially connected Delta channels, plus water exports affect Delta habitat largely through effects on water residence time, water temperature, and the transport of sediment, nutrients, organic matter, and salinity (Monsen et al. 2007). These reverse flows could, in turn, affect the behavior of migrating fish, and habitat suitability for resident and migratory fish and other species. Finally, aquatic organisms often get drawn (entrained) into water pumping facilities, as described later in this chapter.

3. **Net Delta outflows.** Net Delta outflow is the sum of all inflows to, and diversions from, the Delta. It is the flow out of the Delta that would occur in the absence of tides (Oltmann 1988). During dry periods, outflow is a low percentage of the instantaneous tidal flow in the western Delta. Nevertheless, over periods longer than 2 weeks, Delta outflow transports river-derived organic matter to Suisun Bay (Jassby and Cloern 2000) and controls the location of the salinity gradient (Jassby et al. 1995). Delta outflow objectives are based on the monthly average location of the low-salinity zone in the western Delta. Outflow variability is recognized as a key factor promoting diverse native fish communities (Moyle and Mount 2007, Moyle et al. 2010).

FLOW IS MORE THAN JUST VOLUME

Flow is not simply the volume of water, but also the direction of flow, the timing of flow, the frequency of specific flow conditions, the duration of various flows, and the rate of change in flows.

Bunn and Arthington (2002) present four key principles underlying the links between hydrology and aquatic biodiversity and the impacts of altered flow regimes: (1) flow determines physical habitat, (2) aquatic species have evolved life history strategies based on natural flow regimes, (3) upstream-downstream and lateral connectivity are essential to organism viability, and (4) invasion and success of nonnative species is facilitated by flow alterations. Altered flow regimes have been shown to be a major source of degradation to aquatic ecosystems worldwide (Petts 2009).

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Flow Direction in South Delta

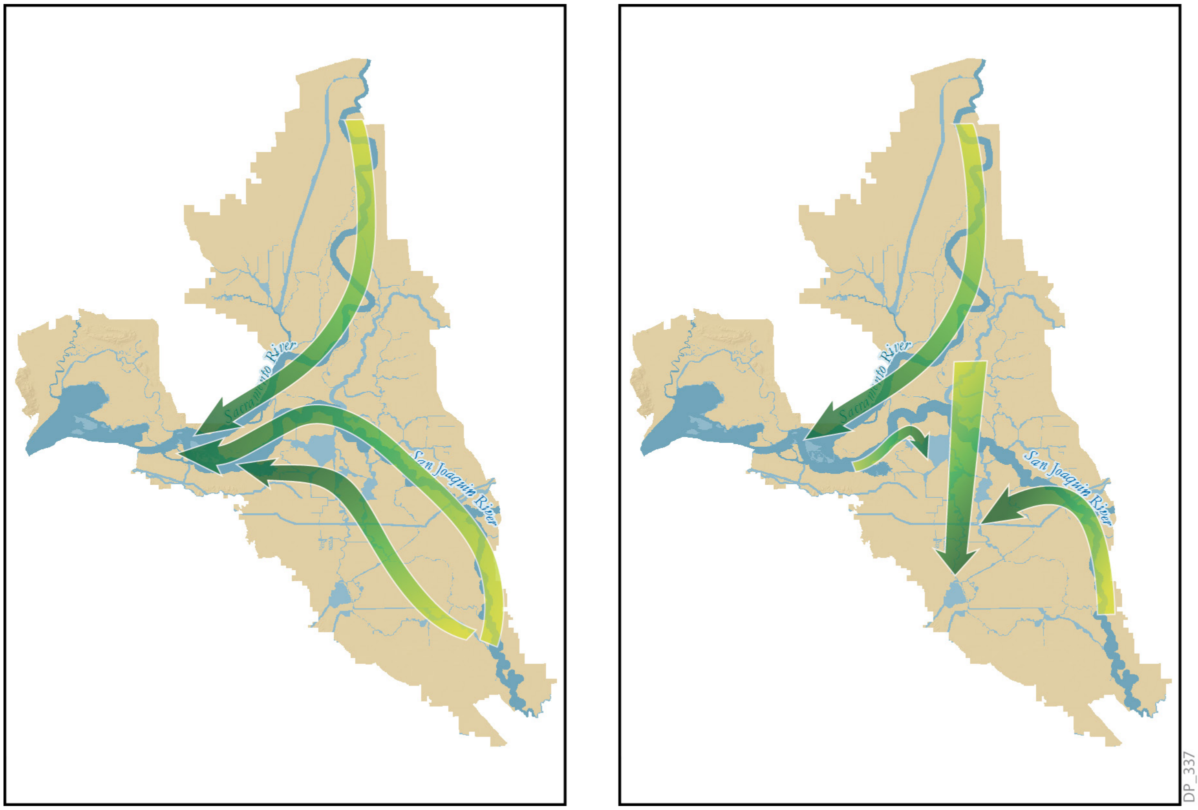
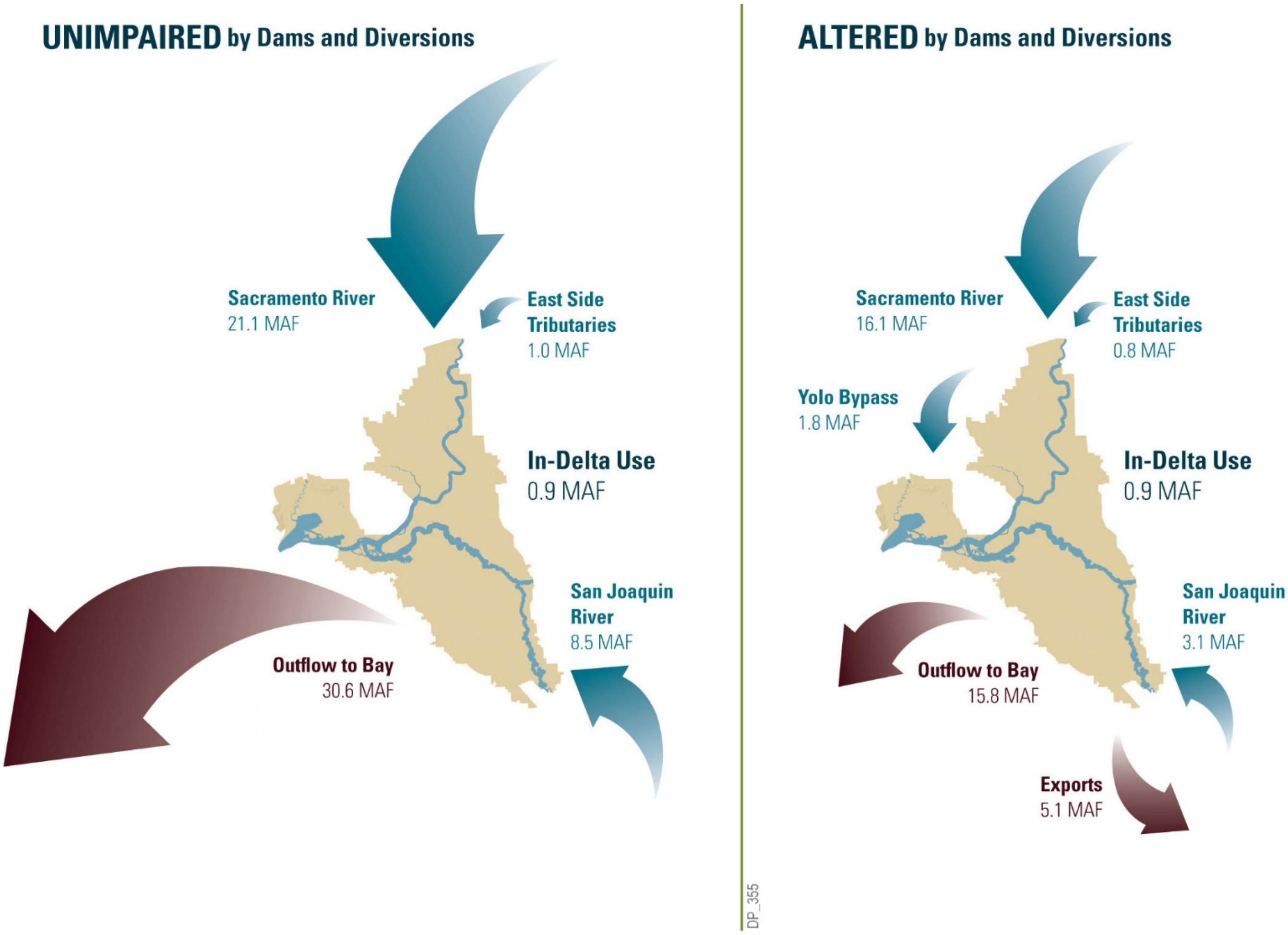


Figure 4-4 The left panel depicts the tidally averaged flow direction in the absence of export pumping. The right panel depicts reversal of tidally averaged flows that occurs during times of high exports (pumping) and low inflows to the Delta.

Present-day Delta flows are very different from historical, natural flows. Water flows have been altered by water supply and flood control infrastructure, including dams on the Sacramento and San Joaquin rivers and their tributaries; levees along these rivers and the Delta's channels; and draining of floodplains, wetlands, and groundwater basins (see Figure 4-5). Flows sometimes have not reflected the Fish and Game Code section 5937 requirement that dam owners should allow sufficient water at all times to pass through a fishway, or in the absence of a fishway, to pass over, around, or through the dam, to keep in good condition any fish that may have been planted or that exist below the dam (DFG 2012). Flows are now closely managed by releases from reservoirs to supply water for agricultural and urban uses, control salinity, and reduce floods. In the Delta, flows have also been rerouted through artificial channels. Flow management and modified Delta channel geometry have altered the salinity and sediment regimes in the Delta (Enright and Culberson 2010, Wright and Schoellhamer 2004), managing salinity for human uses rather than for fish and wildlife. Low winter-spring flows disrupt turbidity and salinity cues for migrating fish (Grimaldo et al. 2009), reduce access to spawning and rearing habits in tributaries and floodplains (Sommer et al. 1997, Feyrer 2004, Feyrer et al. 2007), and limit success for young fish trying to follow natural migration patterns (Feyrer and Healy 2003). Current flow management regulations provide some protection for ecological functions and native species, but the current Delta flow regime is generally harmful to many native aquatic species while encouraging nonnative aquatic species (SWRCB 2010).

Effects of Dams and Diversions on Delta Inflows and Outflows



Data presented as a long-term average. Information based on DWR CALSIM II modeling, which includes projected conditions to protect fisheries.

Delta-Suisun in-Delta use includes water to the Contra Costa Canal and to the Mokelumne and Hetch Hetchy aqueducts.

MAF = millions of acre-feet

Figure 4-5

Water flows more closely approximating the timing, frequency, duration, volume, and rate of change of flow produced naturally by a region's climate are best for native aquatic communities (Poff et al. 1997, Bunn and Arthington 2002, Carlisle et al. 2010). Flow is a major environmental input that shapes ecological processes, habitat, and biotic composition in riverine and estuarine ecosystems such as the Delta. Returning to a more naturally variable hydrograph is a key component of ecosystem restoration because the hydrograph works hand-in-hand with habitat restoration to produce diverse and interconnected food webs, refuge options, spawning habitat, and regional food supplies (Carlisle et al. 2010). Flows should provide species benefits and water supply reliability in the context of current hydrological conditions and degraded habitat. In some cases, flows to benefit the ecosystem will deviate from historical "natural" flows, because the channel geometry, land-water connectivity, and infrastructure limits our ability to mimic historical conditions. Flows will also need to be modified as habitat areas are restored. The Delta Plan, therefore, calls for "more natural functional flows" in the Delta as an important aspect of ecosystem restoration. (See sidebar, More Natural Functional Flow, for a description.)

Flow-related stressors can be reduced or mitigated through improved flow management and concurrent reduction of other stressors. Improved flow management comes from better use of current or improved water infrastructure. The challenge in managing flows is to both restore the Delta ecosystem and improve water supply reliability. Flow-related stressors are likely to increase as population grows and the climate changes. Preparation for these changes must start now.

The State Water Resource Control Board's (SWRCB's) Bay-Delta Water Quality Control Plan (Bay-Delta Plan) identifies water quality objectives to protect beneficial uses of the Bay and Delta, and an implementation program including control of salinity (caused by saltwater intrusion, municipal discharges, and agricultural drainage) through water projects operations. This is a contentious issue of public policy, and the Delta Reform Act directed the SWRCB to develop its new flow criteria using the best available science (Water Code section 85086).

The SWRCB is updating the 2006 Bay-Delta Plan with these steps: (1) review and update water quality objectives, including flow objectives, and the program of implementation in the 2006 Bay-Delta Plan, and (2) make any needed changes to water rights and water quality regulation consistent with the program of implementation. Updating the water quality objectives for the Delta, including an update of flow objectives, is important to protect the Delta ecosystem and the reliability of the Delta's water supplies. The sooner these objectives are set, the earlier the ecosystem can be protected and restored, the greater the possibility that a successful Bay Delta Conservation Plan (BDCP) will be approved, the earlier a more reliable water supply can be improved, and, therefore, the earlier the coequal goals can be achieved. That is why the Delta Plan calls upon the SWRCB to complete its work by specified deadlines. A more detailed explanation of the SWRCB's development of water quality objectives, including flow objectives, is included in Chapter 6.

Entrainment Is One Effect of Altered Flows

Entrainment occurs when fish and other aquatic life are drawn into a water diversion intake and are unable to escape. In the Delta, entrainment occurs primarily at the CVP facilities (Tracy Fish Facility and the nearby Delta-Mendota Canal) and the SWP facilities (including Clifton Court Forebay and the Skinner Fish Facility), as well as other smaller Delta intakes.

Much of the time, net channel flows in most of the south Delta are toward the pumps. This increases the probability that small, weak-swimming young smelt or salmon will be entrained. Depending on the type and size of the fish, the closer a fish is to the pumps, the more likely it is to be entrained. Greater reverse flows caused by pumping in the south Delta increase the numbers of fish entrained.

Some of the entrained fish are "salvaged," meaning they are caught in facilities at the pumps and then trucked and released to an area beyond the pumps' influence. The salvage process decreases the mortality of entrained fish (including salmon). Unfortunately, however, many fish, including delta smelt, are not able to survive the collection, handling, transport, and release.

MORE NATURAL FUNCTIONAL FLOW

What is natural Delta flow? Natural Delta flow is the historical (before 1849) pattern of watershed flows that eventually arrived in the Delta. Historical Delta flows resulted from rainfall in the watershed and the pattern of water storage and release from mountain snowpack, forest and valley soil and vegetation, and the natural topography of creeks, rivers, natural levees, and valley floodplains. These landscape patterns have been modified since 1849, and will largely not be returned to their former state.

Why is natural flow important? Native species are adapted (by natural selection) to the seasonal, interannual, and spatial variability of the historical flow pattern and the functions that come with it. Flows interact with land to create physical habitats and connections where species find food, refuge, and reproduction space. Through a variety of mechanisms, native species can survive, grow, and reproduce better when flows occur in more natural historical patterns.

What does natural flow look like? There were no measurements of natural Delta flow before the watershed was modified by gold mining, agriculture, and water storage. In general, natural flows rise in concert with precipitation patterns and fall slowly as the natural water storage capacity of the watershed is released. Natural flows are not simply water volumes but also include the seasonal timing, magnitude, frequency, duration, and rate-of-change in flows. It is often asserted that "unimpaired Delta inflow" is a good approximation of natural flow. For the Delta, unimpaired flow is the inflow that would be expected if reservoirs were removed but contemporary watershed and valley land uses remained. Unimpaired Delta inflow may overestimate the magnitude of natural Delta inflow and abridge the timing of seasonal peaks.

Will more natural flow work to meet ecosystem goals? Not by itself. Natural flows exist only in the context of natural landscape patterns. The pattern of historical natural flow reflected seasonal and interannual interaction with the historical landscape. For example, historical high flows in winter and spring were intercepted and stored by natural floodplains and then released slowly to the Delta through the summer. Much of the ecosystem functional value of natural flows occurs in these seasonal land and water interactions.

We do not have natural landscapes, so now what? Until large-scale restoration is in place, we can meet ecosystem goals in the interim by using the best available scientific understanding of the *functions* that flows provide to native species. For example, winter-run salmon historically survived low summer flows by finding cold-spring creeks in the watershed for spawning. These creeks are now blocked by dams, but cold water can be released from reservoirs to improve spawning habitat farther down. Another example is using Delta outflow to position the low salinity zone ("X2") in Suisun Bay at key times of the year when the salinity, refuge, and food resources there can benefit native fish. More natural flow is therefore understood to emphasize more natural *functions* rather than the shape of the hydrograph. More natural functional flows could include diverting more flow in wet years and less flow in dry years, as described in Chapter 3. With landscape restoration over time, managing water for functional natural flows should be adaptively managed as ecosystem conditions change. The Delta Plan call for "more natural functional flow" suggests that we can adaptively manage the *functions* that flows provide to the life history needs of native species. Therefore, managing for more natural functional flows protects, restores, and enhances the Delta ecosystem.

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Alteration of water flows also leads to losses of fish from predation. High rates of predation occur at the pumps, and the sloughs and channels near the pumps. Small fish drawn into this part of the Delta have a very low chance of survival. Juvenile salmon drawn into the central Delta through the Delta Cross Channel or Georgiana Slough also have a lower chance of survival than fish staying in the Sacramento River's mainstem. Whether the effects of flow on fish are direct through entrainment or indirect through increased mortality caused by altered flows and predation, the results are the same: fish lost as a result of Delta diversions.

Because of all these factors, managing flows within the Delta is a difficult but important tool for protecting fish. For example, the SWRCB requires reductions in diversions and increases in San Joaquin River inflows during springtime to increase the survival of outmigrating juvenile salmon. The biological opinions for salmon and smelt include measures to reduce entrainment and indirect loss of fish due to altered flows caused by the SWP and CVP diversions. These actions include restrictions on reverse flows in the Old River and Middle River channels in the south Delta and requirements for closing the Delta Cross Channel gates.

Entrainment does not just occur at the Delta pumps. It also can occur at other diversions upstream from the Delta. Larger diversions upstream and in the Delta are screened, but many smaller diversions are not. In-Delta unscreened diversions do not currently appear to entrain substantial numbers of salmon or smelt.

Habitat

Appropriate habitat is required for any organism to survive and reproduce (Hall et al. 1997). Because no two species have exactly the same requirements, habitats are species-specific components of ecosystems.

Expanding habitats for native species is an essential part of restoring the Delta's ecosystem. Recent biological opinions controlling long-term operations of the CVP and SWP require restoration of at least 8,000 acres of intertidal and associated subtidal habitats in the Delta, including Suisun Marsh (USFWS 2008). They also require restoration of 17,000 to 20,000 acres of floodplain rearing habitat for salmon in the Yolo Bypass and lower Sacramento River, including side channels and re-created floodplain terrace areas (NMFS 2009). Some of the tidal marsh acreage may also fulfill requirements for restored floodplains, depending on its location.

Habitat restoration, like water flow, is not just about quantity (or extent), but also about quality, connectivity, and diversity. Land cover types, such as open-water and riparian vegetation, vary greatly and are only one element of habitat (Lindenmayer et al. 2008); an organism's habitat is much more than just land cover. For example, the area of the Delta covered by open water has not changed substantially during the last few decades, but several open-water fish have declined steeply (Sommer et al. 2007, Baxter et al. 2010). This suggests that some of the Delta's open waters have become inhospitable to these certain fish species. The functional habitat available to these open-water fish has shrunk even though the area covered by open water has remained fairly stable. This means that simply changing land cover (for example, increasing riparian habitat) does not automatically increase target species. Other stressors such as poor water quality, predation, or entrainment may make these areas unsuitable.

Habitat loss and fragmentation resulting from human land use causes species loss worldwide (Foley et al. 2005). In estuaries and coastal areas, habitat destruction, coupled with exploitation such as overfishing, are the leading causes of species declines and extinctions (Lotze et al. 2006). Habitat restoration can help recover native species, particularly when other stressors such as altered flows, degraded water quality, or predation by introduced species are also reduced (Carlisle et al. 2010, Lotze et al. 2006).

Taking a large view of an ecosystem, habitats are species-specific "patches" in spatially varied landscapes. The survival and success of organisms is closely associated with the total amount of usable habitat, as well as with habitat patch sizes, shapes, and arrangements (Hannon and Schmiegelow 2002). Habitats that are too small, fragmented, or isolated may not provide long-term support for specific organisms. In general, more, larger, and better-connected patches of a specific habitat create the conditions for persistence or recovery of the species associated with that habitat (Lindenmayer et al. 2008). (See sidebar, Landscape Ecology: A Fundamental Tool for Restoration Planning.)

Much of the original habitat for the Delta's native fish, wildlife, and plants has been urbanized or converted to agriculture over the past 160 years (Healey et al. 2008, Moyle et al. 2010, Baxter et al. 2010). This habitat loss is one of the largest legacy stressors to the Delta ecosystem. The current Delta ecosystem continues to be productive, but its habitat types and conditions support a much different mix of species than the historical Delta. Many of the thriving species are nonnative, such as largemouth bass and the Brazilian water weed *Egeria densa*. Some consider a few nonnative species, such as bass prized by anglers, to be desirable. But too many nonnative plants and animals can upset an ecosystem's balance, creating conditions unsuitable for native aquatic and terrestrial species (Sommer et al. 2007, Healey et al. 2008, Baxter et al. 2010). This conflict and the inadequate habitat for native species that reside in and migrate through the Delta is an important current ecosystem stressor that must be addressed.

LANDSCAPE ECOLOGY: A FUNDAMENTAL TOOL FOR RESTORATION PLANNING

Landscape ecology examines the influence of spatial patterns on ecological processes (Wiens 2002) and considers the ways that species use the landscape for finding food and refuge, and for adapting to change (Simenstad et al. 2000, Lindenmayer et al. 2008). The mosaic of landscape features—or "patches"—and the connections between patches affect species' locations, food and cover, the energy required to obtain those resources, and, ultimately, survival. The landscape perspective considers connections and exchanges between uplands; riversides and wetland edges; and the sloughs, channels, and bays that make up estuarine aquatic habitats. The food webs of these adjacent systems exchange organisms and energy that, in turn, can increase the productivity of each (Cloern 2007). Native estuarine species—terrestrial, semiaquatic, and aquatic—are adapted to the rhythms of the landscape's mosaic of connected habitats and its dynamic processes.

From a landscape perspective, "form begets function." Therefore, correct spatial structure and patterns are prerequisites for restoring and maintaining desired ecosystem processes and functions, and for providing appropriate habitat for native species. In the long term, restoring spatial patterns at ecologically appropriate scales can promote the "self-repair" of ecosystem processes and functions (Teal et al. 2009) and increase resilience to stressors. Consequently, this approach could reduce the operating and maintenance costs of restoration in an era of limited resources. Planning for ecosystem restoration should always consider appropriately large spatial scales (regional or larger), but restoration actions can proceed at smaller scales to optimize the benefits that can be achieved with the often limited opportunities and resources available for restoration (Hermoso et al. 2012).

Additionally, landscape ecology considers people's role in shaping landscape patterns and processes (Turner 1989). Restored landscapes often have agricultural and urban neighbors. Each land use affects the other because they are connected by air, land, and water. Yet humans often want conflicting things (nature areas nearby with abundant wildlife, but also with convenient recreation facilities, no mosquitoes, and no impacts on adjoining farms). A functioning ecosystem depends on many things, including understanding and dealing with its relationship to human activities. The current regulatory and political framework for restoration projects often puts short-term benefits, such as low acquisition cost or immediacy of land availability, before long-term benefits of connectivity and appropriateness of scale. Landscape ecology provides a set of tools for assessing and prioritizing limited restoration opportunities. For example, using the principles of landscape ecology, decisions about land acquisitions for restoration must address how small parcels that become available for restoration might be connected and combined to maximize ecological benefits over the long term.

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The Importance of Land Elevation in Habitat Restoration

Opportunities for habitat restoration in the Delta are constrained first and foremost by the elevation of land, which determines the potential of an area to be restored. As described in Chapter 5, much of the Delta has subsided too deeply to restore its original ecological functions (see Figure 4-6).

Deeply subsided Delta lands can provide terrestrial and wetland habitat for native species only at great cost and with intensive management. They offer few opportunities to recover native ecosystem forms and functions. However, deeply subsided islands could include seasonal wetlands for waterfowl and wildlife-friendly agriculture. Actions that promote carbon sequestration, subsidence reversal, and improved migratory bird habitat are especially valuable.

The most promising restoration opportunities are found in the less-subsided flood basins, river corridors, and brackish tidal marshes on the Delta's perimeter, leading the Council to recommended six priority habitat restoration areas:

- **Yolo Bypass, from the Fremont Weir south toward the Delta.** Winter and spring flooding of the Yolo Bypass provides substantial benefits for spawning and rearing of Sacramento splittail and rearing of salmon (Sommer et al. 2001, Moyle et al. 2007). Projects in the planning stage include fish passage improvements and various approaches, such as notching the Fremont Weir to increase the frequency and duration of inundation during times of the year critical for spawning and rearing of native fish. Restoration of the Yolo Bypass can create conditions that promote enhanced growth and survival of juvenile spring- and winter-run salmon, among other species, and can benefit other migrating salmon.

Habitat Types Based on Elevation, Shown with Developed Areas in the Delta and Suisun Marsh

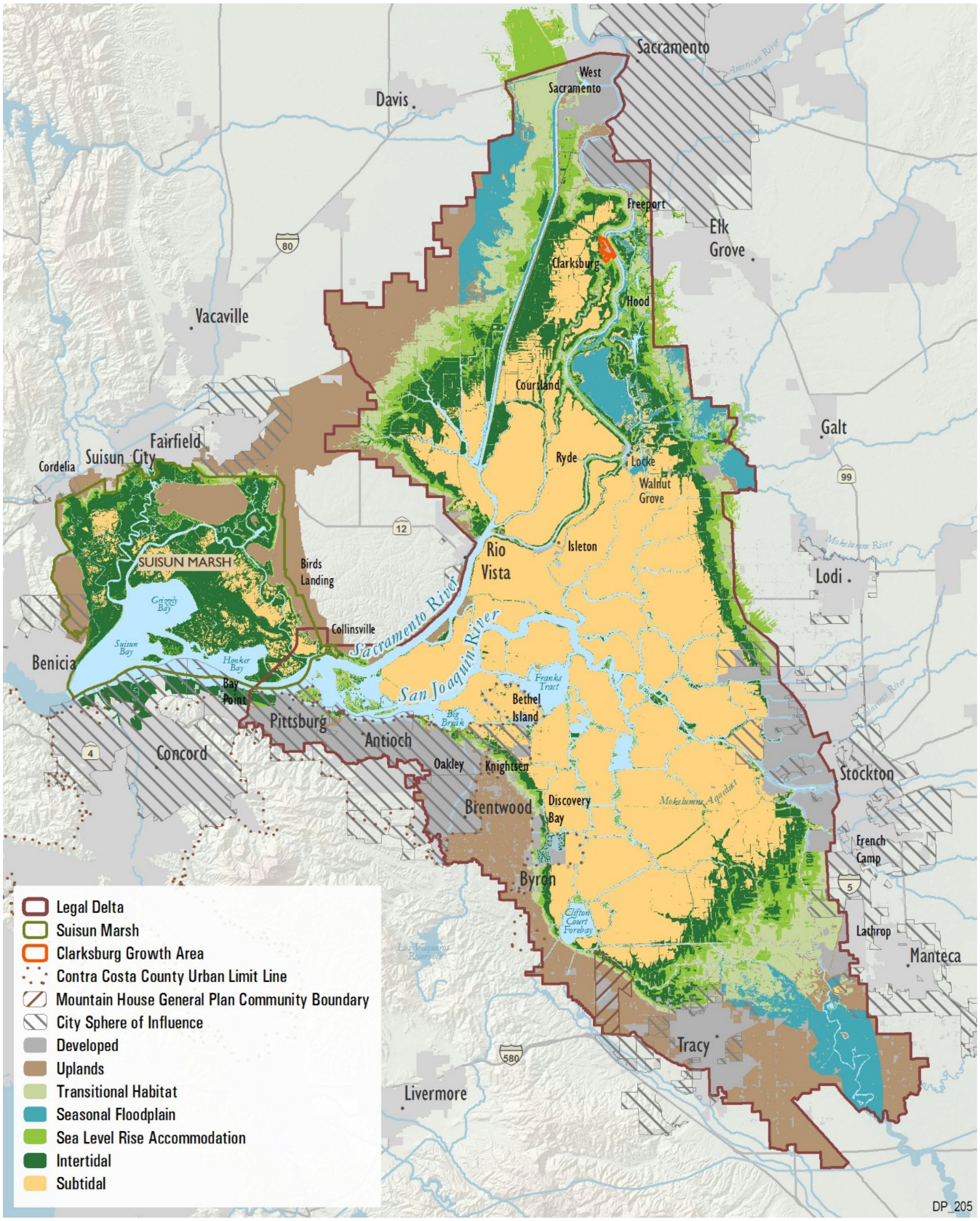

Figure 4-6 *Source: Adapted from DFG 2011*

- **Cache Slough Complex, southwest of the Yolo Bypass.** The flood basins entering the Cache Slough Complex are at the interface between river and tidally influenced portions of the Delta. A restoration project in this area is Liberty Island, which is being allowed to passively restore to marsh after floods breached the island's levees in 1997. Projects in the planning stage include California Department of Water Resource's (DWR's) Prospect Island restoration project. Habitat restoration at Cache Slough can create conditions that help recover delta smelt and that benefit migrating salmon. See the sidebar, Applying Adaptive Management to Ecosystem Restoration, for a hypothetical example implementing principles of adaptive management in projects such as these.
- **Cosumnes River–Mokelumne River confluence.** An existing restoration project is the Cosumnes River Preserve floodplain. Projects in the planning stage include DWR's North Delta Flood Control and Ecosystem Restoration Project on McCormack-Williamson Tract. Restoration here can benefit migrating salmon and contribute to the Delta's food webs.
- **Lower San Joaquin River floodplain between Stockton and Manteca.** Historically, the south Delta and its connection to the lower San Joaquin River contained a complex network of channels with low natural berms, large woody debris, willows, and other shrubs with upland areas supporting open oak woodlands. Projects in the planning stage include the Lower San Joaquin Flood Bypass proposed by the South Delta Levee Protection and Channel Maintenance Authority and its partners. Restoration to a mix of tidal marsh, riparian habitats, and wildlife-friendly agriculture could create conditions to recover riparian brush rabbits and Swainson's hawks, benefit migrating salmon, and serve to reduce the risks from flooding for urban areas.
- **Suisun Marsh.** This is the largest wetland area on the West Coast of the contiguous United States. Suisun Marsh is mostly managed for waterfowl, with levees that disconnect its wetlands from the estuary. An ongoing restoration project is DWR's Blacklock Restoration Project. Projects in the planning stage include California Department of Fish and Wildlife's (DFW's) Hill Slough Restoration Project. Restoration of tidal marsh and associated habitats here can create conditions that contribute to food webs in Suisun and Honker bays, and aid the recovery of longfin smelt and spring- and winter-run salmon.

  Unique local benefited species would also include Suisun song sparrows, saltmarsh harvest mice, and plants such as soft bird's-beak and Suisun thistle. Enhanced management of wetlands can reduce impacts on water quality while still maintaining or improving habitat for waterfowl of other wildlife.
- **Western Delta/Eastern Contra Costa County.** Some islands and tracts at appropriate elevations may be desirable sites for restoration of tidal marsh and channel margins to support food webs and provide habitat for native species. Decker Island is a recent restoration project in this area, and restoration at Dutch Slough is planned. Additional restoration of other islands or tracts may be considered in the BDCP or in local Natural Community Conservation Plans/Habitat Conservation Plans.

These six regions have been highly altered by more than a century of human use and exposure to multiple stressors. Returning a portion of these altered regions to habitat for native species requires a careful assessment of opportunities and challenges. Recommendations provided later in this chapter include actions to prevent or mitigate adverse impacts on opportunities for habitat restoration in these priority restoration areas.

Applying Adaptive Management To Ecosystem Restoration			An adaptive management approach to ecosystem restoration should be used to plan for and assess the ecological outcomes of the restoration action. The following is a hypothetical example of how the Council's three-phase and nine-step adaptive management frame-work (see Appendix C) could be applied to an ecosystem restoration project in the Cache Slough Complex.
Adaptive Management Step			**Hypothetical Cache Slough Ecosystem Restoration Project**
Plan	1	Define/redefine the problem	The Cache Slough Complex includes high biodiversity; however, ecological processes and habitat that benefit native species in the Cache Slough Complex are degraded.
	2	Establish goals, objectives, and performance measures	**Goal:** Re-establish natural ecological processes and habitats to benefit native species in the Cache Slough Complex. **Objective:** Re-establish the hydrologic, geomorphic, and ecological processes necessary for the long-term sustainability of native habitats, and the plant and animal communities that depend upon them. Improve floodplain connectivity and aquatic habitat quality for native estuarine species, including delta smelt, longfin smelt, Sacramento splittail, and Chinook salmon, by offering a suite of natural habitats and improving the food web fish require.
	3	Model linkages between objectives and proposed action(s)	The Cache Slough Complex provides high potential for restoration success because of its physical and biological attributes (such as tidal range, elevation, high amounts of suspended sediment, abundant zooplankton, and observed use by delta smelt). It is hypothesized that improved vernal pool and grassland habitats along with broad nontidal, freshwater, emergent-plant-dominated wetlands that grade into tidal freshwater wetland, shallow subtidal, and deep open-water habitat will increase the amount and quality of food for native species in the estuary. It is hypothesized that restoring tidal channel, wetland, and upland networks will improve conditions for native fishes. It is hypothesized that increases in the quality and quantity of food for native species will lead to increases in native species populations in the estuary. Native species expected to benefit from this restoration include delta smelt, juvenile Chinook salmon, Sacramento splittail, and longfin smelt.
	4	Select action(s) (research, pilot, or full-scale) and develop performance measures	Pilot-scale restoration project in the Cache Slough Complex: restore a subset of the processes supporting the creation of tidal channel, wetland, and upland networks to support native fishes. Performance measures: ▪ Administrative – Properties are identified for the pilot study. Funding sources and budgets for the project and monitoring are in place. Properties are acquired. Restoration planning and design is completed. Environmental compliance permits are obtained. Restoration contractors are selected. ▪ Output – Pilot-scale Delta habitat restoration project is implemented. Progress toward restoring diverse and interconnected habitats for native resident and migratory species in the Cache Slough Complex. ▪ Outcome – Progress toward achieving viable populations of native resident and migratory species. Trends in native Delta species are upward over the next decade.
Do	5	Design and implement action(s)	Design and implement the pilot-study restoration project.
	6	Design and implement monitoring plan	Design and implement the monitoring plan, including baseline monitoring of food abundance for pelagic organisms. Monitor the extent and quality of targeted habitats, connectivity of habitats, and abundance and diversity of species.
Evaluate and Respond	7	Analyze, synthesize, and evaluate	Analyze, synthesize, and evaluate the status and trends of changes in habitats, connectivity of habitats, abundance, and species health and diversity.
	8	Communicate current understanding	Provide project manager(s) and decision makers with annual reports of synthesized information learned. For example, provide a score card of the status and trends of species abundance and diversity, habitat connectivity, and so on.
	9	Adapt	The managers and implementers of the restoration project reconsider their understanding of the problem statement and conceptual model, and decide whether or not to expand from a pilot-study project to a larger-scale restoration effort.

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Migratory Corridors for Native Species

Habitat restoration often targets resident species that use the restored habitat year-round. Successful restoration, however, must also consider species that only periodically use particular habitat patches and corridors. The historical Delta provided migration corridors and rearing habitat for many migratory bird and fish species, including the threatened greater sandhill crane, many species of ducks and geese, salmon, sturgeon, and the introduced striped bass.

In the past, the Delta was a migration route and also an important nursery area for young salmon (or "smolts"). Much of the Delta today presents real risks to migrating salmon; it is no longer a suitable nursery for salmon smolts (Williams 2006). Some Delta channels do provide a greater chance of fish survival than others. For example, salmon leaving the Sacramento River and entering the interior Delta through the Delta Cross Channel have significantly lower survival than fish that stay in the river (Newman 2008), demonstrating that the central Delta has become a gauntlet of risk instead of a viable migratory corridor.

Entrainment at the CVP and SWP southern Delta pumps and increased predation kill salmon smolts. Toxic contaminants and periods of low dissolved oxygen can be harmful. Important factors for route selection and survival of salmon smolts on their way to the ocean include differences in flows through different channels, feeding opportunities, growth rates, and vulnerability to predation (Perry et al. 2009).

On their way back from the ocean to spawn, adult salmon must navigate a maze of Delta waterways where water from many different sources is mixed in artificially connected channels, and where rivers sometimes flow backward (reverse net flows in Old and Middle rivers; see the Delta Flows section) (Monsen et al. 2007). A unique problem is presented by the San Joaquin River, whose polluted and reduced flows are often drawn to the SWP and CVP pumps as a result of reverse flows. During these times, almost no water from the San Joaquin River reaches the confluence with the Sacramento River. Instead, water from the Sacramento River and its tributaries fills most of the Delta, obscuring and confusing the chemical and flow cues that salmon and other migratory fish depend on to find their destinations.

In addition to altered water flow and chemical disruption, migratory fish encounter dams, reservoirs, and other physical barriers that hinder their historical migration. The most formidable barriers are upstream on the Sacramento and San Joaquin rivers and their tributaries, especially the many large and small dams associated with reservoirs, including Shasta, Folsom, and Millerton lakes and Lake Oroville. In the Central Valley, less than one-fifth of the historical spawning habitat is still accessible to Chinook salmon and steelhead (Reynolds et al. 1993, Yoshiyama et al. 1996).

Physical barriers in the Delta help maintain water supplies for agriculture but interrupt fish migration; structures with ledges and drops, such as bridge pilings, boat docks, narrow channels with riprapped edges, or the intakes of the SWP and CVP pumps, create attractive spots for predatory fish to feed on migrating species. The Delta Cross Channel is an example. Sometimes, a barrier can have positive effects. Federal, State, and local officials have recently tested novel bio-acoustic fish fences (BAFFs) at Old River and Georgiana Slough that use light, sound, and air bubbles to steer migrating fish into channels that are thought to provide better habitat and a greater chance of survival.

Some high-quality migratory fish rearing and migration habitat remains at the margins of the Delta, if not in its core. The Yolo Bypass and Cosumnes River floodplains provide good migratory and rearing habitat for salmon, and important habitat for other native fish, birds, and bats. DFW manages the Vic Fazio Yolo Wildlife Area, a 16,000-acre public-private restoration project in the Yolo Bypass, to promote waterfowl and other bird populations. The 46,000-acre Cosumnes River Preserve is jointly owned and operated by The Nature Conservancy, Ducks Unlimited, the Bureau of Land

Management, DFW, DWR, Sacramento County, and private owners to create, enhance, and protect a variety of habitats. These are good illustrations of ecosystem and flood risk reduction projects working together. Wildlife-friendly agriculture also occurs in these floodplain preserve areas and their surroundings. During winter and early spring floods, these floodplains provide plentiful food for migrating salmon and native fish such as splittail, prickly sculpin, and Sacramento sucker (Sommer et al. 2001, Crain et al. 2004). Salmon migrating through these floodplains grow faster and have greater survival. (See sidebar, Better Habitat Equals Greater Growth.) Native fish do particularly well when flows through these floodplains follow more natural patterns. Early February through April, strong flood flows with cool water temperatures benefit many young native fish. Nonnative fish benefit more from later and lower flows with higher temperatures. Floodplain restoration should thus focus on early flooding followed by careful draining. This provides important migration and nursery habitat for native species while keeping nonnative species, including predators, at bay.

BETTER HABITAT EQUALS GREATER GROWTH

This comparison illustrates faster growth in floodplain habitat compared to river habitat. Salmon on the left were reared within Cosumnes River channel habitat, and the salmon on the right were reared within Cosumnes River floodplain habitat. All salmon shown are the same age.

Source: Jeffres et al. 2008

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Actions above and below the Delta also complement actions in the Delta to restore migratory corridors for fish and wildlife. The Bureau of Reclamation, U.S. Fish and Wildlife Service, and DFW have modified Shasta Dam to release colder water for salmon and trout, removed barriers to fish migration such as the Red Bluff Diversion Dam, screened water diversions to reduce entrainment, restored riparian habitats at the Sacramento River National Wildlife Refuge (NWR) and San Joaquin River NWR, and improved habitats in Sacramento and San Joaquin river tributaries where salmon spawn. Efforts to restore flows in the San Joaquin River also can rebuild these migratory corridors.

For example, on Battle Creek, actions to remove multiple dams and fish ladders are being implemented through the Battle Creek Salmon and Steelhead Restoration Project. The primary objective of the restoration project is to restore the ecological processes that would allow the recovery of steelhead and Chinook salmon populations in Battle Creek while minimizing the loss of clean and renewable hydroelectric power through modifications to the hydroelectric project. This project is among the largest coldwater anadromous fish restoration efforts in North America and will restore approximately 42 miles of habitat in Battle Creek and an additional 6 miles of habitat in its tributaries. It will also help restore critically imperiled winter- and spring-run Chinook salmon and Central Valley steelhead. Additional restoration actions are planned for other Sacramento River tributaries including Clear Creek, Deer Creek, and Mill Creek.

On the mainstem of the San Joaquin River between Friant Dam and its confluence with the Merced River, the San Joaquin Settlement Agreement will increase flows, expand channel capacity, and remove barriers to migration to restore spring-run Chinook salmon runs. This long-term action is expected to occur in stages over 20 years. On the Tuolumne River, the largest tributary of the San Joaquin River, the Central Valley Project Improvement Act (CVPIA)

Restoration Plan actions focus on restoring spawning, rearing, and floodplain habitat. The Bobcat Flat Restoration Project includes excavation of 48,500 cubic yards of gravel and coarse material that will be used to restore 1.6 miles of fall-run Chinook salmon and Central Valley steelhead spawning and rearing habitat. Similar habitat restoration projects have been implemented or are planned on other tributaries of the San Joaquin River and the Delta, including the Merced, Stanislaus, Calaveras, and Mokelumne rivers. However, 16 years after the creation of the CVPIA restoration fund, a panel of independent scientists issued a report on the CVPIA Fisheries Program (Reclamation and USFWS 2008) concluding that more could be done to effectively address the most serious impediments to survival and recovery of salmonids.

Wetlands bordering San Pablo Bay downstream of the Delta are home to a host of native and nonnative fish, waterfowl, shorebirds, other wildlife, and endangered plants and important stopping points on the Pacific Flyway. Uncommon species found in and around San Pablo Bay wetlands include longfin smelt, delta smelt, salt marsh harvest mouse, California clapper rail, San Pablo song sparrow, and black rail. All Central Valley anadromous fish migrate through the bay and depend on its open water and marshes for some critical part of their life cycle. The bay and its adjacent marshes are also important nursery grounds for many marine, estuarine, and anadromous fish. More than 40,000 acres of diked baylands and wetlands bordering the San Pablo Bay have been protected and are being restored.

In the Sacramento and San Joaquin valleys, actions to protect, restore, and enhance wetlands carried out by the Central Valley Joint Venture have significantly increased wildlife habitat resources for migratory waterfowl, shorebirds, waterbirds, and riparian songbirds in accordance with conservation actions identified in the Joint Venture's Implementation Plan. The Joint Venture establishes population objectives for these migratory birds then determines the appropriate amount of food, habitat, and water supply necessary to meet the objectives. Wetland restoration becomes a priority when habitat and forage needs for population objectives are not being met.

Successful recovery of native species requires effective habitat restoration. In addition to restoring physical habitat and corridors for movement, reducing other stressors is important too. Together, they help in achieving the coequal goal of a healthier Delta ecosystem.

Riparian and Shaded Riverine Aquatic Habitat

Fish and birds migrating through the Delta need abundant floodplains and appropriate water flows; but they also need streamside trees and shrubs that shade and cool the rivers; undercut riverbanks where smolts and other small fish rest and hide; and trees that drop insects and leaves that contribute to the food web and provide cover, food, and nest sites for songbirds and other wildlife. Unfortunately, along most of the Sacramento and San Joaquin rivers, levees are near the water's edge, not set back from rivers, leaving little room for these habitat features, which often are provided only by trees growing immediately adjacent to or even on the levees themselves.

Because of the importance of these streamsides, water supply or flood risk policies and projects that affect the Delta's rivers and other channels should consider the impact on remaining riparian and shaded riverine habitat. Setting back levees can create additional area for habitat and increased capacity for flood flows. Setting back levees, however, can be expensive and difficult. At the same time, there is considerable controversy over the current policy of the U.S. Army Corps of Engineers (USACE) to require removal of trees and most shrubs from levees under their jurisdiction. A technical manual issued by the Federal Emergency Management Agency (FEMA) for earthen dams has been relied upon heavily to support this vegetation removal policy (FEMA 2005). There is little riverine habitat left. If implemented as proposed, the USACE's order would destroy much of what remains. The Delta Plan calls for the

USACE to reconsider and change its policy in order to protect riverine habitat.

Safe Harbor Agreements

Voluntary safe harbor agreements between wildlife agencies and landowners can contribute to the recovery of species protected by the State or federal Endangered Species Acts. These agreements assure the landowners that the presence of endangered species on their property will not result in restrictions on other activities undertaken on their land. Facilitating and creating standard rules for these agreements with Delta landowners may encourage more landowners to participate in conservation programs.

Suisun Marsh and the Bay Conservation and Development Commission

The Suisun Marsh is one of the Delta Plan's priority habitat restoration areas. It is one of the largest contiguous estuarine wetlands in North America; an important nursery for fish; a wintering and nesting area for waterfowl and waterbirds; and an essential habitat for plants, fish, and wildlife, including several scarce and sensitive species. Suisun Marsh offers unique restoration opportunities because of its position in the Delta ecosystem and the diversity of physical processes it hosts. Suisun Marsh harbors a greater percentage of native fish than the remainder of the Delta, in part because its brackish water limits nonnative species. Additionally, the marsh has many diverse tidal sloughs that provide options for food and refuge (Moyle et al., 2010).

Unlike the deeply subsided Delta, much of the Suisun Marsh is still at elevations suitable for restoration of intertidal habitat, including tidal marsh and shallow water habitat. This area provides the brackish portion of the estuary with the potential to support productive and complex food webs, and with space to adapt to sea level rise. State and local land use policies should reflect the unique role that Suisun Marsh can play.

The San Francisco Bay Conservation and Development Commission (BCDC) is responsible for protecting San Francisco Bay and its shoreline, including Suisun Marsh, through the San Francisco Bay Plan, as described in Chapter 5. It is developing regional strategies to address the impacts of sea level rise and climate change on the Bay. BCDC provides special protection of the Suisun Marsh under the Suisun Marsh Preservation Act through the Suisun Marsh Protection Plan (SMPP). BCDC recently amended the San Francisco Bay Plan to address climate change and sea level rise. The climate change policy, among other things, incorporates sea level rise projection ranges consistent with those developed by the California Ocean Protection Council (2011) and calls for development of a long-term regional strategy to address sea level rise and storm activity. The SMPP and the Suisun Marsh Local Protection Program should also be amended to address climate change and rising sea level.

Ecosystem Water Quality

Chapter 6 deals with water quality issues and contains many recommendations for action. Impaired water quality makes it much harder to restore a healthy Delta ecosystem. Recommendations in Chapter 6 regarding salinity and environmental water quality cover key linkages between ecosystem restoration and water quality.

Consistently good water quality is crucial for successful restoration of aquatic habitats, sustenance of native plants and animals, and other beneficial uses of Delta water. Salinity should be more consistent, with a naturally variable estuarine hydrograph with high-quality river inflows. Nutrient composition and concentrations should not cause excessive growth of nuisance aquatic plants or blooms of harmful algae, and should support diverse and productive aquatic food webs. Dissolved oxygen levels, water temperatures, turbidity, and other attributes should meet the needs of native species. At all times the Delta should be free of substances that exceed toxic concentrations. Discharge of treated wastewater, urban runoff, or agricultural return flows should not adversely affect the Delta.

Chapter 6 focuses on four key areas where the best available science shows the need to protect and improve water quality to achieve the coequal goals (see Chapter 6 for a complete discussion):

- Requiring Delta-specific water quality protection
- Protecting beneficial uses by managing salinity
- Improving drinking water quality
- Improving environmental water quality

Nonnative Species

Among the world's estuaries, the Delta and San Francisco Bay are among the most invaded by nonnative species (Cohen and Carlton 1998). Some nonnative species have been in the Delta for more than a century and seem to be a permanent feature of the Delta ecosystem. Because it is nearly impossible to eradicate nonnative species once they are established, many can be considered legacy stressors that can be managed but not eliminated.

However, the introduction of any new nonnative species has consequences, particularly for native species. Nonnatives can take over habitat space, compete for food and nutrients, alter food webs, modify the physical habitat structure, or prey upon native species (DFG 2011). In wetlands and riparian areas, nonnative vegetation often crowds out native plants and reduces diversity used by resident and migrating birds and other animals (PRBO CalPIF 2008). The result is that nonnative plants, invertebrates, and fish may replace native species, and that change on their native counterparts is often combined with the other stressors such as altered flow, impaired habitat, and poor water quality.

Significant nonnative species in the Delta include (DFG 2008):

- **Overbite clam.** The overbite clam, a bottom-dwelling filter feeder, entered the Delta in the late 1980s and adapted well to its brackish areas. Overbite clams contribute to the reduction of algae and some invertebrates in the Delta, especially in Suisun Bay (Kimmerer 2006), causing loss at the base of the food web, which contributes to the decline of delta smelt and other open-water fish (Sommer et al. 2007).
- **Asian clam.** The Asian clam was first found in the Delta in 1946 (USGS 2001). This clam does not tolerate saline water, but is abundant in freshwater parts of the Delta and in the mainstems of the Sacramento and San Joaquin rivers. Ecologically, this species can alter channel bottoms and competes with native freshwater mussels for food and space (Claudi and Leach 2000). Overbite and Asian clams cannot be effectively controlled, according to many experts (Healey et al. 2008), but they may be managed by manipulating environmental conditions such as flow or salinity to seasonally control their distribution.
- **Zooplankton.** Surveys of Delta waters reveal that introduced zooplankton, probably discharged in ocean ship ballast water in the San Francisco Bay and Delta, have almost completely replaced the original native zooplankton (Winder and Jassby 2011). The success of nonnative zooplankton species was accompanied by an overall decline in zooplankton biomass and size that suggests a decrease in their nutritional value for fish (Winder and Jassby 2011).
- **Nonnative invasive aquatic plants.** The floating water hyacinth, imported as a landscaping plant, proliferated in the Delta in the early 1980s. The Brazilian waterweed was introduced in the 1960s, probably from home aquariums, but did not reach nuisance levels until after the 1987-1992 drought (Jassby and Cloern 2000). These and other nonnative aquatic weeds in the Delta, including water pennywort, Eurasian water milfoil, and parrot feather, pose serious problems to native plants and animals, and hinder boating. The weeds flourish in a wide area where they act as powerful "ecosystem engineers" (Jones et al. 1994, Breitburg et al. 2010) through alteration of habitats, sometimes creating dense mats or thickets that displace native plants, reduce the food web

productivity, reduce turbidity, and interfere with water conveyance and flood control facilities. These invasive plants benefit nonnative predatory fish like largemouth bass. Areas of dense, submerged aquatic vegetation (SAV) may reduce the abundance of native fish larvae and adults (Grimaldo et al. 2004, Nobriga et al. 2005, Brown and Michniuk 2007). Restoration of aquatic habitats must be designed and managed to reduce nonnative SAV if conservation goals are to be met (Nobriga and Feyrer 2007).

- **Bass and sunfish.** Several species of nonnative fish have been introduced in the Delta. Largemouth and smallmouth bass, sunfish including bluegills and warmouth, crappies, and other fish in the centrarchid family are the best examples. They prey on salmon smolts, smelt, and other native fish. The increase in SAV, especially in and around "flooded islands" in the central Delta, enhances bass and bluegill populations (Brown and Michniuk 2007) and possibly populations of other nonnative predators (Grimaldo et al. 2009). Centrarchids harm native fish through predation and competition (Nobriga and Feyrer 2007, Brown and Michniuk 2007). The distribution of centrarchids may be modified by managing conditions such as water velocity, nutrients, salinity, and turbidity to reduce SAV.

The invasion of nonnative species is in the category of globally determined stressors because these species' arrival in the Delta is the result of large-scale natural processes and human activities that are beyond the purview of the Delta Plan. Nonnative species have persisted because they found favorable environments in which to live. Native species are adapted to the varied, complex floodplains, marshes, and other habitats of the historical Delta, with its tidal currents and river flows that constantly change physical, chemical, and biological conditions. In contrast, the stabilized flow pattern, altered habitats, and impaired water quality of the modern Delta often favor nonnative species. Reducing the impacts of nonnative species in the Delta will require addressing flow alterations, pollution (especially nutrients), and physical habitat characteristics.

Future invasions by zebra and quagga mussels are likely and will require considerable preparation, followed by interagency coordination and action. These mussels are an example of an "anticipated stressor" under the Delta ISB's classification of stressor types. Neither has been observed in the Delta yet, but they have proven to be highly invasive when conditions are right. They pose threats comparable to threats from the overbite and Asian clams. They can colonize hard and soft surfaces, often in large densities (greater than 2,800 individuals per square foot) that impede the flow of water through canals and pipes. These mussels also remove particulates in the water, unnaturally enhancing water clarity.

Once introduced, nonnative species are difficult and expensive to control, and often impossible to eradicate. The California Department of Boating and Waterways supports programs to control Brazilian waterweed and water hyacinths where they hinder boating, but only where conditions create the worst nuisances. The best way to prevent new infestations is to avoid the introduction of new species. Improvements in managing ballast water by shipping companies have been instituted recently, but likely more needs to be done.

There is no agreement about the value—or lack of value—of nonnative species. Opinions vary depending on the species and the interest of Delta users. Striped bass are nonnative but prized for their sport and economic value. Introduced to the Delta in the nineteenth century, they prey on native open-water fish such as delta smelt, longfin smelt, and juvenile salmon and steelhead. Striped bass are at the center of an ongoing debate about whether fishing regulations for introduced species should conserve the fish or should be less restrictive to reduce their abundance (DFG 2011).

The draft Ecosystem Restoration Program (ERP) Conservation Strategy acknowledges that many nonnative species will likely remain in the Delta, and emphasizes prevention and adaptation strategies such as public education, preventing establishment of additional nonnative species, and reducing the impacts of established nonnative species. DFW issued its *California Aquatic Invasive Species Management Plan* in 2008, which aims to coordinate the various State efforts to minimize harmful ecological, economic, and human health impacts from aquatic invasive species (DFG 2008).

Hatcheries and Harvest Management

In the Delta, people have harvested fish and shellfish for millennia. Today, fishing, crabbing, crawdadding, and clamming are important recreation activities. Central Valley salmon—most raised in hatcheries—migrate through the Delta and support an economically and culturally important coastal fishery. In the Delta and its tributary rivers, recreational fishing for salmon, sturgeon, striped bass, largemouth bass, shad, and other fish attracts anglers from throughout California and the world. Fishing in the Delta is a centerpiece of the unique cultural, recreational, and natural heritage that makes the Delta a special place (see Chapter 5).

The use of hatcheries to breed fish and regulations to limit overfishing have long been important tools for aquatic resource management. But they carry their own risk. Hatcheries can allow interbreeding, weakening the genetic fitness of a fish species (Israel et al. 2011). Harvest of hatchery-enhanced fish stocks can pose additional risks to native species. Overfishing itself reduces genetic diversity. Fishing regulations generally protect fish from overharvest, but regulations can also help or hurt other fish species. For example, DFW recently proposed changes to striped bass sport fishing regulations to allow greater harvest of striped bass in the hopes of reducing bass predation on native fish, especially salmon. These changes were rejected by the Fish and Game Commission, but it is likely other regulations will be recommended, particularly as the emphasis on saving native fish from nonnative invasives continues. Future proposals should be based on an improved understanding of anglers' behavior as well as a better understanding of the likely response in populations of striped bass and other predators. Harvest regulations and management practices must consider broader effects on nontarget species, including other predators, and the ecosystem.

Striped bass, for example, are not the only animals that prey on salmon. Predators are natural parts of any ecosystem, and predation is a basic ecosystem process. Fish predators in the Delta include many water birds, mammals, and fish such as native pikeminnows and introduced largemouth bass, smallmouth bass, striped bass, catfish, and other species. Nonnative fish consume salmon and other species of concern in the Delta and its tributaries (Lindley and Mohr 2003). Acoustic tagging studies in the San Joaquin River and southern Delta suggest significant predation on hatchery-reared salmon smolts. Survival of tagged salmon smolts released in the lower San Joaquin River was estimated to be only 5 percent in 2010, with much of the loss attributed to predation (San Joaquin River Group Authority 2010). However, despite the evidence of locally high predation, the overall contribution of predation to the decline of salmon, steelhead, and smelt populations is not clear, and the effect of predator controls will remain uncertain without additional study.

Hatchery Management

Another important tool for harvest management is raising fish in hatcheries, later to be released into natural waterways.

In California, hatcheries are particularly important to compensate for dams that block migration routes for salmon and steelhead (see previous Ecosystem Restoration section). The first salmon hatchery in the state was on the McCloud River. Today, California hosts two federal and twenty-one State hatcheries for salmon, steelhead, or trout. In recent years, "conservation hatcheries" for various threatened and endangered species were considered to prevent extinction of a species while restoration and stressor reduction activities are under way.

Hatcheries are important tools, but they involve genetic and ecological risks:

- **Genetic risks.** Human intervention in the rearing of wild animals has the potential to cause genetic change in fish such as salmon (Israel et al. 2011). These changes can impact fish diversity and the health of fish populations. Inbreeding in a fish hatchery can occur when a limited stock is used at the hatchery. Inbreeding can affect the survival, growth, and reproduction of fish. Ironically, conditions in the hatchery may favor fish that best survive in hatchery, not natural, environments. When released, hatchery-produced fish mix with naturally spawned fish, resulting in a lower survival rate once fish are released into rivers and streams. Finally, loss of genetic diversity is a documented effect of overfishing (Holmes 2011), which some have suggested is encouraged by the use of hatchery fish.

- **Ecological risks.** Wild and hatchery fish of the same species often compete in nature. For example, wild and hatchery-reared Chinook salmon share the same habitat and diet. Hatchery-released salmon are larger than wild salmon, resulting in possible predation on wild salmon of the same age. Hatchery production of salmon masks the decline of wild salmon, contributes to the genetic dilution and loss of wild salmon, and increases competition for limited freshwater and ocean resources on which wild salmon depend (McGinnis 1994). Throughout the world, overfishing has led to collapsing fish stocks and food web disruptions (Pauly et al. 1998). Hatchery and harvest effects often also interact. Harvest of salmon from waters where both hatchery and wild fish occur has put wild salmon and steelhead at risk (Lackey 2003). Wild salmon mortalities occur even with controlled fishing regulations. A portion of all fish released after being hooked and caught do not survive. Capture methods such as use of barbless hooks and use of landing nets can help reduce mortality of released fish.

Hatcheries and harvest are not the root problem of species declines in the Delta and Central Valley (DFG and NMFS 2001). Despite considerable fishing pressure in the first part of the twentieth century, striped bass, salmon, and steelhead remained abundant in California. Large declines followed the construction of dams on almost all Central Valley rivers, which greatly reduced access to spawning and rearing habitat. Once fish populations are low and habitat is damaged, their harvest can be an especially important control factor. Hatcheries were intended to substitute for lost spawning and rearing habitat, but nature cannot be so easily mimicked. Artificial propagation can provide abundant fish for restocking, but it cannot replace the abundance, productivity, life history diversity, and broad distribution of viable populations. Successful hatchery propagation will work best if it goes hand in hand with habitat restoration. Ultimately, fish produced in hatcheries must thrive and naturally reproduce once they have left the hatchery (Israel et al. 2011). Accordingly, close attention needs to be paid to genetic management to reduce genetic risks.

Hatchery and harvest regulations, and management practices related to those regulations must be based on the best available science and follow adaptive management protocols for monitoring and evaluating the results. Evaluations of hatchery fish impacts would be aided by better hatchery fish-marking techniques and more extensive marking.

POLICIES AND RECOMMENDATIONS

Policies and recommendations for restoring the Delta ecosystem include the following core strategies to reduce the impact of ecosystem stressors:

- Create more natural functional Delta flows
- Restore habitat
- Improve water quality to protect the ecosystem
- Prevent introduction of and manage nonnative species impacts
- Improve hatcheries and harvest management

Success of Delta ecosystem restoration depends on considering and addressing all stressor categories as well as completing and implementing the BDCP described in Chapter 3. Because reducing or eliminating some stressors, especially the globally determined and legacy stressors, will be difficult, adaptation to unmitigable stressors is also imperative.

Create More Natural Functional Flows

Water flow in the Delta is critically important because flow affects the reliability of water supplies and the health of the Delta ecosystem. The best available science demonstrates that flow management is essential to restoration of the Delta ecosystem. Several important ecosystem stressors, including entrainment, are linked to altered water flows. Greater reverse flows in the south Delta increase the numbers of fish entrained.

Problem Statement

Altered flows in the Sacramento and San Joaquin rivers and their tributaries change flows within and out of the Delta, and affect salinity and sediment in the Delta. Fish and other aquatic species native to the Delta are adapted to natural flow, salinity, and sediment regimes. Current flow, salinity, and sediment regimes harm native aquatic species and encourage nonnative species. The best available science suggests that currently required flow objectives within and out of the Delta are insufficient to protect the Delta ecosystem (SWRCB 2010). Additionally, uncertainty regarding future flow objectives for the Delta impairs the reliability of water supplies that depend on the Delta or its watershed. The predictability of water exports cannot be improved, and the BDCP cannot be implemented without timely SWRCB action to update flow objectives.

Policy

ER P1. Delta Flow Objectives

(a) *The State Water Resources Control Board's Bay Delta Water Quality Control Plan flow objectives shall be used to determine consistency with the Delta Plan. If and when the flow objectives are revised by the State Water Resources Control Board, the revised flow objectives shall be used to determine consistency with the Delta Plan.*

(b) *For purposes of Water Code section 85057.5(a)(3) and section 5001(j)(1)(E) of this Chapter, the policy set forth in subsection (a) covers a proposed action that could significantly affect flow in the Delta.*

23 CCR Section 5005
NOTE: Authority cited: Section 85210(i), Water Code.
Reference: Sections 85020, 85054, 85086, 85087, 85300, and 85302, Water Code.

Recommendations

ER R1. Update Delta Flow Objectives

Development, implementation, and enforcement of new and updated flow objectives for the Delta and high-priority tributaries are key to the achievement of the coequal goals. The State Water Resources Control Board should update the Bay Delta Water Quality Control Plan objectives as follows:

(a) *By June 2, 2014, adopt and implement updated flow objectives for the Delta that are necessary to achieve the coequal goals.*

(b) *By June 2, 2018, adopt, and as soon as reasonably possible, implement flow objectives for high-priority tributaries in the Delta watershed that are necessary to achieve the coequal goals.* [1]

[1] SWRCB staff should work with the Council and DFW to determine priority streams. As an illustrative example, priority streams could include the Merced River, Tuolumne River, Stanislaus River, Lower San Joaquin River, Deer Creek (tributary

Flow objectives could be implemented through several mechanisms including negotiation and settlement, Federal Energy Regulatory Commission relicensing, or adjudicative proceeding. [2]

Prior to the establishment of revised flow objectives identified above, the existing Bay Delta Water Quality Control Plan objectives shall be used to determine consistency with the Delta Plan. After the flow objectives are revised, the revised objectives shall be used to determine consistency with the Delta Plan.

Restore Habitat

Loss of habitat is one of the largest stressors to the Delta ecosystem. The Delta Plan adopts the approach of the multiagency ERP Conservation Strategy (DFG 2011), which includes a map and accompanying text identifying appropriate habitat restoration types within the Delta and Suisun Marsh based on land elevation, included in the Delta Plan within Appendix B. Delta Plan Figure 4-6 is based on the ERP Conservation Strategy map. Policy ER P3 requires habitat restoration actions to use this figure and accompanying text (see Appendix B for additional information). For example, restoring tidal marsh habitat would generally not be appropriate outside the areas labeled "intertidal" on Figure 4-6 unless they connect other tidal marshes into large habitat areas or can recover elevation over time by natural processes.

An integrated, adaptive approach to restoring habitat must address several issues. Each problem statement below highlights one of these issues, followed by specific policies and recommendations intended to address it.

Problem Statement

Features of the Delta landscape, particularly the condition of its waterways, the elevation of its land, and other environmental conditions, have changed dramatically over the past 160 years. Damage to the habitats that support native species in the Delta has led to declines in native animal and plant populations, affecting both resident and migratory species.

to Sacramento River), Lower Butte Creek, Mill Creek (tributary to Sacramento River), Cosumnes River, and American River. Implementation through hearings is expected to take longer than the deadline shown here.

[2] Implementation through adjudicative proceedings or FERC relicensing is expected to take longer than the deadline shown here.

Policies

The appendices referred to in the policy language below are included in Appendix B of the Delta Plan.

ER P2. Restore Habitats at Appropriate Elevations

(a) *Habitat restoration must be carried out consistent with Appendix 3, which is Section II of the* Draft Conservation Strategy for Restoration of the Sacramento-San Joaquin Delta Ecological Management Zone and the Sacramento and San Joaquin Valley Regions *(California Department of Fish and Wildlife 2011). The elevation map attached as Appendix 4 should be used as a guide for determining appropriate habitat restoration actions based on an area's elevation. If a proposed habitat restoration action is not consistent with Appendix 4, the proposal shall provide rationale for the deviation based on best available science.*

(b) *For purposes of Water Code section 85057.5(a)(3) and section 5001(j)(1)(E) of this Chapter, this policy covers a proposed action that includes habitat restoration.*

23 CCR Section 5006
NOTE: Authority cited: Section 85210(i), Water Code.
Reference: Sections 85020, 85022, 85054, 85300, and 85302, Water Code.

ER P3. Protect Opportunities to Restore Habitat

(a) *Within the priority habitat restoration areas depicted in Appendix 5, significant adverse impacts to the opportunity to restore habitat as described in section 5006, must be avoided or mitigated.*

(b) *Impacts referenced in subsection (a) will be deemed to be avoided or mitigated if the project is designed and implemented so that it will not preclude or otherwise interfere with the ability to restore habitat as described in section 5006.*

(c) *Impacts referenced in subsection (a) shall be mitigated to a point where the impacts have no significant effect on the opportunity to restore habitat as described in section 5006. Mitigation shall be determined, in consultation with the California Department of Fish and Wildlife, considering the size of the area impacted by the covered action and the type and value of habitat that could be restored on that area, taking into account existing and proposed restoration plans, landscape attributes, the elevation map shown in Appendix 4, and other relevant information about habitat restoration opportunities of the area.*

(d) *For purposes of Water Code section 85057.5(a)(3) and section 5001(j)(1)(E) of this Chapter, this policy covers proposed actions in the priority habitat restoration areas depicted in Appendix 5. It does not cover proposed actions outside those areas.*

23 CCR Section 5007
NOTE: Authority cited: Section 85210(i), Water Code.
Reference: Sections 85020, 85022, 85054, 85300, 85302, and 85305, Water Code.

Figure 4-7 provides examples of ways a project can implement ER P3.

ER P4. Expand Floodplains and Riparian Habitats in Levee Projects

(a) *Levee projects must evaluate and where feasible incorporate alternatives, including the use of setback levees, to increase floodplains and riparian habitats. Evaluation of setback levees in the Delta shall be required only in the following areas (shown in Appendix 8): (1) The Sacramento River between Freeport and Walnut Grove, the San Joaquin River from the Delta boundary to Mossdale, Paradise Cut, Steamboat Slough, Sutter Slough; and the North and South Forks of the Mokelumne River, and (2) Urban levee improvement projects in the cities of West Sacramento and Sacramento.*

(b) *For purposes of Water Code section 85057.5(a)(3) and section 5001(j)(1)(E) of this Chapter, this policy covers a proposed action to construct new levees or substantially rehabilitate or reconstruct existing levees.*

23 CCR Section 5008
NOTE: Authority cited: Section 85210(i), Water Code.
Reference: Sections 85020, 85022, 85054, 85300, 85302, and 85305, Water Code.

Recommendations

ER R2. Prioritize and Implement Projects that Restore Delta Habitat

Bay Delta Conservation Plan implementers, California Department of Fish and Wildlife, California Department of Water Resources, and the Delta Conservancy should prioritize and implement habitat restoration projects in the areas shown on Figure 4-8. Habitat restoration projects should ensure connections between areas being restored and existing habitat areas and other elements of the landscape needed for the full life cycle of the species that will benefit from the restoration project. Where possible, restoration projects should also emphasize the potential for improving water quality. Restoration project proponents should consult the California Department of Public Health's Best Management Practices for Mosquito Control in California.

How Projects Can Comply with ER P3

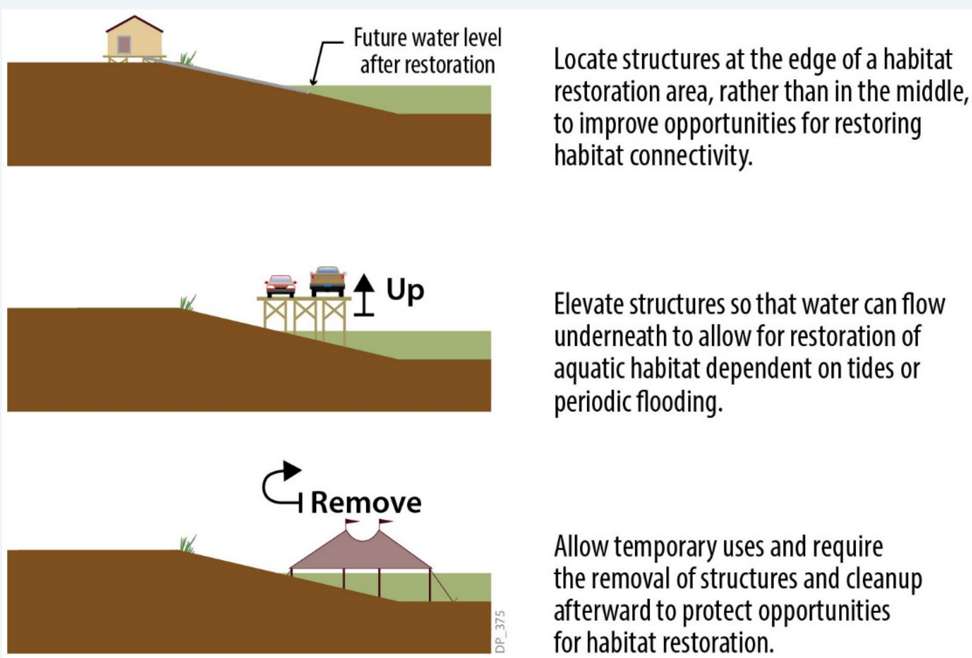

Figure 4-7 ER P3 requires projects located in the priority habitat restoration areas (shown on Figure 4-8) to protect opportunities to restore habitat. This figure shows conceptual examples of how to implement this policy.

Recommended Areas for Prioritization and Implementation of Habitat Restoration Projects

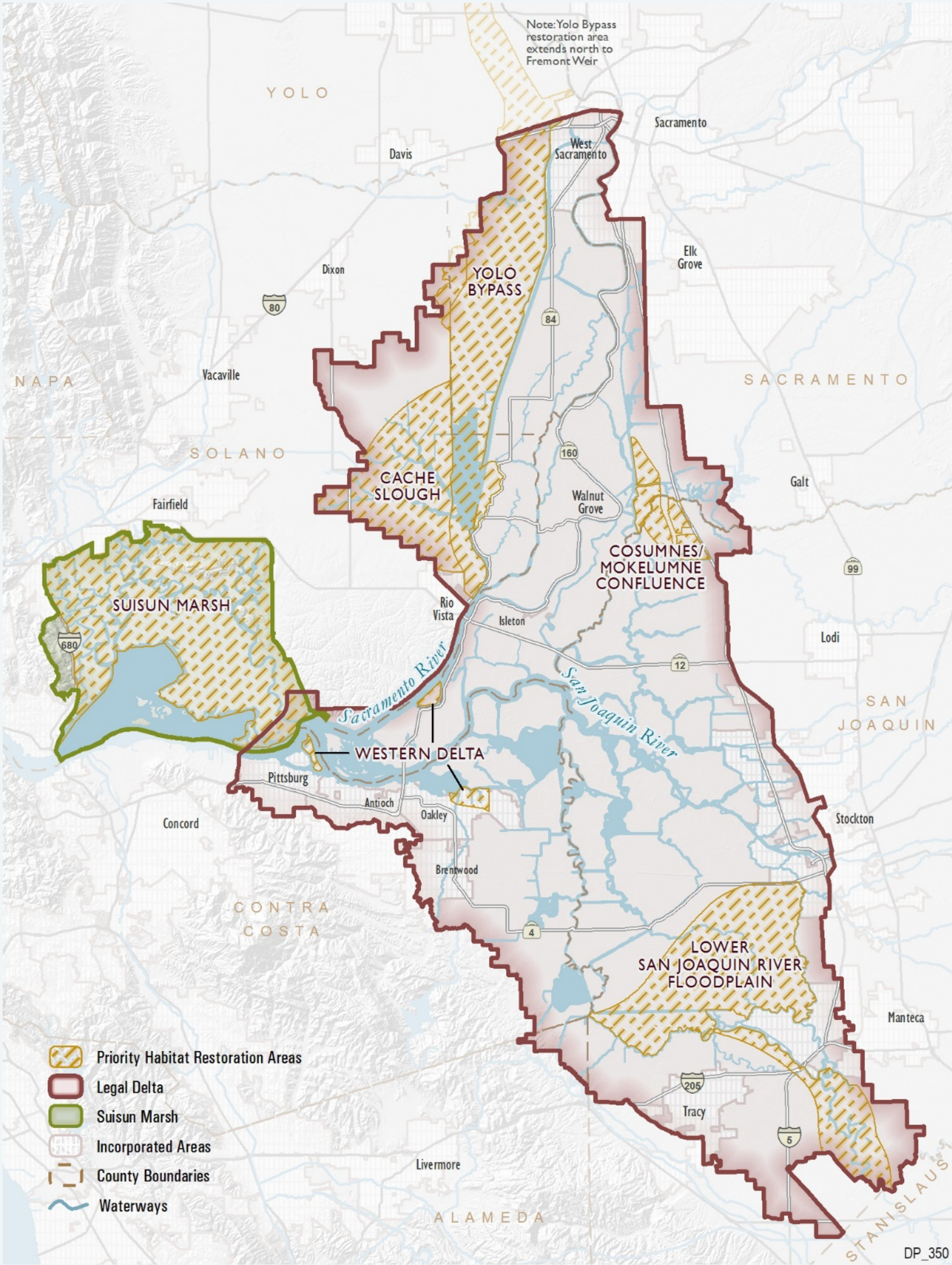

Figure 4-8

Priority habitat restoration areas are large areas within which specific sites may be identified for habitat restoration based on assessments of land use and other issues addressed through further feasibility analysis.

Source: DFG 2011

- ***Yolo Bypass.*** *Enhance the ability of the Yolo Bypass to flood more frequently to provide more opportunities for migrating fish, especially Chinook salmon, to use this system as a migration corridor that is rich in cover and food.*
- ***Cache Slough Complex.*** *Create broad nontidal, freshwater, emergent-plant-dominated wetlands that grade into tidal fresh-water wetlands, and shallow subtidal and deep open-water habitats. Also, return a significant portion of the region to uplands with vernal pools and grasslands.*
- ***Cosumnes River–Mokelumne River confluence.*** *Allow these unregulated and minimally regulated rivers to flood over their banks during winter and spring frequently and regularly to create seasonal floodplains and riparian habitats that grade into tidal marsh and shallow subtidal habitats.*
- ***Lower San Joaquin River floodplain.*** *Reconnect the floodplain and restore more natural flows to stimulate food webs that support native species. Integrate habitat restoration with flood management actions, when feasible.*
- ***Suisun Marsh.*** *Restore significant portions of Suisun Marsh to brackish marsh with land-water interactions to support productive, complex food webs to which native species are adapted and to provide space to adapt to rising sea level action. Use information from adaptive management processes during the* Suisun Marsh Habitat Management, Preservation, and Restoration Plan's *implementation to guide future habitat restoration projects and to inform future tidal marsh management.*
- ***Western Delta/Eastern Contra Costa County.*** *Restore tidal marsh and channel margin habitat at Dutch Slough and western islands to support food webs and provide habitat for native species.*

ER R3. Complete and Implement Delta Conservancy Strategic Plan

As part of its Strategic Plan and subsequent Implementation Plan or annual work plans, the Delta Conservancy should:

- *Develop and adopt criteria for prioritization and integration of large-scale ecosystem restoration in the Delta and Suisun Marsh, with sustainability and use of best available science as foundational principles.*
- *Develop and adopt processes for ownership and long-term operations and management of land in the Delta and Suisun Marsh acquired for conservation or restoration.*
- *Develop and adopt a formal mutual agreement with the California Department of Water Resources, California Department of Fish and Wildlife, federal interests, and other State and local agencies on implementation of ecosystem restoration in the Delta and Suisun Marsh.*
- *Develop, in conjunction with the Wildlife Conservation Board, the California Department of Water Resources, California Department of Fish and Wildlife, Bay Delta Conservation Plan implementers, and other State and local agencies, a plan and protocol for acquiring the land necessary to achieve ecosystem restoration consistent with the coequal goals and the Ecosystem Restoration Program Conservation Strategy.*
- *Lead an effort, working with State and federal fish agencies, to investigate how to better use habitat credit agreements to provide credit for each of these steps: (1) acquisition for future restoration; (2) preservation, management, and enhancement of existing habitat; (3) restoration of habitat; and (4) monitoring and evaluation of habitat restoration projects.*
- *Work with the California Department of Fish and Wildlife and the U.S. Fish and Wildlife Service to develop rules for voluntary safe harbor agreements with property owners in the Delta whose actions contribute to the recovery of listed threatened or endangered species.*

Problem Statement

Current USACE policy requires removal of vegetation from Delta levees, which would reduce already sparse riparian and shaded aquatic habitat along the channels.

Policies

No policies with regulatory effect are included in this section.

Recommendation

ER R4. Exempt Delta Levees from the U.S. Army Corps of Engineers' Vegetation Policy

Considering the ecosystem value of remaining riparian and shaded riverine aquatic habitat along Delta levees, the U.S. Army Corps of Engineers should agree with the California Department of Fish and Wildlife and the California Department of Water Resources on a variance that exempts Delta levees from the U.S. Army Corps of Engineers' levee vegetation policy where appropriate.

Problem Statement

The SMPP and the Local Protection Program components of the SMPP do not yet include climate change provisions. Without these amendments, it is unclear if and how Suisun Marsh will be managed to adapt to rising sea level.

Policies

No policies with regulatory effect are included in this section.

Recommendation

ER R5. Update the Suisun Marsh Protection Plan

The San Francisco Bay Conservation and Development Commission should update the Suisun Marsh Protection Plan *and relevant components of the Suisun Marsh Local Protection Program to adapt to sea level rise and ensure consistency with the Suisun Marsh Preservation Act, the Delta Reform Act, and the Delta Plan.*

Improve Water Quality to Protect the Ecosystem

Chapter 6 includes recommendations about salinity and ecosystem water quality. These recommendations support the protection of water quality for all beneficial uses of water and encourage the identification of water quality impacts of proposed actions. The recommendations also address acceleration of certain total maximum daily loads, low dissolved oxygen, implementation of a Delta Regional Monitoring Program, treatment of wastewater effluent and urban runoff, and Regional Water Quality Control Board engagement in Suisun Marsh.

Problem Statement

The Delta ecosystem is impaired by pollutants from municipal, industrial, agricultural, and other discharges and legacy pollutants flowing into the Delta and its tributaries, including pollutants that bioaccumulate and biomagnify in the food web.

Policies

No policies with regulatory effect are included in this section.

Recommendations

Recommendations for improving ecosystem water quality are included in Chapter 6.

Prevent Introduction of and Manage Nonnative Species Impacts

Problem Statement

Nonnative species are a major obstacle to successful restoration of the Delta ecosystem because they affect the survival, health, and distribution of native Delta wildlife and plants. There is little chance of eradicating most established nonnative species, but management can reduce the abundance of some. The resilience of native species is reduced by ongoing introductions of nonnative species and management actions that enhance conditions for nonnative species.

Policy

ER P5. Avoid Introductions of and Habitat Improvements for Invasive Nonnative Species

(a) The potential for new introductions of or improved habitat conditions for nonnative invasive species, striped bass, or bass must be fully considered and avoided or mitigated in a way that appropriately protects the ecosystem.

(b) For purposes of Water Code section 85057.5(a)(3) and section 5001(j)(1)(E) of this Chapter, this policy covers a proposed action that has the reasonable probability of introducing or improving habitat conditions for nonnative invasive species.

23 CCR Section 5009
NOTE: Authority cited: Section 85210(i), Water Code.
Reference: Sections 85020, 85054, 85300, and 85302, Water Code.

Recommendations

ER R6. Regulate Angling for Nonnative Sport Fish to Protect Native Fish

The California Department of Fish and Wildlife should develop, for consideration by the Fish and Game Commission, proposals for new or revised fishing regulations designed to increase populations of listed fish species through reduced predation by introduced sport fish. The proposals should be based on sound science that demonstrates these *management actions are likely to achieve their intended outcome and include the development of performance measures and a monitoring plan to support adaptive management.*

ER R7. Prioritize and Implement Actions to Control Nonnative Invasive Species

The California Department of Fish and Wildlife and other appropriate agencies should prioritize and fully implement the list of "Stage 2 Actions for Nonnative Invasive Species" and accompanying text shown in Appendix J taken from the Conservation Strategy for Restoration of the Sacramento–San Joaquin Delta Ecological Management Zone and the Sacramento and San Joaquin Valley Regions *(DFG 2011). Implementation of the Stage 2 actions should include the development of performance measures and monitoring plans to support adaptive management.*

Improve Hatcheries and Harvest Management

Problem Statement

Hatcheries and harvest regulation are important tools in fisheries management, but they also pose genetic and ecological risks to native species and the Delta ecosystem. These practices need to employ adaptive management strategies to predict and evaluate outcomes, and minimize risks.

Policies

No policies with regulatory effect are included in this section.

Recommendations

ER R8. Manage Hatcheries to Reduce Genetic Risk

As required by the National Marine Fisheries Service, all hatcheries providing listed fish for release into the wild should continue to develop and implement scientifically sound Hatchery and Genetic Management Plans (HGMPs) to reduce risks to those species. The California Department of Fish and Wildlife should provide annual updates to the Delta Stewardship Council on the status of HGMPs within its jurisdiction.

ER R9. Implement Marking and Tagging Program

By December 2014, the California Department of Fish and Wildlife, in cooperation with the U.S. Fish and Wildlife Service and the National Marine Fisheries Service, should revise and begin implementing its program for marking and tagging hatchery salmon and steelhead to improve management of hatchery and wild stocks based on recommendations of the California Hatchery Scientific Review Group, which considered mass marking, reducing hatchery programs, and mark selective fisheries in developing its recommendations.

Timeline for Implementing Policies and Recommendations

Figure 4-9 lays out a timeline for implementing the policies and recommendations described in the previous section. The timeline emphasizes near-term and intermediate-term actions.

Timeline for Implementing Policies and Recommendations

TIMELINE — **CHAPTER 4: Ecosystem Implementation**

	ACTION (REFERENCE #)	LEAD AGENCY(IES)	NEAR TERM 2012–2017	INTERMEDIATE TERM 2017–2025
POLICIES	Delta flow objectives (ER P1)	SWRCB	●	●
	Restore habitats at appropriate elevations (ER P2)	DFW, DWR, Delta Conservancy	●	●
	Protect opportunities to restore habitat (ER P3)	DFW	●	●
	Expand floodplains and riparian habitats in levee projects (ER P4)	DWR, USACE	●	●
	Avoid introductions of and habitat improvements for invasive nonnative species (ER P5)	DFW, DWR, Delta Conservancy	●	●
RECOMMENDATIONS	Update Delta flow objectives (ER R1)	SWRCB	●	●
	Prioritize and implement projects that restore Delta habitat (ER R2)	DFW, DWR, and Delta Conservancy	●	●
	Complete and implement Delta Conservancy Strategic Plan (ER R3)	Delta Conservancy	●	
	Exempt Delta levees from U.S. Army Corps of Engineers' Vegetation Policy (ER R4)	USACE, DWR, DFW	●	●
	Update the Suisun Marsh Protection Plan (ER R5)	BCDC	●	
	Regulate angling for nonnative sport fish to protect native fish (ER R6)	DFW, CA Fish and Game Commission	●	
	Prioritize and implement actions to control nonnative invasive species (ER R7)	DFW	●	●
	Manage hatcheries to reduce genetic risk (ER R8)	DFW	●	●
	Implement marking and tagging program (ER R9)	DFW	●	●

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Agency Key:

BCDC: San Francisco Bay Conservation and Development Commission
BDCP: Bay Delta Conservation Plan
Delta Conservancy: Sacramento-San Joaquin Delta Conservancy
Council: Delta Stewardship Council
DFW: California Department of Fish and Wildlife
DWR: California Department of Water Resources
RWQCB: Regional Water Quality Control Board(s)
SWRCB: State Water Resources Control Board
USACE: U.S. Army Corps of Engineers

Figure 4-9

Issues for Future Evaluation and Coordination

Additional areas of interest and concern related to the Delta ecosystem may deserve consideration in the development of future Delta Plan updates:

- **Landscape-scale conceptual models.** The Delta Science Program will collaborate with other agencies, academic institutions, and stakeholders to develop landscape-scale conceptual models for the six priority restoration areas identified in ER R2.
- **Workshops to address stressor impacts.** The Delta Science Program, in collaboration with other agencies, academic institutions, and stakeholders, will hold workshops to develop additional recommendations to the Council for measures to reduce stressor impacts on the Delta ecosystem that would support and be consistent with the coequal goals. Recommended measures could be adopted as policies or recommendations by the Council into an amended Delta Plan.
- **Above-the-Delta migration corridors.** The Council will consult with fish and wildlife agencies and others as they complete or update plans to restore habitats for migratory species, such as anadromous fish or songbirds in the Sacramento and San Joaquin valleys above the Delta.

Science and Information Needs

The Delta ecosystem is not static; therefore, additional information is needed for decision making and adaptive management. Specifically, the following information is needed in the following areas:

- Landscape-scale conceptual models for Delta ecosystem restoration.
- Assessment of how flows benefit or harm native wildlife and plants.
- Effects of changing habitat quality and quantity on Delta fish and invertebrates. Examples might include (1) threadfin shad in the south and central Delta, (2) comparison of shallow shoal habitat and deep channel habitat to food resources of young striped bass, and (3) relationship between water turbidity and native fish migration, survival, growth, and/or reproduction.
- Hatchery, harvest, and/or predation impacts on natural fish populations.
- Tools to assess native fish response to restored habitats.
- Entrainment effects on fish populations.
- Tools to assess potential impacts of climate change and sea level rise to viability of species in intertidal habitats.

Performance Measures

Development of informative and meaningful performance measures is a challenging task that will continue after the adoption of the Delta Plan. Performance measures need to be designed to capture important trends and to address whether specific actions are producing expected results. Efforts to develop and track performance measures in complex and large-scale systems like the Delta are commonly multiyear endeavors. The recommended output and outcome performance measures listed below are provided as examples and subject to refinement as time and resources allow. Final administrative performance measures are listed in Appendix E and will be tracked as soon as the Delta Plan is completed.

The Delta Reform Act specifies some performance measures for large-scale ecosystem restoration within the Delta. Ecosystem performance measures should address progress in achieving the objectives set forth in Water Code sections 85302(c) and 85302(e).

Note that performance measures for ecosystem water quality are provided in Chapter 6.

Output Performance Measures

- The SWRCB adopts Delta flow objectives by June 2, 2014. (ER R1)
- The SWRCB adopts flow objectives for the major tributaries by 2018 (or soon as reasonably possible). (ER R1)
- Pilot-scale Delta habitat restoration projects are developed and initiated in the priority areas described in ER R2 by 2015. These projects include tidal brackish and freshwater marsh as well as floodplain restoration, and have clear adaptive management plans aimed at improving outcomes and providing lessons for the development of large-scale restoration projects. Metrics: acres restored by habitat type, and lessons learned. (ER R2)
- Progress, measured in acres of restored or enhanced habitat, is being made toward the biological opinions' targets of restoring 8,000 acres of tidal marsh and 17,000 to 20,000 acres of floodplain rearing habitat. (ER R2)
- The DFW and other appropriate agencies fully implement the list of "Stage 2 Actions for Nonnative Invasive Species." (ER R7)

Outcome Performance Measures

- Progress toward restoring in-Delta flows to more natural functional flow patterns to support a healthy estuary. Metrics: results from hydrological monitoring and hydrodynamic modeling. (ER R1)
- Progress toward decreasing annual trends in both the number of new and existing aquatic and terrestrial nonnative species, and the abundance and distribution of existing aquatic and terrestrial nonnative species in the Delta over the next decade. These trends will be derived from long-term animal and plant monitoring surveys conducted by the Interagency Ecological Program agencies, the California Department of Boating and Waterways, the U.S. Department of Agriculture, the San Francisco Estuary Institute, and others. (ER P5)
- Progress toward the documented occurrence and use of protected and restored habitats and migratory corridors by native resident and migratory Delta species. Trends in occurrence, use, and performance of native species in protected and restored habitats and corridors will be upward over the next decade. These trends will be derived from animal and plant monitoring surveys that are conducted as part of adaptive management strategies for the protection and restoration of these areas. (ER R2)
- Progress toward achieving the State and federal "doubling goal" for wild Central Valley salmonids relative to 1995 levels. Trends will be derived from long-term salmonid monitoring surveys conducted by the National Marine Fisheries Service, U.S. Fish and Wildlife Service, and others. (ER R2)

References

Baxter, R., R. Breuer, L. Brown, L. Conrad, F. Feyrer, S. Fong, K. Gehrts, L. Grimaldo, B. Herbold, P. Hrodey, A. Mueller-Solger, T. Sommer, and K. Souza. 2010. *Interagency Ecological Program 2010 Pelagic Organism Decline Work Plan and Synthesis of Results*. Interagency Ecological Program for the San Francisco Estuary.

BDCP (Bay Delta Conservation Plan). 2012. *Bay Delta Conservation Plan Administrative Draft*, Chapter 3 Conservation Strategy (Section 3.3). February 2012.

BDCP Independent Science Advisors. 2007. *Independent Science Advisor's Report*. November 16.

Breitburg, D. L., B. C. Crump, J. O. Dabiri, and C. L. Gallegos. 2010. Ecosystem engineers in the pelagic realm: Alteration of habitat by species ranging from microbes to jellyfish. *Integrative and Comparative Biology* 50: 188–200.

Brown, L. R., and D. Michniuk. 2007. Littoral fish assemblages of the alien-dominated Sacramento-San Joaquin Delta, California, 1980-1983 and 2001-2003. *Estuaries and Coasts* 30:186-200.

Bunn, S. E., and A. H. Arthington. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. *Environmental Management* 30:492-507.

California Natural Resource Agency. 2009. *California Climate Adaptation Strategy*. 200 pp. http://resources.ca.gov/climate_adaptation/docs/Statewide_Adaptation_Strategy.pdf.

California Ocean Protection Council. 2011. *Resolution of the California Ocean Protection Council on Sea Level Rise*. Adopted March 11.

Carlisle, D. M., D. M. Wolock, and M. R. Meador. 2010. Alteration of streamflow magnitudes and potential ecological consequences: a multiregional assessment. *Frontiers in Ecology and the Environment* 9(5): 264-270.

Claudi, R., and H. Leach (eds.). 2000. *Nonindigenous Freshwater Organisms: Vectors, Biology, and Impacts*. Lewis Publishers. Boca Raton, Florida. pp. 127-147.

Cloern, J. E. 2007. Habitat connectivity and ecosystem productivity: implications from a simple model. *The American Naturalist* 169:E21-E33.

Cohen, A. N., and J. T. Carlton. 1998. Accelerating invasion rate in a highly invaded estuary. *Science* 279:555-558.

Crain, P. K., K. Whitener, and P. B. Moyle. 2004. Use of a restored central California floodplain by larvae of native and alien fishes. In Feyrer, F., L. R. Brown, R. L. Brown, and J. J. Orsi, (eds.), *Early Life History of Fishes in the San Francisco Estuary and Watershed*. American Fisheries Society Symposium 39. Bethesda, Maryland. pp. 125–140.

Delta ISB (Independent Science Board). 2011. Memorandum to Phil Isenberg, Chair, Delta Stewardship Council, and Members of the Delta Stewardship Council: Addressing Multiple Stressors and Multiple Goals in the Delta Plan. January 26. 15pp.

DFG and NMFS (California Department of Fish and Game and National Marine Fisheries Service). 2001. *Final Report on Anadromous Salmonid Fish Hatcheries in California*. Final Review Draft. December 3.

DFG (California Department of Fish and Game). 2008. *California Aquatic Invasive Species Management Plan*. January.

DFG (California Department of Fish and Game). 2011. *Conservation Strategy for Restoration of the Sacramento-San Joaquin Delta Ecological Management Zone and the Sacramento and San Joaquin Valley Regions*. Draft. July.

DFG (California Department of Fish and Game). 2012. Comment letter on Final Staff Draft Delta Plan. June 13.

DWR (California Department of Water Resources). 2003. California Central Valley unimpaired flow data, fourth edition. Bay-Delta office. November 2006.

Enright, C., and S. D. Culberson. 2010. Salinity trends, variability, and control in the northern reach of the San Francisco Estuary. *San Francisco Estuary and Watershed Science* 7(2). http://escholarship.org/uc/item/0d52737t.

FEMA (Federal Emergency Management Agency). 2005. *Technical Manual for Dam Owners, Impacts of Plants on Earthen Dams*. FEMA-534. pp. 115.

Feyrer, F. 2004. Ecological segregation of native and alien larval fish assemblages in the southern Sacramento-San Joaquin Delta. In Feyrer, F., L. R. Brown, R. L. Brown, and J. J. Orsi, (eds.), *Early Life History of Fishes in the San Francisco Estuary and Watershed*. American Fisheries Society Symposium 39. Bethesda, Maryland, pp.67–79.

Feyrer, F., and M. P. Healy. 2003. Fish community structure and environmental correlates in the highly altered southern Sacramento-San Joaquin Delta. *Environmental Biology of Fishes* 66:123–132.

Feyrer, F., M. L. Nobriga, and T. R. Sommer. 2007. Multidecadal trends for three declining fish species: habitat patterns and mechanisms in the San Francisco Estuary, California, USA. *Canadian Journal of Fisheries and Aquatic Sciences* 64:723–734.

Foley, J. A., R. DeFries, G. P. Asner, C. Barford, G. Bonan, S. R. Carpenter, et al. 2005. Global consequences of land use. *Science* 309:570–574.

Grimaldo, L. F., R. E. Miller, C. P. Peregrin, and Z. P. Hymanson. 2004. Spatial and temporal distribution of native and alien ichthyoplankton in three habitat types of the Sacramento-San Joaquin Delta. *American Fisheries Society Symposium* 39:81-96.

Grimaldo, L. F., T. Sommer, N. V. Ark, G. Jones, E. Holland, P. B. Moyle, B. Herbold, and P. Smith. 2009. Factors affecting fish entrainment into massive water diversions in a tidal freshwater estuary: can fish losses be managed? *North American Journal of Fisheries Management* 29:1253-1270.

Grossinger, R. M., A. A. Whipple, J. C. Collins, and D. Rankin. 2010. Historical Delta landscapes: Conceptual models for building a diverse and resilient future. Bay Delta Science Conference.

Hall, L. S., P. A. Krausman, and M. L. Morrison. 1997. The habitat concept and a plea for the use of standard terminology. *Wildlife Society Bulletin* 25:173–182.

Hanak, E., J. Lund, A. Dinar, B. Gray, R. Howitt, J. Mount, P. Moyle, and B. Thompson. 2011. *Managing California's Water: From Conflict to Reconciliation*. Public Policy Institute of California: San Francisco, California. 482 pp.

Hannon, S. J., and F. Schmiegelow. 2002. Corridors may not improve the conservation value of small reserves for most boreal birds. *Ecological Applications* 12:1457–1468.

Healey, Michael. 2007a. Delta Vision Context Memorandum: Delta Ecological Principles. http://deltavision.ca.gov/BlueRibbonTaskForce/July2007/PostMtg/Day_1_Item_5_Handout_2.pdf.

Healey, Michael. 2007b. Design Principles for a Sustainable Ecosystem in the Bay-Delta. http://deltavision.ca.gov/BlueRibbonTaskForce/Oct2007/PostMtg/Item_6_Handout1.pdf.

Healey, M. C., M. D. Dettinger, and R. B. Norgaard, eds. 2008. *The State of Bay-Delta Science, 2008*. Abstract. CALFED Science Program: Sacramento, California. 174 pp.

Hermoso, V., F. Pantus, J. Olley, S. Linke, J. Mugodo, and P. Lea. 2012. Systematic planning for river rehabilitation: integrating multiple ecological and economic objectives in complex decisions. *Freshwater Biology* 57:1–9.

Holmes, B. 2011. Overfishing eats away at genetic diversity of fish. *New Scientist*. http://www.newscientist.com/article/dn20699-overfishing-eats-away-at-genetic-diversity-of-fish.html. July 15.

Israel, J. A., K. M. Fisch, T. F. Turner, and R. S. Waples. 2011. Conservation of native fishes of the San Francisco Estuary: Considerations for artificial propagation of Chinook salmon, delta smelt, and green sturgeon. San Francisco Estuary and Watershed Science, John Muir Institute of the Environment, UC Davis.

Jassby, A. D., and J. E. Cloern. 2000. Organic matter sources and rehabilitation of the Sacramento-San Joaquin Delta (California, USA). *Aquatic Conservation: Marine and Freshwater Ecosystems* 10:323-352.

Jassby, A. D., W. J. Kimmerer, S. G. Monismith, C. Armor, J. E. Cloern, T. M. Powell, J. R. Schubel, and T. J. Vendlinski. 1995. Isohaline position as a habitat indicator for estuarine populations. *Ecological Applications* 5:272-289.

Jeffres, C. A., J. J. Opperman, and P. B. Moyle. 2008. Ephemeral floodplain habitats provide best growth conditions for juvenile Chinook salmon in a California river. E*nvironmental Biology of Fishes* 83(4): 449–458.

Jones, C. G., J. H. Lawton, and M. Shachak. 1994. Organisms as ecosystem engineers. *Oikos* 69:373–386.

Kimmerer, W. J. 2006. Response of anchovies dampens effects of the invasive bivalve *Corbula amurensis* on the San Francisco Estuary foodweb. *Marine Ecology Progress Series* 324:207–218.

Lackey, R. T. 2003. Pacific Northwest salmon: forecasting their status in 2100. *Reviews in Fisheries Science* 11(1): 35-88.

Lindenmayer, D., R. Hobbs, and J. Miller, et al. 2008. A checklist for ecological management of landscapes for conservation. *Ecology Letters* 11:78–91.

Lindley, S. T., and M. S. Mohr. 2003. Modeling the effect of striped bass (*Morone saxatilis*) on the population viability of Sacramento River winter-run Chinook salmon (*Oncorhynchus tshawytscha*). National Marine Fisheries Service. Fish Bulletin 101:321–331.

Lotze, H. K., H. S. Lenihan, B. J. Bourque, R. H. Bradbury, R. G. Cooke, M. C. Kay, S. M. Kidwell, M. X. Kirby, C. H. Peterson, and J. B. C. Jackson. 2006. Depletion, degradation, and recovery potential of estuaries and coastal seas. *Science* 312:1806–1809.

McGinnis, M.V. 1994. The politics of restoring versus restocking in the Columbia River. *Restoration Ecology* 2(3): 149-155. http://www.nwfsc.noaa.gov/resources/salmonhatchery/risks.cfm#genetic.

Monsen, N. E., J. R. Cloern, and J. R. Burau. 2007. Effects of flow diversions on water and habitat quality: Examples from California's highly manipulated Sacramento-San Joaquin Delta. *San Francisco Estuary and Watershed Science* 5(3):1-16. http://escholarship.org/uc/item/04822861.

Moyle, P. B., P. K. Crain, and K. Whitener. 2007. Patterns in the use of a restored California floodplain by native and alien fishes. *San Francisco Estuary and Watershed Science* 5(3):1–27. http://repositories.cdlib.org/jmie/sfews/vol5/iss3/art1.

Moyle, P. B., W. A. Bennett, W. E. Fleenor, and J. R. Lund. 2010. Habitat variability and complexity in the upper San Francisco Estuary. *San Francisco Estuary and Watershed Science* 8(3):1-24. http://escholarship.org/uc/item/0kf0d32x.

Moyle, P. B., and J. F. Mount. 2007. Homogenized rivers, homogenized faunas. *Proceedings of the National Academy of Sciences* 104:5711-5712.Newman, K. B. 2008. *An Evaluation of Four Sacramento-San Joaquin River Delta Juvenile Salmon Survival Studies*. Stockton FWO, U.S. Fish and Wildlife Service.

NMFS (National Marine Fisheries Service). 2009. Biological Opinion and Conference Opinion on the Long Term Operations of the Central Valley Project and the State Water Project. http://swr.nmfs.noaa.gov/ocap/NMFS Biological and Conference Opinion on the Long Term Operations of the CVP and SWP.pdf.

Nobriga, M. L., and F. Feyrer. 2007. Shallow-water piscivore-prey dynamics in California's Sacramento-San Joaquin Delta. *San Francisco Estuary and Watershed Science* 5(2):1-15. http://escholarship.org/uc/item/387603c0.

Nobriga, M. L., F. Feyrer, R. D. Baxter, and M. Chotkowski. 2005. Fish community ecology in an altered river delta: Spatial patterns in species composition, life history strategies, and biomass. *Estuaries and Coasts* 28:776-785.

Oltmann, R. N. 1998. Measured flow and tracer-dye data showing anthropogenic effects on the hydrodynamics of south Sacramento-San Joaquin Delta, California, Spring 1996-1997. U.S. Geological Survey Open-File Report 98-285.

Palmer, M. A., E. S. Bernhardt, J. D. Allan, P. S. Lake, G. Alexander, S. Brooks, J. Carr, S. Clayton, C. N. Dahm, J. Follstad Shah, D. L. Galat, S. Gloss, P. Goodwin, D. H. Hart, B. Hassett, R. Jenkinson, G. M. Kondolf, R. Lave, J. L. Meyer, T. K. O'Donnell, L. Pagano, P. Srivastava, and E. Sudduth. 2005. Standards for ecologically successful river restoration. *Journal of Applied Ecology* 42:208–217.

Pauly, D., V. Christensen, J. Dalsgaard, R. Froese, and F. Torres Jr. 1998. Fishing down marine food webs. *Science* 279:860-863.

Perry, R. W., J. R. Skalski, P. L. Brandes, P. T. Sandstrom, A. P. Klimley, A. Ammann, and B. Macfarlane. 2009. Estimating survival and migration route probabilities of juvenile Chinook salmon in the Sacramento–San Joaquin River Delta. *North American Journal of Fisheries Management* 30:142-156.

Petts, G. E. 2009. Instream flow science for sustainable river management. *Journal of the American Water Resources Association* (JAWRA) 45(5):1071-1086.

Poff, N. L., J. D. Allan, M. B. Bain, J. R. Karr, K. L. Prestegaard, B. D. Richter, R. E. Sparks, and J. C. Stromberg. 1997. The natural flow regime. *BioScience* 47:769-784.

Postel, S., and B. Richter. 2003. *Rivers for Life: Managing Water for People and Nature*. Island Press, Washington, DC.

PRBO CalPIF (Point Reyes Bird Observatory California Partners in Flight). 2008. *Bringing the Birds Back: A Guide to Habitat Enhancement for Birds in the Sacramento Valley* (R. DiGaudio, K. Kreitinger, and T. Gardali, lead authors). California Partners in Flight Regional Conservation Plan No. 2. http://www.prbo.org/calpif.

Reclamation and USFWS (Bureau of Reclamation and U.S. Fish and Wildlife Service). 2008. Listen to the River: An Independent Review of the CVPIA Fisheries Program. Prepared by a panel of independent reviewers under contract with Circlepoint.

Reynolds, F. L., T. J. Mills, R. Benthin, and A. Low. 1993. Restoring Central Valley streams; a plan for action. Sacramento, California: California Department of Fish and Game. pp. 129. http://www.dfg.ca.gov/fish/documents/Resources/RestoringCentralVallyStreams.pdf.

Sacramento-San Joaquin Delta Conservancy. 2012. *Delta Conservancy Strategic Plan*. Public Review Draft. March 26.

San Francisco Estuary Institute. 2012. Sacramento-San Joaquin Delta Historical Ecology Investigation: Exploring Pattern and Process. Aquatic Science Center. Prepared for the California Department of Fish and Game and Ecosystem Restoration Program. August.

San Joaquin River Group Authority. 2010. *Annual Technical Report on Implementation and Monitoring of the San Joaquin River Agreement and the Vernalis Adaptive Management Plan (VAMP)*. http://www.sjrg.org/technicalreport/2010/2010_SJRGA_Annual_Technical_Report.pdf.

Simenstad, C.A., W. G. Hood, R. M. Thom, D.A. Levy, and D. L. Bottom. 2000. Landscape structure and scale constraints on restoring estuarine wetlands for Pacific Coast juvenile fishes. *Concepts and Controversies in Tidal Marsh Ecology*. M. P. Weinstein and D. A. Kreeger, eds. pp. 597–630. Kluwer Academic Publishers: Dordrecht, Netherlands.

Sommer, T., B. Harrell, M. Nobriga, R. Brown, P. Moyle, W. Kimmerer, and L. Schemel. 2001. California's Yolo Bypass: evidence that flood control can be compatible with fisheries, wetlands, wildlife, and agriculture. *Fisheries* 26:6-16.

Sommer, T., R. Baxter, and B. Herbold. 1997. The resilience of splittail in the Sacramento–San Joaquin Estuary. *Transactions of the American Fisheries Society* 126:961–976.

Sommer, T., C. Armor, R. Baxter, R. Breuer, L. Brown, M. Chotkowski, S. Culberson, F. Feyrer, M. Gingras, B. Herbold, W. Kimmerer, A. Mueller-Solger, M. Nobriga, and K. Souza. 2007. The collapse of pelagic fishes in the Upper San Francisco Estuary. *Fisheries* 32:270–277.

SWRCB (State Water Resources Control Board). 2010. *Development of Flow Criteria for the Sacramento–San Joaquin Delta Ecosystem*. California Environmental Protection Agency, Sacramento, California.

Teal, J. M., N. G. Aumen, J. E. Cloern, K. Rodriguez, and J. A. Wiens. 2009. *Ecosystem Restoration Workshop Panel Report*. CALFED Science Program.

Turner, M. G. 1989. Landscape ecology: the effect of pattern on process. *Annual Review of Ecology and Systematics* 20:265–275.

USFWS (U.S. Fish and Wildlife Service). 2008. Formal Endangered Species Act Consultation on the Proposed Coordinated Operations of the Central Valley Project (CVP) and the State Water Project (SWP). http://www.fws.gov/sfbaydelta/documents/SWP-CVP OPs BO 12-15 final signed.pdf.

USGS (United States Geological Survey). 2001. Nonindigenous species information bulletin: Asian clam, *Corbicula fluminea* (Müller, 1774) (*Mollusca: Corbiculidae*). Florida Caribbean Science Center, Gainesville, FL.

Villamanga, A. M., and B. R. Murphy. 2010. Ecological and socio-economic impacts of invasive water hyacinth (*Eichhornia crassipes*): a review. *Freshwater Biology* 55:282-298.

Whipple, A. A. 2011. Abstract: "Habitat Characteristics of Past Delta Landscapes: Knowledge for Improving Future Ecosystem Resilience." California-Nevada Chapter of the American Fisheries Society 2011 Conference Abstracts. http://www.afs-calneva.org/_files/Cal-Neva_AFS_Conf_2011_Abstracts.pdf. Historical and Current Delta Waterways figure provided via personal communication between San Francisco Estuary Institute Aquatic Science Center and Delta Science Program staff.

Whipple, A. A., R. M. Grossinger, J. C. Collins, and D. Rankin. 2010. The Historical Yolo Basin Landscape: What Parts Make the Whole? Bay-Delta Science Conference Abstract. Sacramento, California.

Wiens, J. A. 2002. Riverine landscapes: Taking landscape ecology into the water. *Freshwater Biology* 47: 501–515.

Williams, J. G. 2006. Central Valley salmon: A perspective on Chinook and steelhead in the Central Valley of California. *San Francisco Estuary and Watershed Science* 4(3):1-418. http://escholarship.org/uc/item/21v9x1t7.

Winder, M., and A. D. Jassby. 2011. Synergies between climate anomalies and hydrological modifications facilitate estuarine biotic invasions. *Ecology Letters* 14:749-757.

Wright, S. A., and D. H. Schoellhamer. 2004. Trends in the sediment yield of the Sacramento River, California, 1957-2001. *San Francisco Estuary and Watershed Science* 2(2): 1-15. http://escholarship.org/uc/item/891144f4.

Yoshiyama, R. M., E. R. Gerstung, F. W. Fisher, and P. B. Moyle. 1996. *Historical and Present Distribution of Chinook Salmon in the Central Valley Drainage of California*. Sierra Nevada Ecosystem Project: final report to Congress. In Assessments, commissioned reports, and background information. Center for Water and Wildlife Resources, University of California at Davis. Davis, California. pp. 309–362.

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