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Towards the Protection, Restoration, and Enhancement of the Delta Ecosystem: A Synthesis

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STEWARDSHIP
COUNCIL

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1. Introduction

The Delta Reform Act of 2009 (Water Code Section 85000-85350) requires that the Delta Stewardship Council adopt a Delta Plan (the Plan) to achieve the coequal 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 (Water Code Section 85054). In the time since the Plan was adopted in 2013, a significant shift in State planning for Delta ecosystem protection, restoration, and enhancement has occurred. State and federal agencies discontinued their conservation planning under the Bay Delta Conservation Plan, which was founded on broad-based ecosystem protection and restoration, and instead the State initiated California EcoRestore, an initiative that focuses on the completion of tidal wetland and floodplain restoration requirements from existing biological opinions by 2020. This shift prompted a review of the Delta Plan to examine whether its strategies are still suited to achieve the ecological goals of the Delta Reform Act. As such, the Delta Stewardship Council (Council) is developing an amendment of the Plan's Chapter 4, Protect, Restore, and Enhance the Delta Ecosystem.

Council staff are reviewing the best-available science to inform amendment of Chapter 4 of the Delta Plan. To support this effort, Council staff have developed three science synthesis papers. This paper focuses on approaches to protect, restore, and enhance the Delta and is accompanied by other papers focused on climate change, and the ecosystem. A review of approaches to the protection, restoration, and enhancement of the Delta ecosystem is of interest for the Chapter 4 amendment given recent advances in research on species conservation, restoration science, and rapid advances in climate science since the Delta Plan was adopted in 2013 (SFEI-ASC 2016, Dettinger et al. 2016, Gardali et al. 2017).

Despite anthropogenic alterations to the region, the Delta is recognized broadly as an estuary of global importance given its role in supporting biodiversity (Water Code 85022, Myers et al. 2000). Policy initiatives have defined goals and objectives for improving the ecological health of the Delta. Hundreds of millions of public dollars have been invested in actions aimed at recovery of endangered species and rehabilitating ecological processes within the Delta watershed (CDFW et al. 2014). Despite this, ecological and geomorphic functions of the Delta remain impaired and species continue to decline (Healey et al. 2016, Wiens et al. 2016).

The Delta Reform Act defines restoration as "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" (Water Code 85066).

According to the Delta Reform Act, the Delta Plan shall include measures that promote all of the following characteristics of a healthy Delta ecosystem (85302(c)):

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.

Furthermore, the Delta Plan shall include the following sub-goals and strategies for restoring a healthy ecosystem (85302(e)):

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.

Moreover, the Delta Reform Act states that, “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” (29702(a)).

There is broad scientific recognition of the importance of human benefits and engagement that healthy ecological conditions provide to society (Suding et al. 2015, Wiens et al. 2016). Integrating human benefits into restoration planning will help enhance the Delta as an evolving place.

The Delta Reform Act specifies consideration of “the future impact of climate change and sea-level rise” (Water Code Section 85066), and identifies a restoration timeline horizon of 2100 (Water Code Section 85302). More generally, Executive Order B-30-15, signed by Governor Brown in April 2015, requires that State agencies incorporate climate change into planning and investment decisions, and that they prioritize natural infrastructure and actions for climate preparedness.

The purpose of this paper is to examine whether the Delta Plan strategies are still suited to achieve the ecological goals of the Delta Reform Act, given recent scientific advances. This examination includes assessments of (1) human benefits of ecosystem health, (2) efficacy of a portfolio of approaches to protection, restoration, and enhancement, (3) sub-regional differences in opportunities, constraints, and approaches, (4) considerations for conservation planning, and (6) current applicability of Delta Plan core strategies. It concludes with a discussion of the implications for current protection, restoration and enhancement, and broad considerations for Delta Plan strategies.

For convenience, as in the Delta Plan, "the Delta" refers to the statutory Delta and Suisun Marsh, collectively.

2. Society and Restoration

The Delta Reform Act requires consideration of the cultural, recreational, and economic aspects of the region as an evolving place (Water Code Section 85020 & 85054). While the Delta Plan addresses “Delta as a Place” as a separate section, Chapter 5, of the Delta Plan, the Delta Plan Chapter 4 considers a wide range of human activity associated with restoration including recreation, agriculture, and stakeholder engagement. Building on the work in the Delta Plan, recent Council reports have expanded on the need to consider society when doing restoration in the Delta (DSC 2014). The Delta Independent Science Board released a review of “Delta as an Evolving Place” in 2017 which concluded that human-nature systems are critical to Delta as place and that we need to further explore this topic scientifically. Furthermore, the 2017-2021 Science Action Agenda (SAA) has also identified as a Priority Science Action Area the need to “invest in assessing the human dimensions of natural resource management decisions” (Delta Science Program 2017).

Humans depend directly on the biological integrity of our landscapes in our pursuit of economic and cultural prosperity (Postel and Carpenter 1997). There are many approaches to describing this interdependence between nature and society. Heynen et al. (2006:1-20) focus on a “metabolic” relationship between society and nature in which economic and social value is produced from material transformations within nature. Taking the argument further, geographer Jason Moore argues that our modern economy is dependent on cheap “labor” performed by nature (Costanza et al. 1997, Moore 2014). That is, modern economies are reliant on their ability to capture value produced by natural systems. Beyond political economy, other researchers have emphasized the social benefits to a healthy ecosystem. For example, many scholars have pointed out there exists a strong relationship between social resilience and ecological resilience (Adger 2000). Others work contends that the relationship between society and nature are more fundamental with the materiality of society and nature being categorically inseparable (Bakker and Bridge 2006). Milligan and Kraus-Polk (2017a) extend this framework to the Delta and argue that the society-nature binary has harmed the progress of restoration efforts in the Delta. Although there are nuances between perspectives on the social and economic effects of environmental degradation, there is widespread agreement that our social and economic systems are at the very least reliant on our environments.

Because of the important relationship between society and the nature, many theorists have developed unique environmental ethics for natural resource management. These approaches offer different frameworks for approaching humans' relationships with nature. Human approaches to natural resource management fit into many frameworks of environmental ethics. Broadly speaking, most environmental ethics are founded on either a teleological view of nature or a deontological view of nature (Table 2-1). In the teleological view, nature has value because it produces tangible social or private benefits. This view includes wide range of environmental ethics such as animal rights (Singer 2015), utilitarian anthropocentrism (Batavia and Nelson 2017), and more recently ecosystem services (Aragão et al. 2016). In the deontological view, nature has inherent value and should be protected not just as a means to an end, but as something that has inherent value. These views include conservation biology (Batavia and Nelson 2017), deep ecology (Naess 1973), and ecofeminism (Warren 1996). Still more environmental ethics exist outside the teleology-deontology binary. For example, some religions including many traditional Native American beliefs view the value of nature as spiritual (Ferguson and Tamburello 2015) while the socionatures approach challenges the notion that nature and society are ethically or materially distinct entities in the first place (Hollifield 2009). Current scientific pursuits and debates are focused on explicitly and implicitly exploring these frameworks as approaches to protect, restore, and enhance ecological conditions on the landscape at local, regional, and global scales.

Across the spectrum of environmental ethics is an imperative to restore degraded ecosystems. Driven by a pluralistic approach to environmental ethics, society committed to the creation of environmental policies and significant public expenditures toward natural resource issues. Still, our current environmental policies are stretched thin because economic development, population growth, and resource use exceed the carrying capacity of our planet's ecosystems, and trigger impacts to these same stressors (Doremus 1991). Society's interest in the protection and restoration of ecosystems continues to be a subject of debate, with growing support for more sustainable management of the landscape (Dunlap and Mertig 1992, Fairbrother 2016).

Table 2-1. Selected Environmental Ethics by Underlying Framework

Ethical Framework	Teleology	Deontology	Others
Description	Value is derived from the function or utility of the environment.	The environment has inherent value.	The environment gets value through divinity. Value is a product of nature and so nature can't be evaluated from.
Examples	Ecosystem Services (Aragão et al. 2016) Animal Rights (Singer 2015) Utilitarian Anthropocentrism (Batavia and Nelson 2017)	Conservation Biology (Batavia and Nelson 2017) Deep Ecology (Naess 1973) Ecofeminism (Warren 1996)	Religious Views (Ferguson and Tamburello 2015) Socionatures (Holifield 2009)

Literature on ecosystem restoration increasingly affirms the need to consider human needs and benefits from restored lands. For example, Suding et al. (2015) includes engaging with and benefiting society in their four principles for planning restoration, The Society for Ecological Restoration International Primer on Ecological Restoration updated their categories for consideration to include "the human element" of restoration (Shackelford et al. 2013), and scholars increasingly emphasize that restoration actions interplay with socio-economics and cultural values (Hobbs 2007).

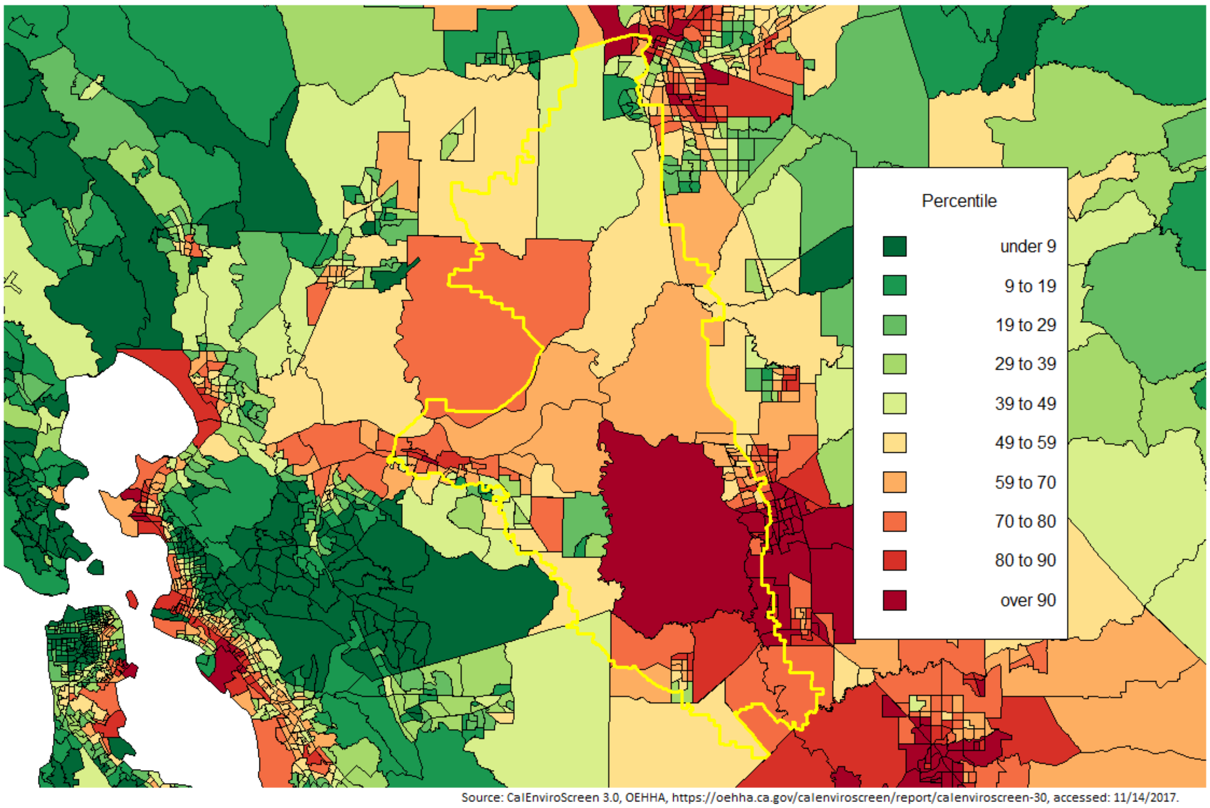
At a high level, research on restoration indicates that projects are a good investment for society (Peh et al. 2014). Literature on cost-benefit analysis for restoration shows that most projects are a good investment for society. According to an analysis by De Groot et al. (2013), "very high benefit-to-cost ratios were found for restoration of most ecosystems". According to biome-based estimates the Delta could see a benefit to cost ratio of approximately 6:1 for coastal wetland restoration (De Groot et al. 2013). Cost to benefit analysis offers a useful overview of the value of restoration ecology, but it has significant limits. For example, the authors leave out regionally specific benefits, as well as benefits which are not readily quantifiable. No explicit benefit estimations exist for Delta restoration. However, high-level scenario comparisons have indicated there are multiple approaches to achieving significant ecosystem and human benefits in the Delta (Lund et al. 2007, 2010)

This paper argues that restoration provides critical benefits regardless of a decision maker's ethical approach to the environment. The ecosystem services approach offers a strong teleological justification for restoration. The Human Benefits in the Delta section provides a broad overview of human benefits associated with restoration with special consideration for Delta communities.

2.1 Human Benefits in the Delta

As a region, the Delta's population is relatively young (~30% below the age of 19) and experiences troubling rates of poverty (20.54% of the school-aged population in the Delta live in poverty compared to the state population in 2015 (Brinkley 2018). Despite these challenges, Delta high schools have a higher graduation rates than the State average (Brinkley 2018). The median income in the Delta of $59,844 from 2011-2015 was less than the median statewide income of $61,818 (Brinkley 2018). Other metrics show that social and environmental vulnerability in the Delta are a pressing concern. CalEnviroScreen 3.0 (CalEnviroScreen) is a social and environmental vulnerability indicator create by the Office of Environmental Health Hazard Assessment (OEHHA) and CalEPA. CalEnviroScreen uses twenty indicators of environmental health and population characteristics and provides a score to each census tract in California with a higher score indicating higher vulnerability (CalEPA and OEHHA 2017). The average Delta census tract is significantly more vulnerable than the average census tract Statewide; the Delta mean percentile score was 62.7%. Some Delta census tracts were among the most socially and environmentally vulnerable in the State (Figure 2-1). Because of the intersection of social and environmental vulnerability in the Delta, socially conscious restoration has the potential to improve the conditions for Delta residents and provide a variety of benefits to residents. Broadly, these benefits fit into four non-mutually exclusive categories:

1. Ecosystem Services
2. Economic benefits
3. Social benefits
4. Cultural/psychological benefits



Source: California Office of Environmental Health Hazard Assessment 2017
Figure 2-1. Social and Environmental Vulnerability in the Delta

2.2 Ecosystem Services

Approaches that address ecosystem services combine strategies for economic frameworks and conservation of natural systems, and view the environment in the context of its utility to society (Costanza and Daly 1992, Constanza et al. 1997, Turner and Daily 2008, Fisher et al. 2009). These approaches seek to estimate the economic value of ecological functions as goods and services for humans. The valuation frameworks applied within ecosystem services science have proliferated in the recent past, although there has been significant disagreement around their appropriateness, applicability, and ability to represent the depth of knowledge which resides in existing ecological and restoration sciences (Schroter et al. 2014).

Ecosystem services approaches are a response to growing recognition of the need to consider economic trade-offs associated with natural resource management (Soule 1985); balanced with a growing recognition of the benefits humans derive from the environment and societal dependence on the landscape for water, food security, waste management, etc. (Postel and Carpenter 1997). Specific ecosystems and ecological functions can be viewed as goods and services which provide benefits to humans. Economic frameworks enable monetization of goods and services with the intent of increasing the relevance of ecological value in forums dominated by economic rationales, and result in efforts to shift attitudes, behaviors, and policy instruments towards human benefits of the environment at local, regional, and global scales (Costanza et al. 1997, Fisher et al. 2008, Fisher et al. 2009).

There are a few key issues to consider for implementation of ecosystem services valuation approaches in the Delta ecosystem. Market-based ecosystem service implementation is strained by two challenges. First, ecosystem services frameworks are not well suited to address the uncertainties associated with restoration of complex ecosystems, their full suite of functions, and the need for careful evaluation and adaptive management at restoration sites (Palmer and Filoso 2009). Second, the broadening definition of restoration and the activities which are implemented under the “restoration” umbrella leads to the valuation of systems that do not result in the recovery of self-sustaining ecosystems (Palmer and Filoso 2009, Palmer and Ruhl 2015). Each of these problems presents difficulty for reliable ecosystem service valuation in a system as complex as the Delta.

For effective protection and restoration of ecosystems, Palmer and Filoso (2009) discuss the importance that markets, which involve restoration, contribute to solving ecological problems and provide an uplift in environmental conditions rather than enable impacts to natural systems through mitigation pathways. This is a fundamental concern discussed in the “International Standards for Restoration Practice” (McDonald et al. 2016).

Assessments of ecosystem services are useful tools for stressing the importance of ecosystem processes to human society. They offer opportunities to elevate the perceived value of ecosystem restoration and preservation. However, ecosystem services approaches are limited in their ability to characterize and understand ecological complexity (Palmer and Filoso 2009, Norgaard 2010). They do not comprehensively leverage the multiple analysis frameworks that have been developed in ecology and restoration science. Lastly, Norgaard (2010) argues that effective application of economic models requires larger shifts in social, political, and economic arenas before they would effectively motivate outcomes at a local scale (e.g., project scale). So, while ecosystem services approaches do offer opportunities, they are not a panacea for ecosystem restoration.

2.3 Economic Benefits

Although the economic benefits of restoration are significant, society’s ability to confront the complexity of social-environmental problems is diminished if the broader context of environmental problems beyond economic valuation is not considered (Norgaard 2009). One reason for this is that stakeholders in a competitive environment can make economically rational decisions that result in predictable catastrophes. The Delta is one such environment where significant loss to all stakeholders is possible without cooperation (Madani and Lund 2011). Madani and Lund (2011) use a game theory model to emphasize that cooperation between Delta stakeholders and environmentalists will improve gains for all parties. The gains from a cooperative attitude toward restoration would benefit community livelihoods and reduce risk for many actors in the region. A functionally restored ecosystem would benefit a wide range of livelihoods and make the state and region more stable.

Many livelihoods are indirectly affected by the quality of the Delta ecosystem. Commercial fishing and recreation, however, are directly affected. The Delta waterways help support California's $1.5 billion commercial and recreational fishing industry (TNC 2017). Maintaining the ecosystem is critical to supporting the 80% of commercial fishery species that migrate through or live in the Delta (Water Education Foundation date unknown). The Delta ecosystem is similarly important for recreation. In 2009, 9% of Delta primary zone residents worked in a recreation related industry (Delta Protection Commission [DPC] 2012). There is a qualitative link between Delta tourism and ecosystem quality. In a marketing focus group on tourism for two Delta communities, participants identified "water," "waterways," "wildlife," "bird watching," and "exploring" among their list of "best things about the Delta" (AugustineIdeas 2015). Research in ecosystem restoration makes the affirmative case that including tourism as a part of restoration planning benefits the tourism industry and drives restoration activities (Blangy and Mehta 2006). Future restoration projects should consider this potential relationship. At present, much of the restoration land in the Delta is hard to access and/or off-limits to the public (Milligan and Kraus-Polk 2016). In addition to improving conditions for commercial fishing and recreation, restoration activity supports livelihoods in agriculture. In 2016, more than two thirds of conservation projects in the Delta were in agricultural production (Melcer and Anderson 2017).

2.3.1 Reduced Risk

Beyond livelihoods directly supported by restoration, some restoration activities can help reduce risk in the Delta. There are many sources of economic risk in the Delta, but perhaps the most persistent and systemic risk is the risk to delta levees. As the Council's draft State Investments in Delta Levees (2015) notes: "The Sacramento-San Joaquin Delta (Delta) is an intersection of multiple interests and dependencies. A common thread that holds these interests together is an extensive system of over 1,100 miles of levees" (DSC 2015:3). Ecosystem restoration offers several avenues to reducing risk of levee failure through subsidence reversal, flood control services, setback levees:

- Subsidence reversal is the first opportunity for restoration reduce levee risk in the Delta. One of the key geologic sources of risk to Delta levees is subsidence (DSC 2015). Subsidence in the Delta is driven by the oxidation of the peat soils on reclaimed islands. Delta subsidence effects levees by placing lateral pressure on the peat soil foundations increasing systemic risk of levee failure (Mount and Twiss 2005). This puts people, property, and ecosystems protected by levees at risk. A subsidence reversal project on Twitchell Island has successfully accreted 4 cm/yr (Bates and Lund 2013). Given time, this accreted soil could reduce levee risk.

- Tidal wetland restoration would provide flood control services (Mitsche and Gosselink 2000). Wetlands absorb energy (especially during flood events) which reduces risk of levee failures. Restoration projects in the Delta are already being managed to reduce flood risk for communities. The Yolo Bypass is an example of a restoration project, which is managed for flood control, agriculture, and ecosystems (Sommer et al. 2001).
- The Delta Plan calls for setback levees where appropriate (DSC 2013). Levee setbacks in provide increased flood system capacity, reduced velocity and erosion, and significant gains in ecosystem quality (USACE 2017). Levee setbacks alter channel geometry to create more space in the channel. This reduces pressure on the levee and provides habitat in the channel and on the setback gradient.

Finally, the Delta is an important source of water for the state of California. In addition to local and regional water users, the Central Valley Project and State Water Project export water from the Delta. Although it is the policy of the State of California to reduce reliance on Delta exports, nearly two thirds of Californians rely on Delta water for some part of their water supply (Anderson 2014). There are key linkages between water supply and levee risk for some central Delta islands. Levee failure in central Delta islands could lead to salinity incursion, harming in Delta water-users and water exports (Lund et al. 2007). Regulatory risk to Delta water supply is also significant. In the 1990s, for example, Federal regulatory agencies were placed under a court order to set water standards consistent with the Endangered Species Act (Lubell et al. 2014). Therefore, ecosystem restoration should remain a priority for the State’s water agencies because an improved Delta ecosystem would significantly reduce the long-term regulatory risk to Delta water supply. Decreased exports have economic costs for the state. Economic estimates indicate that ending exporting would cost approximately $1.5 billion a year while even a 50% reduction would cost $400 million a year in the cost of water scarcity (Tanaka et al. 2011).

2.4 Social Benefits

Though ecosystem restoration offers significant economic benefits, not all benefits to restoration are explicitly economic. Ecosystem restoration in the Delta would also provide broad social benefits. These social benefits enhance community capacity and promote justice. Globally, ecosystem restoration projects have been used to enhance community assets (Rahman and Minkin 2007, Harper and Rajan 2007), alleviate poverty (Narain and Agarwal 2007, Jodha 2007, Cao et al. 2009), and promote democracy and community participation in governance (Amanor 2007, Kurien 2007, Murombedzi 2007). Social conditions in the United States differ substantially from their global counterparts. Nevertheless, restoration projects in the United States that are managed to produce social benefits for communities have experienced their own successes. Research on multiple restoration projects in the United States suggests that restoration can help communities alleviate environmental injustices (Pastor 2007).

Ecosystem degradation is at the core of environmental injustices. Warlenius et al. (2015) argue that significant environmental degradation harms communities and therefore produces an “ecological debt”. Ecosystem restoration is one method for achieving environmental justice through repaying that “debt.” Because of this connection, the interplay between environmental sustainability and environmental justice comes up frequently in the literature (Agyeman and Evans 2003, Walker and Bulkeley 2006, Holden et al. 2017). Insofar as restoration ecology is a tool for achieving environmental sustainability it is also a tool for achieving environmental justice. In the Delta environmental degradation and ecosystem restoration opportunities are key environmental justice issues within communities that exhibit high levels of environmental and social vulnerability (Figure 2-1).

Functioning ecosystems provide a number of benefits that have implications for human health, such as through improvements to water quality and air quality. They improve water and air quality through land use opportunity cost. Conversion of natural lands to urban and agricultural land is a primary driver of pollution globally (Foley et al. 2005). Conversely, ecosystem functions regulate climate, increase soil quality, improve air quality, and improve water quality (Smith et al. 2013). Air quality and water quality have clear links to human health and well-being (Schwarzenbach et al. 2010, WHO 2013). Improved environmental quality could offer major regional benefits with regards to human health and well-being.

2.5 Cultural/Psychological Benefits

In the Delta, the ecosystem provides important cultural resources to tribes native to California. For example, in a letter to the Delta Stewardship Council, the Hoopa Valley Tribal Council describes salmon as “integral to the customs, religion, culture, and economy of the Hoopa Valley Tribe and its members” (2012). For tribes in the region, ecosystem restoration can offer spiritual/cultural benefits and the restoration of degraded material culture. Tribes with direct historical interests in the Delta emphasize “sacred connection with the land” (Yocha Dehe Wintun Nation 2015), maintaining “traditional resources” while achieving economic gains (Shingle Springs Band of Miwok Indians 2016), and “protecting and preserving the finite resources that our Ancestors left for us to care for, for future generations” (Wilton Rancheria, date unknown). These views emphasize the need for environmental stewardship. Although there exists significant diversity among Native American views on human’s relationships with nature (Krech 2000), many traditional views of nature believe in the inherent (deontological) or spiritual value of nature. This connection demands special attention for ecosystem restoration because studies in public health have shown that the displacement from indigenous lands and degradation of those lands has documented negative impacts on the health and wellbeing of indigenous people (King et al. 2009).

Some benefits to restoration are impalpable but important. Examining a restoration project in New Zealand, Roche and Rolley (2011) found that proximity to an ecosystem restoration area increased workplace happiness. Other research has shown that people tend to be happier in “natural” environments than in built landscapes (MacKerron and Mourato 2013). Farmer et al. describe the long-term educational benefits for primary school students who go environmental field trips (2007). There is also a significant body of work arguing that access to restored environments improve community health and lifestyles (Bowler et al. 2010, Speldewinde et al. 2015). In order to achieve these outcomes, project must be managed with consideration for human benefits (Dufour and Piégay 2009).

Restored habitat, park, and open space management requires addressing conflicts between human uses and protected species. In some cases, protecting the species may not be compatible with reasonable human use. Nonetheless, recent research suggests that restored lands in the Delta are extensively used by the community (sometimes illicitly) (Milligan and Kraus-Polk 2016). The question, then, is not "should restoration projects give the public access to restored lands?" but "should restoration projects consider the human activity that is already occurring?" Milligan and Kraus-Polk offer this suggestion: "Our overarching recommendation is to apply more integrative approaches to restoration that treat humans and human agency as integral to the ecology of these environments" (Milligan and Kraus-Polk 2017b:18). To that end, the planning process for restoration projects should grant consideration to community benefits in the selection and management of restoration projects.

2.6 Restoration for Society

Section 2 described a number of ethical approaches society can take towards nature. In general, those approaches emphasize either the intrinsic value of non-human nature or the use-value of it. Regardless of the approach taken, restoration actions in the Delta are justified either by the uniqueness of the natural system or the value provided by the system to society. Because of the importance of the ecosystem, restoration actions in the Delta are an important social concern. Considering social benefits as a core part of the planning and management practices of restoration will maximize the benefits provided by restoration. However, restoration is unlikely to provide many significant benefits if restoration actions are not appropriately targeted to address the Delta's deteriorated ecosystem. The following sections of this paper provide a scientific basis for creating a stronger and more balanced restoration portfolio for the Delta.

3. Approaches to Natural Resource Management

Myers et al. (2000) identified the California floristic province as one of 25 biodiversity hotspots of global importance. Rivers and wetlands (fresh water systems) are critical components, supporting the most diverse and species rich ecosystems within the California floristic province and throughout the arid and semi-arid portions of North America. These ecosystems support more than 80% of the terrestrial biodiversity despite their limited spatial distribution (< 2% of the landcover; Johnson et al. 1977, Cooperrider et al. 1986, Johnson 1989, Chaney et al. 1990, Naiman et al. 1993, Ohmart 1996, Svejcar 1997, RHJV 2004). The Delta and its watersheds support more than 750 species of plants and wildlife (Healey et al. 2016). Riparian and wetlands are two of the most important ecosystem types within California and greater western North America (DeSante and George 1994, CALFED 2000, RHJV 2004, Goals Project 2015).

While ecologically important, riparian and wetland ecosystems are some of the most impacted and degraded ecosystems on the landscape. They reside at low points on the landscape, and are affected by activities throughout the watershed. Flow impairment, loss of flood/marsh plain connectivity, and land conversion have significantly reduced the extent of functioning ecosystems within the Delta (Katibah 1984, Bay Institute 1998, Golet et al. 2013, DWR 2016b). Today less than 5% of the historical riparian and wetland ecosystems remain (Bay Institute 1998, GIC 2003, Whipple et al. 2012). Land subsidence and urbanization constrain the type and locations of restoration opportunities within the region.

Hobbs et al. (2014) argue that a comprehensive range of approaches is required to manage ecosystems on altered and changing landscapes. These approaches include the protection of existing ecosystems, ecosystem restoration, the development of analogs to naturally occurring ecosystems (e.g., managed wetlands), or enhancing working or urban landscapes to provide habitat resources to species (Bay Institute 1998, Moyle et al. 2012, SFEI 2016). These different approaches vary in their potential to re-establish and sustain geomorphic processes, vegetation communities and their dynamics, and fundamental ecological functions such as food web productivity. This in turn effects the extent to which these approaches can support the life history needs of the species communities that make up the full complement of biodiversity of the region as highlighted by Myers et al. (2000).

Although these approaches all exist along a continuum, Palmer and Ruhl (2015) caution against generalizing ecosystem management and restoration approaches under an umbrella concept given the fundamental differences of each in supporting ecosystem function. They urge scientists and policy makers to be accurate when aligning ecosystem management approaches with policy objectives. In order to address these concerns and to provide clarity on the approaches needed to achieve the ecological goals and objectives of the Delta Reform Act of 2009, the following sections provide a review of conventional approaches to conservation biology, reconciliation ecology, and approaches to support biodiversity on working lands.

3.1 Conservation Biology

Conservation biology is a discipline whose objectives include the protection of earth's biodiversity including species, ecosystems, and the function of evolutionary processes. Soule (1985) described key postulates drawn from evolutionary and ecological theory which underpin approaches to biodiversity protection. These postulates represent several sub-disciplines including conservation genetics, landscape ecology, and biogeography, which provide rich scientific frameworks for understanding the needs of species, and the function of ecosystem dynamics, and evolutionary processes.

Two fundamental strategies support the conservation of natural community composition, ecological processes, and evolution through direct consideration of the natural history needs of species. The first is the ecosystem preservation strategy of reserving space on the landscape to protect these characteristics of ecosystems (ecosystem preservation by establishing reserves). Considerations of scale, shape, connectivity, composition, and opportunities to enhance reserve form and function through adjacent land use provide depth to this strategy (Wiens 2009, Dybala et al. 2014, Wiens et al. 2016).

The second approach is ecosystem restoration – the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed (SER 2004, McDonald et al. 2016). This strategy works in tandem with ecosystem preservation by expanding ecological functions of the preserved ecosystems.

There is broad recognition in restoration science that ecological systems are dynamic rather than static, and restoration and management approaches should consider targeting resilience and adaptive capacity given changing environmental conditions (Hilderbrand et al. 2005, Suding et al. 2015, McDonald et al. 2016). Suding et al. (2015) describes four guiding principles for the concept of ecosystem restoration: ecological integrity, long-term sustainability, societal benefit, and consideration of past and future conditions. This is consistent with McDonald et al. (2016), who note that the target outcomes of ecosystem restoration should incorporate "the capacity for the ecosystem to adapt to existing and anticipated environmental change." This recognition is reflected in the Delta Reform Act of 2009 definition of restoration (Water Code 85066, see page 1 of this synthesis paper).

Another component of restoration is the consideration and re-establishment of the fundamental physical processes (e.g., geomorphic, chemical, others) which are key drivers of ecological functions such as vegetation succession or food web function (Larsen and Greco 2002, Greco et al. 2007, Cloern et al. 2016). Targeting re-establishment of both physical and biological processes in ecosystem restoration, also termed "process-based restoration", is key to the development of characteristics at various spatial scales such as vegetation community composition and structure, and meeting habitat needs of sensitive specialist species (Beechie et al. 2010, Greco 2013, Wiens et al. 2016).

McDonald et al. (2016) note that some systems require continued management of issues such as non-native invasive species as a component of ecosystem restoration. A critical component of the implementation of ecosystem preservation and restoration is the evaluation of success (Palmer et al. 2005, Palmer et al. 2016a). This includes the development of monitoring and adaptive management approaches that identify intervention thresholds where actions are implemented when ecological outcomes are not being met (Seadstedt et al. 2008, Lund 2013, Nagarkar and Raulund-Rasmussen 2016).

The effects of climate change and sea-level rise will require considerations in project siting, design, and also are also important context when considering tradeoffs with existing land-use (Harris et al. 2006, Dettinger et al. 2016). Land elevation, geomorphic process trajectories, and plant community composition are all affected by changing climate and hydrology (Moore et al. 2013, Wiens et al. 2016). The potential for greenhouse gas reduction, subsidence halting or reversal, and the benefits of a resilient ecosystem to humans, and climate adaptation are additional aspects with relevance in tradeoff analyses (Knox et al. 2015). Further, the Delta is an important region for ecological adaptation to a changing climate given its proximity to the ocean, role in watershed connectivity, and the potential for riparian and wetland restoration (Dettinger et al. 1995, Lebassi et al. 2009, Seavy et al. 2009, Morelli et al. 2017, see Climate Change Synthesis Paper for more in-depth discussion).

Multiple scientific works demonstrate that ecosystem preservation and restoration can protect and re-establish species communities and ecological function (Suding 2011, Palmer et al. 2016). Many specific studies of restoration within the watersheds that terminate in the Delta demonstrate successful re-established of ecosystems positive native species response. Gardali et al. (2006), Golet et al. (2008), and Golet et al. (2013) discuss positive land bird and other wildlife response to ecosystem restoration on the Sacramento River. Howell et al. (2010) document the response of the State and Federally Endangered least bell's vireo (*Vireo bellii pusillus*) to restoration on the San Joaquin Wildlife Refuge. Silveira et al. (2003) describe establishment of the largest recorded colony of State threatened bank swallow (*Riparia riparia riparia*) after levee removal and restoration on the Sacramento Wildlife Refuge. Dybala et al. (2018) found increasing abundance in land bird populations along Putah Creek in response to restoration actions.

3.2 Reconciliation Ecology

Alternative strategies have been identified to address the conservation of biodiversity in built landscapes where process-based restoration is not possible. Rosenzweig (2003) introduced the concept of reconciliation ecology, and described an approach to introduce novel analog ecosystems through the modification of built or significantly altered landscapes in an effort to support biodiversity. Rosenzweig (2003) frames this approach as a supporting strategy to preservation and ecosystem restoration. While this approach shares the overarching objective of conventional conservation biology to support the Earth's biodiversity, it requires a departure from the postulates that underpin it. Specifically, reconciliation ecology acknowledges that some species will not be able to adapt to novel analog ecosystems, and thus by extension, components of ecosystem structure such as community composition, and interspecific processes such as co-evolution may be lost (Rosenzweig 2003).

The principles of reconciliation ecology are distinct from ecosystem restoration strategies (or restoration ecology), and so are the expected biological outcomes (Lundholm and Richardson 2010). Reconciled landscapes, by design, will not target a full suite of geomorphic or ecological processes, and the suite of species that benefit from these more focused novel analogue ecosystems will be limited. For example, Suddeth Grimm and Lund (2016) propose actions using reconciliation ecology principles to balance the ecological needs of salmon, waterfowl species, and human agriculture within the Yolo Bypass. This approach optimizes ecosystem conditions for salmon and waterfowl, however, it does not provide habitat or resources for the full suite of biodiversity dependent on the region's riparian and wetland ecosystem. Other proposals within the same region which apply restoration ecology principals and target re-establishment of geomorphic processes, vegetation communities, and ecological processes are better suited to address the ecological needs of the full complement of riparian and wetland biodiversity. These proposals require changes in agricultural land use, however (e.g., Philip Williams and Associates 2003, Fischer et al. 2008, Opperman et al. 2010, DWR 2016a, Greco and Larsen 2014).

Reconciliation ecology is important in specific regions of the Delta that are precluded from extensive restoration due to restoration constraints such as subsidence, and urban and industrial land use. Within regions with urban and industrial land uses, significant opportunities to develop analog habitats exist. These include green engineering and infrastructure as part of levees, and actions that serve other functions but may also resemble historical landscape features (e.g., urban design features, parks, sea and level rise adaptation approaches). The unique challenges of land subsidence within the interior and western Delta and considerations of sea-level rise (see the Climate Change Synthesis Paper) present challenges to application of restoration ecology principles. These locations present opportunities to implement reconciliation ecology solutions to address other objectives while providing value to native species (e.g., carbon sequestration wetlands, vegetation features on levees; Bates and Lund, 2013). The 2017 update to the Central Valley Flood Protection Plan (DWR 2016b) provides specific guidance on the ecosystem restoration needs of riverine species communities within the Sacramento and San Joaquin River watersheds. It also describes a set of multi-benefit projects which can augment overall species restoration needs through the application of reconciliation principles.

As with ecosystem restoration, reconciliation ecology requires scientific evaluation and adaptive management to ensure the desired project objectives and ecological functions are being realized (Lundholm and Marlin 2006, Palmer and Filoso 2009, Lundholm and Richardson 2010). Sandstrom et al. (2013) undertook one such investigation within the Delta watershed. Researchers evaluated levee repair sites near urban areas along the lower Sacramento River where vegetation features had been engineered in rock revetment to benefit rearing salmonids. Results indicate that salmonids are not responding to engineered habitat features, however, and preliminary recommendations from this work included the consideration of directing investments upstream where processed-based restoration principles could be applied and may provide more direct ecological benefits. As with ecosystem restoration, reconciliation ecology requires scientific evaluation and adaptive management to ensure that project objectives are being achieved.

In built landscapes where process-based restoration is not possible ecological value can be introduced, or remnant ecosystems can be modified and diversified. However, these “reconciled ecosystems” which provide novel, reconciled analogs to ecological systems do not necessarily result in functional novelty and require scientific evaluation of their benefits. This approach is in the Delta most appropriate for areas with urban and industrial land uses, and areas subject to land subsidence within the interior and western Delta where it can be combined with other objectives (e.g., carbon sequestration, flood management).

3.3 Biodiversity on Working Lands

Within the Central Valley of California, the concept of supporting biodiversity on agricultural lands has been a focus of conservation funding programs given that agriculture is the dominant land use within the Central Valley of California (Burmester 2014). Within the Delta, more than two thirds of the landscape was in agricultural production as of 2014 (DOC 2017), and will remain as such even if landscape scale conservation objectives such as those developed for the Bay Delta Conservation Plan were implemented. Therefore, agriculture will always play an important role in the function and resilience of the Delta ecosystem.

Fundamental research questions exist regarding the ecological value of agricultural lands. These include understanding 1) the biological response from adoption of better management practices and 2) how much those practices will contribute to improved ecological functions. The Delta Science Program 2017-2021 Science Action Agenda has identified investigation of “the most cost-effective methods to improve species habitat on working lands” as a high priority science action for the Delta.

Maxwell (2016) argues that the loss of ecosystems to agriculture is of greater importance to biodiversity than climate change in the near term. To address the effects of ecosystem loss from land conversion, the adoption of better management practices on adjacent working lands may augment more direct approaches such as ecosystem restoration. Gonthier et al. (2014) discusses the importance of the spatial scale of management practices, and suggest that preservation of multiple taxonomic groups will require multiple scales of conservation.

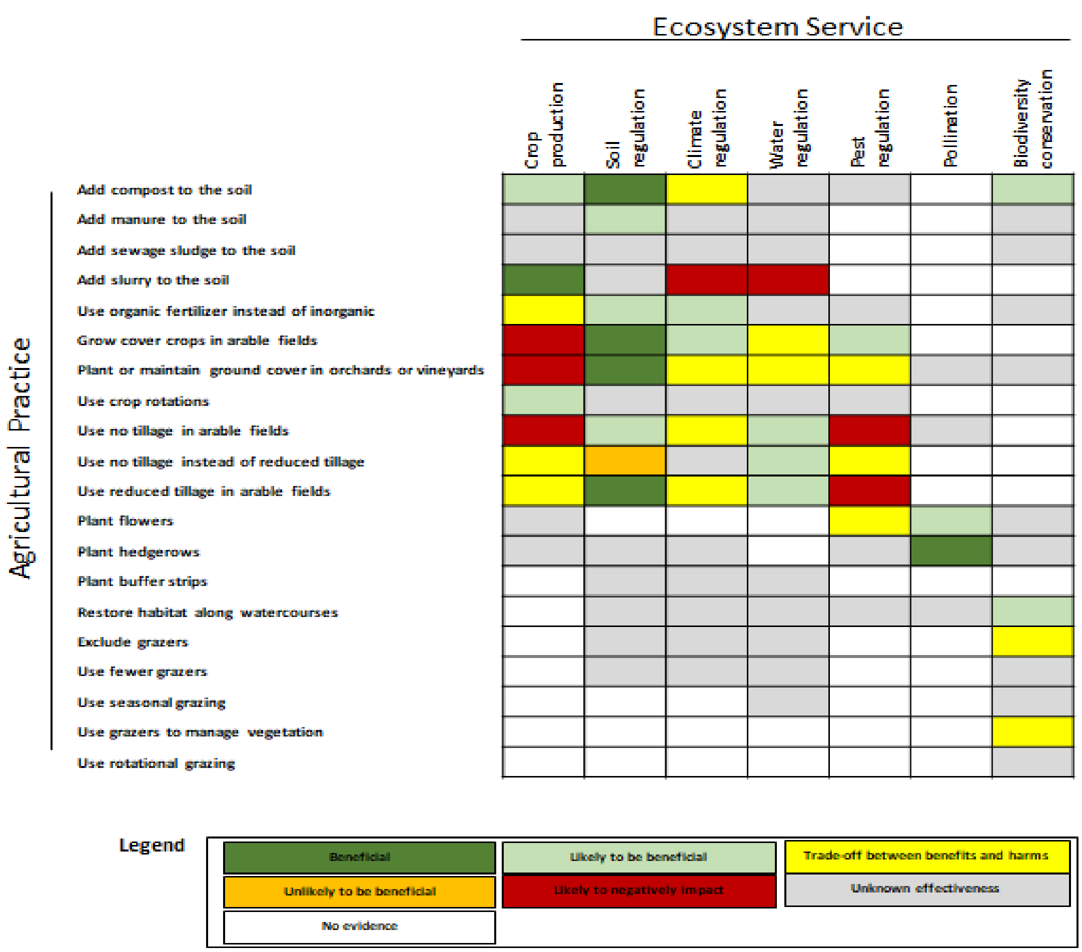
An important dichotomy of ecological enhancement on agricultural lands is described through the conceptual models of land sparing versus land sharing (Fischer et al. 2008). Land sparing models retain areas with remnant ecosystems and natural land cover, creating a more heterogeneous landscape. Land sharing or “wildlife friendly agriculture” models incorporate management practices targeting wildlife benefits on agricultural landscapes, resulting in homogenous agricultural landscape. Land sparing models better support biodiversity given the retention of ecosystem components, and are increasingly important in the context of population growth and pressures on the landscape (Phalan et al. 2011). This is especially true for species with large range sizes or subpopulations in the surrounding landscapes where collective management changes would be needed to realize net benefits (Ricketts et al. 2001, Tscharntke et al. 2005, McKenzie et al. 2013). Economic tradeoffs exist between these models, and land sparing may require incentives to be feasible under certain coniditions (Phalan et al. 2011). Underwood et al. (2017) demonstrate that analyses evaluating the potential to support biodiversity with agriculture require inclusion of other regional processes such as land-use planning to fully account for tradeoffs. Further, policy instruments such as the Williamson Act, intended to protect agricultural land from development through incentives, may constrain implementation of ecosystem restoration in a land sparing context. Under current law, counties decide whether recreational and natural lands are included in Williamson Act lands. Many of the current Williamson Act preserve designations by counties with land in the Delta do not include these designations as primary (as opposed to compatible) uses, which may discourage land owners from converting land through restoration or land sharing given the potential for loss of the financial incentives associated with Williamson Act designation.

Few studies have evaluated the use and function of agricultural landscapes by wildlife to analogous natural ecosystems. Elphick (2000) compared flooded rice fields and semi-natural wetlands in the Sacramento Valley and found that while foraging efficiencies for water birds were at times higher in semi-natural wetlands, benefits were realized due to the increased distribution of habitat that flooded rice field provided, and the resulting reduction in predator exposure.

Working lands provide crucial, time-sensitive, opportunities for subsidence reversal to take place and could create substantial amounts of suitable intertidal habitat in the future. As described in the Climate Change Synthesis paper, if subsidence reversal takes place at appropriate elevations and locations within islands, it could help form a critical part of ecosystem adaption to climate change. In addition, some subsidence reversal activities, like wetland creation or a switch from row crops to rice cultivation, are eligible for carbon market revenues and could provide landowners economic incentives to implement those practices on their land.

Shackelford et al. (2017) provided a synopsis of more than 200 studies on farmland, riparian areas, and grazed areas in California and other Mediterranean ecosystems, and evaluated the evidence of about twenty practices and their effects on crop production, soil, water, pest regulation, pollination, and biodiversity. They found that the effectiveness of many practices was unknown (Table 3-1).

Table 3-1. Evaluation of Ecosystem Services Provided by a Range of Agricultural Practices



Source: Shackelford et al. (2017)

Aquatic and terrestrial species benefits involve consideration of a variety of practice changes including water management, harvest techniques, and different crop types – such as annual crops (e.g., corn, alfalfa) and perennials (e.g., orchards, vineyards). Shuford et al. (2016) observed greater waterbird richness and abundance in a mosaic of dry and flooded crop types, water depths, and corn management practices on Staten Island in the Delta.

Importantly, there has been a dramatic increase of orchard and vineyard area in the Delta with an additional 26,702 acres by 2016 since 2010, see Table 3-2 (DPC 2012, LandIQ 2016). These trends have negative implications for biodiversity in the landscape, and limit the potential for using wildlife-friendly agriculture, or land sharing with wildlife. Orchards and vineyards have relatively low value for most wildlife, in part because understory vegetation that would provide food and cover typically is removed or maintained at a low height (DWR 2016a). In addition, “dense woody cover” of vineyards and orchards do not provide suitable foraging habitat for the State-listed threatened Swainson’s hawk (Buteo swainsoni), which largely rely on alfalfa fields to scavenge (England 1997). Furthermore, orchards and vineyards provide food for ground squirrels, with the unintended consequence for adjacent levees of increased density of burrows, which may threaten levee integrity (Van Vuren et al. 2013).

Table 3-2. Vineyard and Orchard Acreage Change in the Delta

	2010 Acreage	2016 Acreage	Acreage Change
Vineyards	22,095	38,503	16,408
Orchards	20,780	31,074	10,295
Total	**42,875**	**69,577**	**26,703**

Sources: 2010: DPC (2012); 2016: LandIQ (2016)

Shuford and Dybala (2017) and Shuford and Hertel (2017) note that the recent conversion of agricultural field crops to orchards and vineyards has reduced the amount of land suitable for use as habitat by at least 16 at-risk bird species. These include the species that are well adapted to using agricultural lands such as the State-listed threatened greater sandhill crane (Antigone canadensis tabida) (Littlefield and Ivey 2000), and also non-native game species such as ring-necked pheasant (Coates et al. 2017).

The relative benefits of retaining islands of suitable habitat within a matrix of agricultural lands (“land sparing”) compared managing agricultural lands for native species use (“land sharing”, wildlife friendly farming) depend on the target species considered. A number of species in the Delta benefit from wildlife friendly farming (e.g., water birds, tricolored blackbirds, greater sandhill crane, Swainson’s hawk), and are adversely affected by rapid conversion of agricultural fields to orchards and vineyards.

4. Ecosystem Properties that Promote Resilience

The previous section provided a review of conventional conservation biology, reconciliation ecology, and supporting biodiversity on working lands. Each of these approaches to natural resource management provide an opportunity to re-establish ecological resilience within the Delta. Resilience is defined as the ability to absorb change and persist after a perturbation (Holling 1973). This concept applies to all aspects of an ecosystem including physical processes, biological processes, communities, and populations. Ecological resilience within the Delta landscape has been lost with the historical loss of wetland and riparian ecosystems and their function (Bay Institute 1998, Whipple et al. 2012, Wiens et al. 2016). Given that Delta ecosystems are expected to be further stressed by a rapidly changing climate, re-establishing ecological resilience is an important restoration target (see Climate Change Synthesis Paper). The re-establishment of ecological resilience is an important in sustaining the societal benefits of restoration and a healthy environment (Holling 2001, Walker et al. 2004, Folke 2006, Virapongse et al. 2016). Ecosystems with greater connectivity, complexity, redundancy, or size are thought to have greater resilience (SFEI-ACS 2015, 2016). These properties should be incorporated in a way that anticipates the expected environmental change.

Promoting ecosystem resilience requires thinking beyond single-species habitat models (see the Ecosystem Synthesis Paper). Species-specific models are helpful in narrowing down decision-making for specific regulatory functions, but there has been debate about their ability to generate overarching ecological models that benefit other species or increase ecological resilience (Lambeck 1997, Lindenmayer et al. 2002, Standish et al. 2014). Instead, the presence of multiple species that contribute to the same ecological function (e.g., multiple grazers, or multiple predator species) are thought to promote resilience (Elmqvist et al. 2003). A diversity of responses to environmental change among species contributing to the same ecosystem function (“response diversity”), is considered critical to resilience (Elmqvist et al. 2003). Response diversity is particularly important for ecosystem renewal and reorganization following change, and provides adaptive capacity.

Targeting ecological resilience requires consideration of landscape-scale ecosystem properties, including connectivity, complexity, redundancy, and scale (SFEI-ASC 2016). “A Delta Renewed” (SFEI-ASC 2016), includes guiding principles for creating and maintaining resilient landscapes. “The principles draw from several recent efforts to develop science-based approaches to achieving long-term ecological health and resilience for the Bay-Delta system” (p. 17). The guiding principles include:

1. Appreciate that people are part of the Delta (see Section 2, “Society and Restoration”)

2. Consider landscape context to apply the right strategies in the right places (see Section 4, “Subregional Opportunities and Constraints”)

3. Restore critical physical and biological processes (See Section 7, “Delta Plan Core Strategies”)

4. Restore appropriate landscape connectivity
5. Restore landscapes with a focus on complexity and diversity
6. Create redundancy of key landscape elements, populations, and habitat types
7. Restore at large scales, with a long time horizon in mind

The first three principles are discussed elsewhere in this paper. This section briefly discusses the ecosystem properties considered in the last four principles, as well as the resilience that these properties are often thought to confer on ecosystems or even landscapes.

4.1 Connectivity

Connectivity is a core concept underpinning multiple ecosystem components, and is especially relevant to the conceptual models defining riparian and wetland systems and their geomorphic and ecological processes (Nilsson and Svedmark 2002). These include issues of flow and flooding, related connections between channels, floodplains and the groundwater system, nutrient and carbon cycling, vegetation community patch dynamics, and species-habitat interactions (Vannote et al. 1980, Naiman et al. 1988, 2002, Ward 1989, Junk et al. 1989, Poff et al. 1997, Naiman and Decamps 1997). The various aspects of connectivity are crucial to riparian and wetland systems ability to support large amounts of biodiversity, and heighten the important of these ecosystems in light of ecological adaptation and a rapidly changing climate (Naiman et al. 1993, Seavy et al. 2009, see Climate Change Synthesis Paper).

The history of agricultural development and flood control has impacted each of these aspects of ecological connectivity at a landscape scale within the Delta (Katibah 1984, Bay Institute 1998 Whipple et al. 2012). Loss of connectivity within the Delta has led to the loss of food web function, riparian and wetland vegetation development, and has resulted in species declines (Stella et al. 2006, Ahearn et al. 2006, Moyle et al. 2012, Cloern et al. 2016, See Ecosystem Synthesis Paper for detailed discussion of the conditions of the Delta).

For hydrologic connectivity - there are three types to consider in addition to a temporal dimension: longitudinal, lateral, and vertical connectivity (Ward 1989).

Longitudinal connectivity allows aquatic species to migrate freely upstream and downstream along the riverine network and allows for transport of nutrients, sediment, and vegetation propagules and seeds to travel downstream. Within the Delta watershed dams and other structures (e.g., weirs, culverts) are impediments to this connectivity, with the most noticeable ecological effect being interference with the migration patterns of aquatic species such as salmon. Re-establishing and addressing stressors to longitudinal hydrologic connectivity, from upper watersheds to the ecosystems of the bay, is critical to many species that reside in or migrate through the Delta. An illustrative example is anadromous fish that historically spawned in cold-water tributaries to the Delta, but are now limited to spawning in areas downstream of major dams. It is not feasible to contemplate the removal of most major dams in California at this time, although there may be opportunities for removal of outdated and underperforming small barriers. Nevertheless, enhancing connectivity in tributaries that provide high quality aquatic habitat would aid species persistence in a rapidly changing climate.

Lateral connectivity allows aquatic species access to temporally limited floodplains and tidal plains, and for the ecological processes between aquatic channels and adjacent wetlands. Increasing connectivity between aquatic and wetland habitats, such as between channels and marsh plains, allows fish greater access to food resources (West and Zedler 2000), and allows nutrient provisioning of open water by productivity in tidal marshes (Cloern 2007). Increasing connectivity between channels and floodplains allows native fish to utilize inundated floodplains in winter and spring and increases their food intake (Moyle et al. 2012).

Vertical connectivity allows for channel interactions with the groundwater table, and in the Delta has linkages with key chemical and physical processes such as oxidation of peat soils and subsidence. Of note, water ways within the Delta have been "over-connected" (Wiens et al. 2016) as a result of development and flood management. A system of highly interconnected, and structurally relatively uniform deep channels was created, which provides excellent habitat for nonnative predators, but is lacking in the highly heterogeneous shallow tidal habitat that provides predator refugia and foraging habitat for native fishes (West and Zedler 2000).

Another aspect of connectivity is related to the distribution and extent of ecosystem components such as vegetation. For example, connectivity within and between patches of similar vegetation type allows for the movement of organisms during their life cycle, and for the flow of genes between subpopulations of organisms. In this context, criteria defining connectivity is specific for each species and how it uses the landscape. Actions to protect, restore, and reconcile lands should consider the life history needs of the species community. For example, marsh restoration should be implemented in a manner that supports the movement of organisms between patches and enables gene flow across wildlife species sub-populations (e.g., black rails [Laterallus jamaicensis]) (SFEI-ASC 2016).

One last concept is the connectivity across ecosystem types. Key processes and energy flows occur across these gradients. Currently wetlands within the Delta are disconnected from uplands by the levee system. Establishing connectivity between aquatic and terrestrial ecosystems may promote resilience in the face of environmental change (Seavy et al. 2009). By restoring broad connections between tidal marsh and gradually sloping adjacent uplands, tidal marsh may have the opportunity to expand upslope when sea level rises (see the Climate Change Synthesis Paper).

4.2 Heterogeneity and Complexity

In riparian and wetland systems, heterogeneity and complexity used synonymously and characterized as the outcome of physical, chemical, and ecological processes interacting (Naiman and Decamps 1997, Stallins 2006). These driving processes vary temporally and by spatial scale, and include watershed-specific hydrologic variability, the interaction of flows with landforms and vegetation communities (e.g., shaded riverine aquatic habitat; DeHaven 1989), and climate and weather (Naiman and

Decamps 1997). Multiple aspects of ecosystem heterogeneity and complexity have been greatly reduced in the Delta over the last 160 years through the loss of these processes (Moyle et al. 2010, Whipple et al. 2012, Table 3-3). SFEI-ACS (2016, p. 23) directly associates this loss of ecosystem complexity with the loss of species diversity in the Delta. Restoration of heterogeneous and complex ecosystems will require re-establishment of the underlying processes that drive complexity (discussed in Section 3). This diversity can promote ecological resilience and enhance native biodiversity by providing a range of options for species, and by expanding the types and numbers of species that a landscape can support. SFEI-ACS (2016, p. 23) recommend the protection and restoration of (1) a variety of habitat types, (2) complexity within habitat types, (3) physical gradients (e.g., temperature and salinity gradients), and (4) biodiversity (genetic, species, and ecosystem diversity).

4.3 Redundancy

A key characteristic for managing risk to environmental resources at the landscape scale is the incorporation of redundancy of ecosystems and species populations (Peterson et al. 1998, Ahern 2013, SFEI-ACS 2016). SFEI-ACS (2016) state that redundancy can increase ecological resilience by providing “backups”, so that loss of a population or landscape element does not lead to extirpation of a species or elimination of a landscape element across the entire Delta. They include as examples multiple discrete ecosystem patches, multiple populations, and multiple movement corridors. They also recommend the creation of “functional redundancy” (i.e., “multiple species performing similar functions”).

4.4 Scale

Geomorphic, chemical, and ecological processes operate at various spatial and temporal scales, requiring consideration in the siting and design (Palmer et al. 2016b, SFEI-ACS 2016). For example, fluvial geomorphic processes operate at the site (erosion), reach (meander/braiding), and watershed (watershed zone) scale (Schumm 1977). Ecological restoration requires consideration of various temporal scales related to targeted geomorphic and ecological processes such as tidal cycles, flood regimes, vegetation succession, and sea-level rise (SFEI-ACS 2016). Such considerations require long term planning horizons such that they encompass expected dynamics.

5. Subregional Opportunities and Constraints

The Delta region lies at the convergence of California’s largest watersheds, those of the Sacramento and San Joaquin Rivers, and smaller watersheds of the eastside tributaries Mokelumne, Cosumnes, and Calaveras Rivers. These watersheds vary in their hydrography, water quality, sediment input, and geomorphic influence (Bay Institute 1998, SFEI-ASC 2016). Historical reconstruction by Whipple et al. (2012) revealed three primary Delta landscapes: the central Delta, where historically a freshwater tidal wetland was interwoven with myriad tidal channels, the north Delta, with flood basins lying parallel to the riparian forests of the Sacramento River and its distributaries, and the south Delta, where branching distributary networks supported a broad floodplain that gradually merged with tidal wetlands. Farther to the west, the Suisun Marsh was dominated by brackish tidal marsh.

The modern Delta, however, has been transformed into a simplified and degraded system, with extensive channels and open water, more human land use (mainly agriculture) and fragments of marsh (SFEI-ASC 2014, see Ecosystem Synthesis Paper for more in-depth discussion). More than 160 years of accumulated impacts – land cover conversion, land development, levees and channelization, water diversions, altered flows, not to mention invasion by non-native species – have significantly altered the landscape and ecosystem (Bay Institute 1998, Moyle et al. 2012, Whipple et al. 2012). Furthermore, the Delta will continue to experience major changes due to sea-level rise, other effects of climate change, floods, and continuing land subsidence.

Landscape position is a strong determinant of restoration potential and ecological trajectory (SFEI-ASC 2016). Elevation can be destiny, since it affects how frequently and deep an area may be inundated by fluvial or tidal flows, and thus the hydrological regime of a site. Only areas within the intertidal range (mean lower low water to mean highest high water) are suitable for tules and other emergent vegetation species that make up a tidal marsh. Land subsidence of Delta islands, combined with projected rates of sea-level rise limit current and future opportunities for tidal marsh plain restoration in much of the western and interior Delta (Bates and Lund 2013). While it may not be possible to recover natural ecosystem forms and functions on deeply subsided lands, reconciliation ecology approaches could re-establish ecological values as seasonal wetlands, managed wetlands, and croplands that can serve as surrogate habitat for wildlife (“wildlife-friendly agriculture”).

The longitudinal gradient from fluvial to tidal flows is another environmental driver, in terms of hydrologic regime, sediment deposition, and water quality (Whipple et al. 2012, SFEI-ASC 2016). A dynamic salinity gradient from fresh water to saltwater is one of the most characteristic features of an estuary (Interagency Ecological Program [IEP] 2015). The brackish “low salinity zone” is an important region for retention of organisms and particles and for nutrient cycling (Jassby et al. 1995, Kimmerer 2004, IEP 2015, SWRCB 2017). Delta smelt use seasonal pulses of flows, salinity, and turbidity to cue spawning migrations from Bay to upper Delta (IEP 2015). Opportunities to protect and restore habitat and migration corridors for fish species will vary regionally (SFEI-ASC 2016, Moyle et al. 2012).

Given that opportunities for ecosystem restoration vary by region with respect to river hydrology, tidal forcing, and constraints such as subsidence and urbanization, establishing resilient ecosystems will require spatially explicit conservation planning. Where landscape suitability exists, process-based ecosystem restoration should be prioritized over other approaches given its ability to support resilience and physical and ecological processes. Where subsidence and developed land uses constrain the types of conservation actions, reconciliation ecology or agricultural practices that support biodiversity can augment process-based ecosystem restoration. An important component of these latter approaches will be strategically located subsidence reversal activities which can reduce risk and support future restoration opportunities.

An example of this regional conservation planning is Moyle et al. (2012), which envisions different future outcomes for four different parts of the estuary, identified as: (1) the Sacramento River and Bypass Habitat Arc, (2) the Eastside Rivers, (3) the Central Delta Lowlands and Lakes, and (4) the Lower San Joaquin River Floodplain. Given different habitat conditions and physical drivers, these four regions present different opportunities and constraints, and require different approaches for protection, restoration, and enhancement of the ecosystem. The Department of Fish and Wildlife provides a different perspective on regional conservation actions in the draft Delta Conservation Framework (e.g., see Conservation Opportunity Regions, CORs).

Key human and socio-economic landscape attributes such as land use, urbanization, water development, and flood control activities are also crucial considerations that influence the types of actions that could be employed to achieve ecological recovery of the Delta landscape. Levees, agriculture, water supply infrastructure, and recreation each exert an important influence on the potential for ecosystem protection, restoration and enhancement. Restoration planning should consider the socio-economic and cultural values, needs and expectations of the local communities. Understanding the geographic setting and local context is critical to matching appropriate strategies to each location and situation.

6. Considerations for Conservation Planning

More than 230 stakeholder groups play some role in management of the Delta, and many hold very different and sometimes conflicting viewpoints (Luoma et al. 2015). Given the many complex issues that affect the ecosystem, the challenge of effective management of the Delta has been characterized as a “devilishly wicked” problem (Luoma et al. 2015). Collaborative institutions have played a key role in Delta decision-making, as they provide an inclusive approach to bringing together diverse groups of stakeholders (Lubell et al. 2014). Such partnerships can build upon localized knowledge and develop policies and strategies that are tailored to specific local ecosystem issues; furthermore, they can result in developing more innovative approaches to address problems beyond more often rigid regulatory frameworks (Lubell 2002). Although the current governance structure that has been set up for Delta management is complex, its organizational structure allows different stakeholders to exert at least some influence over the system, and the institutional diversity allows for more opportunities for collaboration and innovation (Lubell et al. 2014).

With the passage of the Delta Reform Act, the actors in the complex web comprising the Delta governance structure have to consider how to address the goal of protecting, restoring, and enhancing the Delta ecosystem. The Delta Reform Act anticipated that he Bay Delta Conservation Plan would have established broad ecosystem preservation and restoration goals and objectives, which targeted the natural communities within the region. With the State’s shift to more focused conservation actions, the Delta currently lacks overarching science-based ecosystem preservation and restoration objectives, to guide management of the Delta Ecosystem.

Recovery goals and biodiversity targets play a key role in translating ecological science and policy into on the ground action (Tear et al. 2005). Science-based objectives are often used to provide a unified understanding of conservation objectives among stakeholders, increased efficiency and cost-effectiveness, and to make progress toward measurable goals (Metrick and Weitzman 1998, Margules and Pressey 2000, Tear et al. 2005, Carwardine et al. 2009, Johnson et al. 2009, Faaborg et al. 2010, Williams and Madsen 2013, Dybala et al. 2017a, Dybala et al. 2017b). To develop these objectives, clear communication about the ability of various natural resource management approaches to deliver ecological benefits and biodiversity protection is required (Palmer and Ruhl 2015). Such information was presented in Section 3 of this synthesis paper.

The Delta is one of the most studied ecosystems in the world (Luoma et al. 2015), so the rich body of ecological science that has been developed over the past few decades can be leveraged in developing targets that address the objectives of the Delta Reform Act. For example, since the release of the 2013 Delta Plan, as part of the Delta Landscapes Project, SFEI synthesized key ecological principles to guide planning of future restoration and enhancement efforts in the Delta so they support desired physical and ecological functions - in a manner that also maintains the Delta's agricultural character and its function as the water supply hub for the State (SFEI-ASC. 2016).

A recent initiative for guiding conservation planning for the Delta is the Delta Conservation Framework (DCF). CDFW (2017) is currently developing the DCF which provides a common long-term, landscape-level vision for how to create a mosaic of working agricultural and habitat lands in a manner which results in improved ecosystem functions. The DCF developed seven different "conservation opportunity regions" (CORs) which divided the Delta and Suisun Marsh into smaller regions with distinct characteristics (e.g., local land use, ecosystem types, communities, etc.); the description for each COR has a common vision, a description of opportunities for conservation, and potential solutions for known challenges. The intent of the DCF though is not to provide a prescriptive target for what habitat actions should take place, rather the expectation was that collaborative stakeholder groups (i.e., "Regional Partnerships") would build upon the foundations of the DCF and develop more specific and refined conservation strategies and approaches tailored to the unique characteristics of the local region. For some of the CORs, the Regional Partnerships have already been organized while other CORs would need to launch new Regional Partnerships.

While the purpose of the DCF was not to provide specific habitat objectives for the Delta, other planning efforts which include the Delta, such as recovery plans and conservation strategies can support the development of specific ecosystem preservation and restoration goals. Recovery plans are driven by requirements of the federal and State endangered species acts. Conservation plans are often products of federal and State initiatives or interagency committees (e.g., Central Valley Joint Venture, Bank Swallow Technical Advisory Committee). The habitat preservation and/or restoration targets of these plans is provided in Appendix A, and a summary of these various planning, implementation and science and adaptive management forums are discussed in the Ecosystem Synthesis Paper. Although most of these efforts are narrowly focused on benefiting a single species or suite of similar species (e.g., riparian birds), the Delta Reform Act calls for providing benefits to a broad range of native species and migratory birds. Nonetheless, these plans provide valuable insight into the scale of habitat preservation, enhancement, and restoration necessary to benefit the wide multitude of species which rely upon the Delta ecosystem.

7. Delta Plan Core Strategies

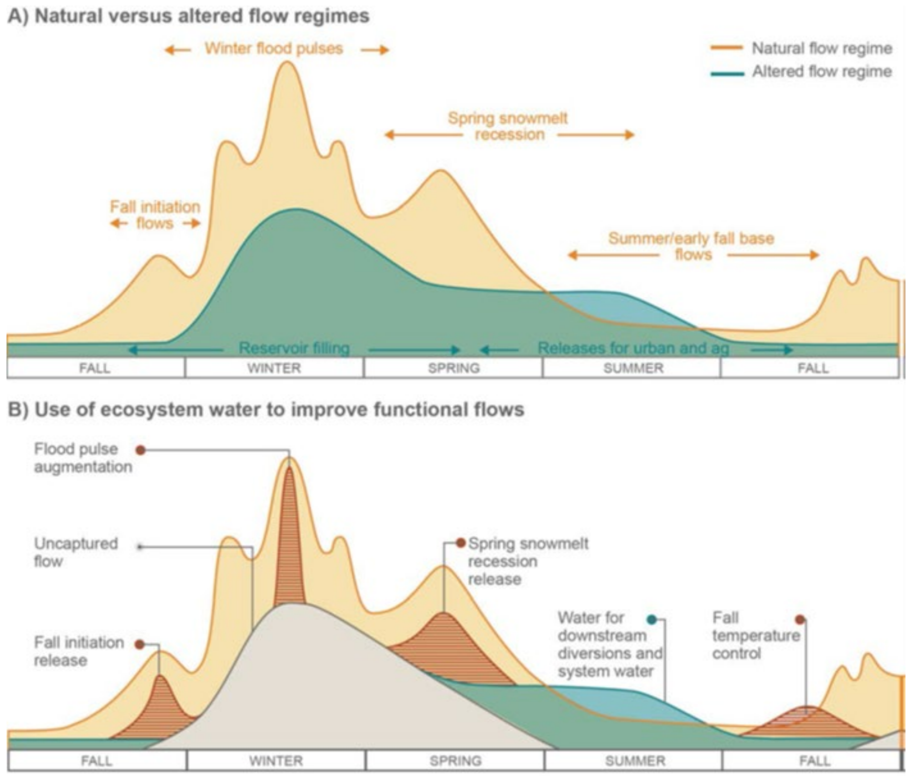
Chapter 4 of the Delta Plan identifies five core strategies to reduce the impact of ecosystem stressors on the Delta ecosystem: (1) create more natural functional Delta flows, (2) restore habitat, (3) improve water quality to protect the ecosystem, (4) prevent introduction of and manage non-native species, and (5) improve hatcheries and harvest management. Improving the ecosystem conditions within the Delta will require achieving gains in all strategy areas in parallel (Hanak et al. 2013). This section synthesizes key recent scientific advances related to these core Delta Plan strategies. This section discusses these strategies in the context of societal benefits and the approaches to natural resource management reviewed above.

7.1 Create More Natural Functional Delta Flows

The geomorphic conditions and ecosystems of the Delta have evolved over the past several millennia under the influence of stream flow patterns and tidal influence (Poff et al. 1997). Within the Delta watershed, the interaction of surface waters and the landscape has been significantly altered (i.e., limited) through floodplain disconnection, and much of the streamflow variability has been reduced through the construction and operation of dams and diversions to meet flood management, water supply, and hydropower needs (Knowles 2002, Lund et al. 2010).

A crucial component of improving ecosystem health within the Delta is addressing the alterations to the natural flow components and water quality (i.e., temperature, salinity) of Delta tributaries, Delta outflow, and within the interior Delta (SWRCB 2017). Considerations of key aspects of flow regimes such as magnitude, frequency, duration, timing, and rates of change are linked to geomorphic and biological process which support vegetation recruitment, fish, wildlife, and society (Poff 1997, Schwarzenbach et al. 2010, Kiernan et al. 2012, Smith et al. 2013, WHO 2013).

Multiple approaches exist to address altered flow regimes. These include restoration of natural flows, re-establishment of a component of unimpaired flows, synthetic management of flows targeting components of the natural flow hydrograph (functional flows water management approach, Yarnell et al. 2015). Each of these approaches attempts to address current managed river system departures from components of the natural flow hydrograph, including winter flooding peaks, spring snow melt recession flows, and lost water quality signals from early season rain events (Figure 7-1).



Source: Gartrell et al. 2017.

Figure 7-1. Illustration of Unimpaired (a) and Functional (b) Flows

Re-instution of these natural flow aspects of the hydrograph is key in providing opportunities for ecological adaptation and ecosystem resilience in light of a changing climate and shifting hydrograph (Yarnell et al. 2015, Yarnell et al. 2016, Poff 2017). Importantly, Lund et al. (2010) note that channel simplification and floodplain disconnection are underappreciated stressors in current management discussions of flows. Increasing flood plain connectivity along Delta tributaries and tidal marsh within the Delta are fundamental to realizing the benefits of flow management (Matella and Merenlender 2015, SWRCB 2017). Significant opportunities for lateral (flood plain/marsh plain) reconnection exist throughout the Delta watershed, and more locally within the Delta (e.g., Moyle et al. 2012, SFEI-ASC 2016, DWR 2016f).

Re-establishing longitudinal connectivity from the upper watersheds throughout the Delta to the Bay will have benefits (Null et al. 2014, SWRCB 2017). For example, fish passage improvement actions would reduce stress and mortality in lower parts of the system, and reconnecting fish with cold water habitats above dams would reduce the need to manage spawning conditions with flows on specific watersheds (Moyle et al. 2008). A comprehensive assessment of the longitudinal passage improvement opportunities was developed by DWR (2014) and a subset of these passage obstacles have been prioritized for restoration through the Central Valley Flood Protection Plan pending investigation, design, and funding (DWR 2016d). Current status of efforts for longitudinal connectivity, including passage at major dams, are summarized in the Fish Migration Improvement Opportunities report (DWR 2014).

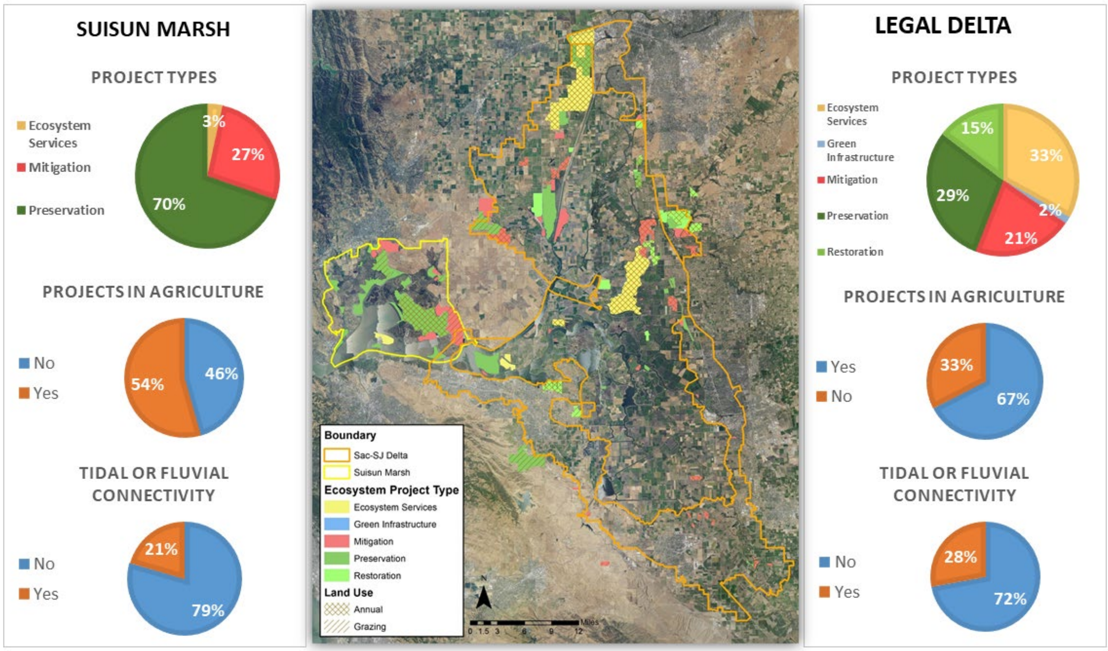
The State Water Resources Control Board is in the process of updating the Bay-Delta Water Quality Control Plan (WQCP) water quality standards. SWRCB (2017) has identified re-establishing a component of unimpaired flows as the selected approach to addressing flow restoration within the Delta. This approach addresses the functional components of the hydrograph, inter-annual variation based on real time environmental conditions, and is more feasible than a purely synthetic approach which targets high value conditions every year (Delta ISB 2015). This approach may be augmented by subsequent incorporation of a functional flows component that does seek to optimize ecosystem conditions ecologically stressful periods of drought (Delta ISB 2015).

Quantifying and communicating information on ecosystem flow components (i.e., species vs. water quality) would improve management and understanding system management within the Delta and its watershed (Gartrell et al. 2017). In a recent report, Gartrell et al. (2017) determined that in more recent years, the amount of water designated for ecosystem purposes has increased significantly according to DWR data, however they also highlighted the fact that uncaptured Delta outflow – often considered water for ecosystem purposes – is required to meet water quality control criteria and protects in-Delta water use and south Delta water exports from salinity intrusion. As such, implementation of an accounting system that provides information and clarity regarding the estimation of the water assigned for environmental uses would help improve management decisions and also help to reduce conflicts about interpretation of how the system works (Gartrell et al. 2017).

The Delta Ecological Flows Tool (EFT) is a decision support tool which integrates ecological considerations in evaluations of water management scenarios for the Sacramento River and Delta through integrating a range of representative ecological response variables with hydrological management tools (ESSA Technologies 2013). This tool, or something similar, could be further developed and calibrated to help managers implement functional flows in a way that also meets water quality and water supply needs for human users.

7.2 Restore Habitat

Hundreds of millions of public dollars have been invested to improve ecosystem health within the estuary (CDFW et al. 2014). Despite these expenditures and parallel advances in the ecological sciences, conservation objectives within the Delta and Suisun Marsh are not being met (Healy et al. 2016). The current portfolio of management actions within the Delta is not well balanced, with most action targeting objectives other than re-establishment of ecosystem elements above existing conditions. Figure 7-2 illustrates the project purpose, spatial extent, and existing land cover/land use of various types of conservation actions (i.e., restoration, mitigation, ecosystem service) as catalogued in the EcoAtlas database (Melcer and Anderson 2017). While the Delta has experience significant historical loss of geomorphic and ecological function, ecosystem restoration targeting these losses has been limited.



Source: Melcer and Anderson 2017

Figure 7-2. Breakdown of Past Habitat Improvement Projects in the Delta

The cumulative impacts and stressors of the late 19th and early part of the 20th century (Bay Institute 1998, Whipple et al. 2012) have generated a substantial need for re-establishment of ecosystems on the landscape. Conservation funds dedicated to ecosystem preservation or restoration have supported the acquisition of land, however, many currently remain in active agricultural production. Reconciliation ecology principles have been employed broadly on levees, floodways, and water conveyance infrastructure, with each being engineered to incorporate vegetation or managed analogue wetland ecosystems. Ecological restoration projects targeting geomorphic process and native vegetation communities which are not tied to mitigation (i.e., projects which contribute to ecological uplift beyond existing conditions) have accounted for 15 percent of ecosystem conservation projects in the Delta.

Current activities aimed at restoration and reduction of stressors are largely driven by mitigation requirements related to operation of the State and federal water projects, and maintenance of the flood management system of the Sacramento and San Joaquin River systems (see, e.g., Reasonable and Prudent Alternatives [RPAs] identified in both Long-Term Operations of the Central Valley Project and State Water Project; Fish Restoration Program Agreement). These mitigation activities are a vital component of an ecosystem restoration portfolio. However, they are designed to offset specific current day infrastructure impacts either in-kind, or designed to avoid jeopardy or critical habitat modification of endangered species. This means, that mitigation alone is unlikely to significantly address the legacy impacts and improve conditions beyond the current baseline (Palmer and Filoso 2009). Therefore, achieving the goals and objectives of the Delta Reform Act (ecosystem restoration which improves the existing conditions through re-establishment of complex and connected ecosystems, and recovery of endangered species) will require actions above and beyond offsetting the impacts of the water supply and flood control infrastructure operations and maintenance.

As described in the Climate Change Synthesis Paper, it is uncertain whether existing tidal marsh accretion processes in the Delta and Suisun Marsh will be able to outpace sea-level rise (Reed 2002, Drexler et al. 2009, Drexler 2011, Callaway et al. 2012). While limited information exists on expected trajectories of sediment dynamics within the Delta (e.g., Stern et al. 2016, Sankey et al. 2017), there is a need to better understand these processes in the context of expected changes in the hydrograph. Bates and Lund (2013) evaluated the suitability of different Delta islands for subsidence reversal given island elevations, accretion rates, mean sea level, probabilities of levee failure, lost agricultural revenues, and potential aquatic habitat up to 2100. Since then, new information on sea-level rise (California Ocean Protection Council 2017), island elevations (Wang and Ateljevich 2012), and probabilities of failure (DSC 2017) has come out for the Delta and Suisun Marsh. Further complicating subsidence reversal success, is the finding by Brooks et al. (2012) that the compaction of the Quaternary sedimentary column is also contributing to region-wide subsidence. Early research indicates that subsidence reversal practices can be effective (Sharma et al. 2016). Strategic implementation of subsidence reversal efforts will, over a longer time horizon, support the development of opportunities for tidal wetland restoration, and reduce the risk associated with levee failures (California Ocean Protection Council 2017, Nerem et al. 2018).

An important need for restoration planning is to have access to updated map layers of vegetation communities and existing conditions. In 2007, the State Legislature required the Department of Fish and Wildlife to develop and maintain a vegetation mapping standard for the state (Fish and Game Code Section 1940). This standard is manifested in the Survey of California Vegetation and implemented by the Vegetation Classification and Mapping Program (VegCAMP). VegCAMP focuses on developing and maintaining maps and the classification of all vegetation and habitats in the state to support conservation and management decisions at the local, regional and state levels. VegCAMP adheres to the National Vegetation Classification Standard and the dataset for the Delta was completed in 2006 and for Suisun Marsh in 2015. Continuous, adequate funding is crucial to ensure regular updates of VegCAMP in order to understand trends in vegetation communities over time.

7.3 Improve Water Quality to Protect the Ecosystem

Ecosystem water quality has important implications on the ecological health of the Delta. The Central Valley Regional Water Quality Control Board has identified the watershed as impaired for aquatic life by several specific contaminants. Nutrients, contaminants, dissolved oxygen, turbidity, and temperature all have effects on geomorphic and ecological processes, aquatic and terrestrial vegetation structure and function, wildlife and fish health, and resilience characteristics such as connectivity and diversity (Baldwin et al. 2009, Fong et al. 2016, Lehman et al. 2017). Further, reconnection of floodplains and re-establishment of vegetation communities can have important implications for municipal water quality, including increased levels of dissolved organic carbon (Chen et al. 2010). As tidal wetlands accrete sediment naturally in the system, restoration sites could experience an accumulation of sediment bound contaminants that may negatively affect anticipated outcomes. Key sources of constituents of concern include urban sources such as storm water and wastewater discharges, and agricultural dischargers (Lund 2016). Currently, State and Regional Water Resource Control Board programs and policies are in place to address these issues.

Expansion of acoustic and optical instruments deployed in the Delta over the past decade has greatly improved understanding of how tidal variability affects flow and transport of constituents, how the first flush at the beginning of the wet season delivers sediment and other constituents that affect water quality, and how sediment supply and turbidity are critical for ecosystem health (Fichot et al. 2016). Advances in understanding nutrient dynamics and their role in the altered food-web, aquatic water weeds, harmful algal blooms, and water clarity have been made through deployment of modern sensor technologies and networks (Schoellhamer et al. 2016).

Significant water quality improvements are expected from upgrades at Sacramento Regional Wastewater Treatment Plant through reduction of nitrogen and nutrient levels discharge effluent. A collaborative investigation, Operation Baseline, is underway by the US Geological Survey, SFEI, and multiple university partners in an effort to quantify current and post project conditions as they related to water quality and potential implications on food web function.

The Delta Smelt Resiliency Strategy (Smelt Resiliency Strategy) is a science-based document that has been prepared by the State of California (Natural Resources Agency) to address immediate and near-term needs of delta smelt. The Smelt Resiliency Strategy includes an action for the State to fund entities such as the Sacramento Stormwater Quality Partnerships and local governments whose stormwater discharges into the Delta, to implement improvements that will further reduce contaminant loading. The proposed 2017-18 budget by Governor Brown includes funding for the State Water Resources Control Boards Storm Water Grant Program to help fund dry weather and stormwater water runoff projects.

7.4 Prevent Introduction of and Manage Nonnative Species Impacts

Non-native species have significant impacts on multiple aspects on the Delta ecosystem. These include effects on the terrestrial and aquatic vegetation community structure, impacts on water quality, and direct and indirect effects on native species (Boyer et al. 2012, 2015, Delta ISB 2015). Given the widespread distribution and sheer number of nonnative species which currently inhabit the Delta, it will not be possible to eradicate these species from the Delta (McDonald et al. 2016). Management of nonnative species will need to focus on preventing new invasive species from colonizing the Delta to the extent possible and attempting to prevent already established invasive species from expanding their range within the Delta. Although, habitat restoration and enhancement efforts are focused on creating habitat for native species, they may often also likely benefit nonnative fish (Nobriga and Feyrer 2007). Conversion of terrestrial habitat to shallow aquatic habitat creates new open areas that could be potentially colonized by aquatic weeds such as egeria (Durand et al. 2016) or invasive bivalves like

Potamocorbula. It will likely be very challenging, if not impossible, to allow native species to access enhanced or newly restored habitats, while selectively precluding their use by invasive species, considerations for habitat restoration and enhancement planning need to take into consideration the very likely probably that the project will be directly affected by invasive species.

Many historical changes to the Delta, such as timing and volume of flows, salinity levels and other water quality changes, and reduction and shifting of habitat, have made the Delta more hospitable to certain non-native species like the largemouth bass, sunfishes, Mississippi silverside, and other alien species (Moyle et al. 2013, Moyle and Bennett 2008, Baxter et al. 2010). All major aquatic habitats in the Delta and Suisun Bay have been affected by invasive species, which has negatively impacted native fish species (Mount et al. 2012:24). With respect to invasive aquatic vegetation, the total invaded area of submersed and floating aquatic vegetation in the Delta increased by 60%, from 7,100 acres to 11,360 acres from 2008 to 2014 (Ta et al. 2017). Going forward, as Section 6 of the Climate Change Synthesis Paper described, non-native species are likely to fare better than native species.

For successful invasive aquatic vegetation management, clear identification of the desired outcome, timing, prevention, early detection, rapid response, and eradication or control are required (Anderson 2005, Williams and Grosholz 2008). Combating non-native species in the face of climate change will require increased efforts from agencies currently responsible for addressing non-native species. As the Climate Change Synthesis Paper emphasizes, early detection and monitoring of new non-native species will be crucial to stopping new species from spreading in the Delta because it is easiest to eradicate non-native species when they first begin to colonize a habitat (Rahel and Olden 2008). Increased coordination and sharing of resources among entities involved in invasive species management will also be vital to stopping the spread of these new species (Hellmann et al. 2008).

Nonnative fish species such as striped bass have been shown to predate on native salmon and smelt, however data indicate that they predominantly feed on other nonnative species, because those are more common and most fish predators are opportunistic feeders (Grossman 2016). Targeted removal of species such as striped bass is unlikely to reduce predation mortality for native species though since the most likely outcome would be a compensatory increase in abundance of a competing predator (Grossman 2016).

Much remains to be understood about the role invasive aquatic vegetation plays in altering water quality, nutrient levels, sedimentation, and ecological communities. Documented cases of herbicide resistance, which have been observed in other states such as Florida, call for innovative solutions.

The lack of permanent funding remains a barrier in the creation of a long-term monitoring and control program. For example, hyperspectral remote sensing has been funded only for selected periods of years, and future sustained funding remains uncertain. In addition, programs critical for rapid response and eradication have faced budget cuts in recent years (Ta et al. 2017).

7.5 Improve Hatcheries and Harvest Management

As the construction of dams over the past century disconnected spawning habitats many native fish species populations have declined, and harvest plans and hatchery programs have been developed (CDFW 2010). There is considerable debate on the conservation benefits of hatcheries. They may contribute to the survival of species such as salmonids, but hatcheries also affect the genetic recovery of these species (NMFS 2014, Le Luver et al. 2017). In the long term, functional flows, restoration of floodplain and rearing habitat, and connectivity to spawning habitats are of the utmost importance for species viability and genetic resilience. In the interim, effective management of artificial propagation programs and assurance colonies is critical to limit the genetic effect of hatcheries on naturally spawned populations and to ensure persistence of existing salmonid species and races.

Efforts to improve hatchery and harvest management do not directly influence Delta habitat restoration, enhancement, and restoration efforts, however, they both are important management tools to help protect and promote recovery of salmon populations. Many areas of uncertainty remain as identified by the California Hatchery Scientific Review Group (HSRG). These include determining reproductive success of hatchery- and natural-origin salmonids spawning naturally, and determining how genetic differences contribute to any differences in these success rates. Other information needed is to determine the effect that hatchery-origin salmonids have on natural-origin salmonids through direct competition, predation, spreading diseases, and other effects. Another area of research is how increased domestication of hatchery-origin fish may lead to decreased fitness and how these negative effects can be avoided.

The HSRG also called for the development of Hatchery and Genetic Management Plans (HGMP) for each hatchery program in California; the intent of the HGMPs is to determine how hatchery management strategies can be implemented in a way that also ensures the protection and recovery of wild-origin salmonids. Some HGMPs have been completed, but many others remain incomplete.

Hatchery goals for anadromous fish currently focus on ‘mitigation’ and are assessed by the number of juvenile fish reared and released (California HSRG 2012). While the number of juvenile fish, and ultimately their returning number, is important, the genetic integrity of species adapted to specific conditions is also important for their survival. As the proportion of hatchery-bred fish has increased, there has been genetic introgression of maladaptive genetic changes into species such as naturally spawning winter-run Chinook salmon (*Oncorhynchus tshawytscha*) (Myers et al. 2004, Araki et al. 2008). Such introgression may reduce overall fitness (Myers et al. 2004, Araki et al. 2008), including in wild-origin steelhead populations (NMFS 2009). The Ecosystem Synthesis Paper contains recommendations for how measures to support more effective hatchery management should be implemented to help support recovery of wild, self-sustaining populations of salmon.

8. Implications for Protection, Restoration and Enhancement of the Delta Ecosystem

The prior sections of this paper summarize key approaches to natural resource management as they relate to establishing ecological resilience in the context of a rapidly changing climate. Those sections review the best available science within focused subject areas covered in this paper. The subject areas addressed in this paper were identified because of their potential influence on achieving the coequal goals and relevance in amending Chapter 4 of the Delta Plan. This section summarizes and discusses the implications of the preceding science synthesis relative to the protection, restoration, and management of the Delta ecosystem. These implications provide the basis for the considerations included in Section 9, Considerations for Amending Chapter 4 of the Delta Plan.

1. Re-establishment of a healthy and functioning Delta ecosystem, through restoration, protection and enhancement could provide significant social benefits.

   Because of these social benefits, meaningful consideration of enhancing the Delta as a place should include a suite of activities that would improve the natural conditions for the region's communities. The benefits that society should expect from landscape-scale restoration in the Delta broadly fit into four categories: ecosystem services, economic benefits, social benefits, and cultural/psychological benefits.

2. Specific ecosystems and ecological functions can be viewed as goods and services which provide benefits to humans.

   Economic frameworks enable monetization of goods and services with the intent of increasing the relevance of ecological value in forums dominated by economic rationales. In the Delta ecosystem market-based ecosystem service implementation is challenged, because ecosystem services frameworks are not well suited to address the uncertainties associated with restoration of complex ecosystems and the broadening definition of restoration and the activities which are implemented under the "restoration" umbrella leads to the valuation of systems that do not result in the recovery of self-sustaining ecosystems.

3. Many of the region's and State's enterprises are supported by the Delta and would be improved by a healthy Delta ecosystem.

   These enterprises include recreation, commercial fishing, agriculture, and industry. Indirectly, a healthy Delta ecosystem would support service industries and real estate in the Delta through offering enhanced natural amenities. The benefits of protecting, enhancing, and restoring the Delta would include improving environmental conditions for some of California's most environmentally vulnerable populations. This would be a significant step toward greater environmental justice. These communities would benefit from the concomitant benefits of restoration to human health and well-being. In addition to these benefits, the Delta is an important cultural resource for California's tribes and other communities.

4. While restoration in the Delta would in theory generate social benefits, realizing these benefits would require conscious, coordinated, and collaborative planning.

   Project proponents cannot take societal benefits of protecting, enhancing, and restoring the Delta ecosystem for granted. A restoration project without public access likely will not benefit the recreation economy. A reconciliation project that maintains intensive agricultural practices likely will not improve water or air quality. A salmon restoration plan that excludes tribal actors may further alienate the tribes from an important cultural resource. However, if human benefits are considered a priority, restoration activities can be successful for both society and the ecosystem. This approach requires that Delta scientists and agencies begin to give social benefit of restoration activities the same level of rigorous consideration as already is given to ecological benefits.

5. The protection, restoration, and enhancement of the Delta ecosystem requires a comprehensive and balanced portfolio of approaches to fully support regional biodiversity.

   These approaches can be based on biology preservation of high quality existing ecosystems and ecosystem restoration, and augmented through reconciliation ecology and enhancing biodiversity on working lands where restoration is not possible. Success will require science efforts which provide clear and accurate information on the ability of each approach (and practices within each approach) to comprehensively support biodiversity, and policy, planning, and implementation which carefully align approaches with desired ecological outcomes.

6. A key overarching conservation target for the Delta is ecological resilience.

   Restoration of resilient ecosystems, (i.e., ecosystems that have the ability to absorb change and persist after a perturbation) is of heightened importance in the context of a rapidly changing climate. Achieving resilience at the project, sub-regional, and landscape scale requires careful planning, design, and implementation of actions that address issues of connectivity, complexity, redundancy, and scale. Issues of connectivity include restoration of physical (e.g., hydrology and sediment transport) and biological (e.g., movement of propagules, fish, and wildlife) connections between bay and tidal marshes, as well as between channels and floodplains. Incorporation of these considerations allows for ecological processes along these elevational gradients to be restored, and transport of sediments and nutrients to marsh- and floodplains, which promotes productivity and maintenance of elevation in the face of sea-level rise.

7. Sub-regional opportunities and constraints vary and should inform the approaches to natural resource management at the sub-regional and project scale.

Landscape position is a strong determinant of restoration potential and ecological potential given characteristics such as elevation, hydrology and tidal influence, and constraints such as subsidence and urban land uses. Constraints on where ecosystem restoration approaches are feasible heighten the importance of these locations. These considerations should inform tradeoff and prioritization analyses and specific project design. This requires analyses at a sub-regional and landscape scale.

8. The development of science-based, measureable, and time bound objectives are an important step in the achieving coordinated and effective ecological goals – further they are a requirement of the Delta Reform Act of 2009. Given that the Delta is one of the most studied ecosystems in the world, rich scientific and conservation planning information exists to support the development of comprehensive objectives which support achieving the ecological goals of the Delta Reform Act of 2009.

9. Advances in science across multiple disciplines support and have specific implications for the 5 core strategies identified in the 2013 Delta Plan.

Table 8-1 summarizes the specific findings related to the core strategies, which were discussed in detail in section 7.1 through 7.5.

Table 8-1. Summary of Implications from Improved Scientific Understanding on Delta Plan Core Strategies

Core Strategy	Key Findings
Delta Flows	• Restoring components of the natural flow regime is a crucial aspect of improving ecosystem health and function within the Delta and its watershed. • The SWRCB (2017) provides a scientific basis and approach for achieving re-establishing important aspects of the flow regime. It describes approaches which address issues of temperature management, tributary, Delta outflow, and within Delta flows. • The requirement to balance reservoir operations for water supply, flood management, and maintaining suitably cool water for salmon spawning and adult salmon holding conditions is currently a major constraint on achieving a full suite of functional flow components for ecosystem health. • Addressing hydrologic (longitudinal and latitudinal) connectivity combined with restoration of components of the flow regime would contribute to ecological recovery of the Delta while minimizing tradeoffs with consumptive human uses • Implementation of an accounting and system that provides information and clarity regarding the estimation of environmental water would improve management decisions and reduce conflicts around system operations.

Table 8-1. Summary of Implications from Improved Scientific Understanding on Delta Plan Core Strategies (contd.)

Core Strategy	Key Findings
Habitat Restoration	• A comprehensive range of approaches is needed to manage ecosystems on an altered and changing landscape – these include presevation of existing areas, process-based ecosystem restoration, development of analogue habitats in urban and working lands. • Current natural resource management approaches are not well balanced within the Delta. Process-based ecosystem restoration is limited. A significant component of the conservation actions have focused on development of analog ecosystems developed on principles similar to those described under reconciliation ecology. Many of these lands remain in agricultural production (e.g., 54% in Suisun Marsh; 67% in the legal Delta). • Achieving the goals and objectives of the Delta Reform Act (environmental variability, connectivity, process-based recovery of ecosystems and species populations) will require actions that address legacy ecosystem loss above and go beyond offsetting the impacts of the water supply and flood control infrastructure operations and maintenance through mitigation. • It is uncertain whether tidal marsh accretion in the Delta and Suisun Marsh will be able to outpace sea-level rise, with implications for existing tidal marsh, as well as for future restoration. • Strategic and near-term implementation of subsidence reversal efforts will support the development of opportunities for tidal wetland restoration. Early research on managed wetland accretion rates indicates that such efforts will not work across the deeply subsided areas of the Delta (e.g., central and western Delta), therefore, islands require evaluation given current elevation and sea-level rise projections. • Given the uncertainties associated with activities described under Section 3 (Natural Resource Management Approaches) projects, adaptive management, as called for in the Delta Reform Act will be an important component for implementing actions related to habitat restoration. The Delta ISB determined that it was a struggle to fully implement adaptive management in the Delta for restoration projects for a number of reasons, including lack of funding for monitoring, current culture of management in the Delta, lack of priority, an inflexibility decision-making, regulations, and permitting. • A critical information need is the routine update of Department of Fish and Wildlife's VegCAMP land cover and land use dataset under the direction of Department of Fish and Wildlife using vegetation mapping standards as directed by State Legislature (Fish and Game Code Section 1940). These data provide detailed understanding of existing conditions within the Delta, and provide the foundation for analyses in ecological science, conservation planning, and environmental permitting.

Table 8-1. Summary of Implications from Improved Scientific Understanding on Delta Plan Core Strategies (contd.)

Core Strategy	Key Findings
Water Quality	• Environmental water quality has important implications on the success of many aspects of ecosystem restoration, including re-establishment of physical and ecological processes, vegetation, and fish and wildlife populations. • Improving environmental water quality will require actions related to flows, restoration project sighting and design, and mitigation of point and non-point source inputs from both urban (i.e., municipal, industrial, etc.) and agricultural sectors. • Advances in remote sensing and in-situ techniques have increased understanding of water quality dynamics and efforts to integrate water quality considerations in restoration planning are needed. • Current upgrades to Sacramento Regional Wastewater Treatment Plant and ongoing scientific investigations (e.g., Project Baseline) will provide key insights into the effects of water quality constituents on food web function, and inform the prioritization and development of future system improvements.
Non-native Species	• Non-native species are significant stressors on native biota given the impaired state of the Delta ecosystem. • Comprehensive eradication of non-native species within the Delta and its watershed is not possible given the sheer number of non-native species, and the geographic scope of non-native species distribution. • Efforts to manage non-native species require focus on the prevention of new introduction, and management of highly *invasive* non-native species which have significant impact on the structure and function of the ecosystem (e.g., aquatic invasive weeds, *Arundo donax*, *Lepidium latifolia*). • Actions which target ecosystem resilience through re-establishment of functional flows, geomorphic processes such as floodplain inundation, and improvements in water quality may indirectly contribute to non-native species management efforts. These actions may also be subject to the colonization of non-native species, especially in a rapidly changing climate, requiring monitoring and adaptive management. • Management of non-native species requires increased coordination and funding prioritization across agencies within the Delta and its watershed.
Hatcheries and Harvest Management	• Effective management of artificial propagation programs and assurance colonies are critical interim tools while re-establishment of functional flows, restoration of floodplain and rearing habitat, and connectivity to spawning habitats are established. • Uncertainties regarding the impacts of hatchery-origin on natural-origin populations is a key area of research. • California Hatchery Scientific Review Group's recommendation of development and implementation of Hatchery and Genetic Management Plans remains a critical objective in addressing protection and recovery of wild-origin salmonids.

9. Considerations for the Delta Plan Amendment

The Delta Plan includes 14 regulatory policies, a suite of recommendations, and performance measures. Amendment of Chapter 4- Protect, Restore, and Enhance the Delta Ecosystem could include changes or additions to the narrative text, new or refined recommendations and/or policies, new or refined performance measures, or a combination of all three. While recommendations are not regulatory policies, they can help inform activities and emphasize priorities. Performance measures help evaluate the response to management actions and the factors that may influence achievement of the coequal goals, and include metrics, baseline conditions, and targets for desired future conditions.

The implications of the preceding science synthesis relative to the protection, restoration, and management of the Delta ecosystem yield a sufficient basis from which to consider changes to Chapter 4 of the Delta Plan. These implications were discussed in Section 8, Implications for the Protection, Restoration, and Management of the Delta Ecosystem. Periodic updates or amendments to the Delta Plan are intended to support successful achievement of the coequal goals by addressing factors such as new or changed conditions in the Delta and its watershed, best available science, changes to pertinent state policies or institutions, or others. The following discussion presents initial high level considerations for amending Chapter 4 of the Delta Plan in light of the scientific information and implications presented herein.

1. The findings of this synthesis paper do not foundationally change the core strategies of Chapter 4 of the Delta Plan. In combination with the findings of the Climate Change paper, they do heighten the importance of re-establishment of resilient ecosystems which provide benefits to both humans and native species. Discussions within Chapter 4 should explicitly include landscape elements which promote resilience (i.e., targeting increases in connectivity across ecosystem components, complexity, redundancy, and patch size through protection, ecosystem restoration, and enhancement).

2. Recognition of the need to integrate the human dimension in achieving the co-equal goals of the Delta Reform Act of 2009 have heightened since the adoption of the 2013 Delta Plan. Discussion of the social benefits of a healthy Delta ecosystem are currently limited in Chapter 4 of the Delta Plan. Discussions of the benefits that society should expect (ecosystem services, economic benefits, social benefits, and cultural/psychological benefits) need to be included and better integrated within the Delta Plan. Opportunities to address human vulnerabilities and issues of environmental justice should be identified. Plan policies and recommendations should be reviewed for opportunities to incorporate considerations of social as well as ecological benefits in restoration planning and implementation. Key information gaps and areas of research requiring prioritization should be identified.

3. The Delta is subject to sea-level rise, subsidence, and urbanization, all of which constrain where ecosystem restoration can be implemented versus other conservation actions. Updates to Chapter 4 narrative should provide clear and accurate characterization of the ecological potential of various approaches to natural resource management. Discussions within Chapter 4 could provide the planning and implementation guidance to achieve coordinated and integrated protection, restoration, and enhancement actions which optimize ecological outcomes (Recommendation ER R2). This includes review of priority habitat restoration areas that support ecosystem restoration in the context of tradeoffs due to sub-regional constraints, opportunities, and future conditions (Policy ER

P3, Recommendation ER R2). Policies and recommendations could be reviewed for opportunities to support these considerations.

4. Chapter 4 could provide discussion of the prioritization of ecological restoration as a continued core strategy. It can also discuss opportunities to augment this approach through the creation of analogue ecosystems, or opportunities to support biodiversity on working lands, and provide guidance on the implementation of these approaches. Specifically, the value of these approaches within areas with urban and industrial land uses, and areas subject to land subsidence within the interior and western Delta where it can be combined with other objectives (e.g., carbon sequestration, flood management).

5. Chapter 4 could consider providing guidance on sub-regional opportunities and constraints. An important component of this discussion is the identification of sub-regions where subsidence reversal practices on working lands, such as wetland creation or a switch from row crops to rice cultivation. The concept, offer a crucial, time-sensitive, opportunity to create substantial amounts of suitable intertidal habitat in the future and could form a critical part of ecosystem adaption to climate change (Policy ER P2, ER P3, Recommendation ER R2). Policies and recommendations could be reviewed for opportunities to support these considerations.

6. Recovery and conservation planning efforts have established specific objectives and decades of restoration planning support the development of science based, measurable, and time bound objectives. An understanding of the magnitude of landscape-scale ecological change required to achieve the ecological goals of the Delta Reform Act of 2009 would support coordination and alignment of sub-regional conservation strategies. The Delta Plan could provide this important component of conservation planning through discussion and review and refinement of Performance Measures.

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