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*The State of Bay–Delta Science* 2016 (SBDS) is a collection of papers that summarizes the scientific understanding of the Sacramento–San Joaquin Delta, emphasizing progress made during the past decade.It builds on the first SBDS edition (Healey et al. 2008). Paper topics for this edition address the most relevant scientific issues in the Delta identified by senior scientists and managers. The topical papers cover issues ranging from contaminants in the Delta to levee stability, and from Delta food webs to recent discoveries about salmon migration. These papers are written for a scientific audience. Two additional papers, one describing the challenges of managing water and ecosystems in the Delta and another that discusses policy implications of the recent scientific findings, are written for a general audience. The papers will be published in at least two issues of *San Francisco Estuary and Watershed Science* and will be available as a set electronically.

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SPECIAL ISSUE: THE STATE OF BAY–DELTA SCIENCE 2016, PART 1

# The State of Bay–Delta Science 2016: An Introduction

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## ABSTRACT

*The State of Bay–Delta Science 2016* (*SBDS*) is a collection of papers that summarizes the scientific understanding of the Sacramento–San Joaquin Delta, emphasizing progress made during the past decade. It builds on the first *SBDS* edition (Healey et al. 2008). Paper topics for this edition address the most relevant scientific issues in the Delta identified by senior scientists and managers. The topical papers cover issues ranging from contaminants in the Delta to levee stability, and from Delta food webs to recent discoveries about salmon migration. These papers are written for a scientific audience. Two additional papers, one describing the challenges of managing water and ecosystems in the Delta and another that discusses policy implications of the recent scientific findings, are written for a general audience. The papers will be published in at least two issues of *San Francisco Estuary and Watershed Science* and will be available as a set electronically.

## KEY WORDS

Sacramento–San Joaquin Delta, state of science, ecosystem, hydrodynamics, water supply, management challenges

## INTRODUCTION

*The State of Bay–Delta Science* (*SBDS*) is a synthesis of the current scientific understanding of the Delta, emphasizing progress made on key research questions and remaining knowledge gaps. The first edition of *SBDS* (Healey et al. 2008) provided a system-wide baseline for the state of scientific knowledge of the system, and a reframing of the interaction between science and policy. In this new edition, various authors summarize the state of science in relation to a dozen issues in the Delta. Paper topics were chosen after surveying senior scientists and managers in the Delta to identify the most topical science issues. This introductory essay is intended to set the stage for the topic-focused papers that follow by providing a brief description of the Delta and its ecology, linking issues to individual papers where appropriate. In addition, a previously published paper (*Luoma et al. 2015*) describes the challenges facing water and environmental managers in the Delta and a final paper (Healey et al., submitted) will synthesize the main advances in scientific understanding over the past decade and their policy implications. The primary audience for these papers is managers and policy-makers, whereas scientists are the primary audience for the topic-focused papers. The papers will be published among at least two issues of *San Francisco Estuary and Watershed Science* but will be accessible as a set electronically.

## THE DELTA

The Delta of the Sacramento and San Joaquin rivers is the hub of the statewide water redistribution system, one of the largest waterworks in the world, that is managed to achieve flood control, reliable water supply, and environmental conservation (Figure 1). This system, with the Delta at its heart, feeds the country's most productive agricultural sector, and is critical to much of the rest of California's $2.2 trillion economy, the eighth largest in the world (Luoma et al. 2015). Managing the Delta to prevent floods and meet the ever-changing demands for water is an ongoing problem of great complexity (Luoma et al. 2015).

## THE PHYSICAL DELTA

Prior to 1850, the Delta was a 700-square-mile complex of low islands, shifting channels, large woody debris, and tule marshes (Whipple et al. 2012) that bedeviled early settlers but was the natural habitat of many species now in trouble. The historic wetlands and river floodplains have been transformed into a patchwork of islands protected by 1800 km of levees (Figure 2) that are used primarily for agriculture with some residential property. Only about 3% of the original marsh remains (Whipple et al. 2012). Before levee construction, the aquatic and terrestrial ecosystems of the Delta interacted strongly, and this interaction was critical to the ecology of native species (Wiens et al. 2016; Brown et al., forthcoming; Perry et al. 2016). The levees have isolated the aquatic and terrestrial ecosystems, contributing to the problem of native species conservation. But the levees protect valuable farmland, and are part of the infrastructure of the water export system (Luoma et al. 2015). Furthermore, many island surfaces have subsided several meters (Moore and Shlemon 2008) so that breaching the levees would create ponds, which are attractive habitat for non-native species, rather than wetlands beneficial to native species (Grossman 2016, this volume; Brown et al., forthcoming).

Freshwater flowing through the Delta forms a hydraulic barrier to the intrusion of seawater from San Francisco Bay (MacWilliams et al., submitted). If river flows drop too low, the hydraulic barrier is weakened and circulation driven by the tides can carry salt, dissolved organic material, bromide, and other chemicals to the water supply diversion points in the Delta (Schoellhamer et al., submitted; Deverel et al., submitted). Reservoir releases are crucial to maintaining the hydraulic barrier in summer and fall when rainfall is limited. During prolonged droughts, however, there is increased risk that reservoir supplies will not be sufficient to maintain the flows that keep salinity away from the interior Delta (Dettinger et al., submitted). Droughts (and floods) are a feature of California's climate (Dettinger et al., submitted). Both unprecedented droughts and unprecedented floods are potential consequences of climate change, and both increase the risk of catastrophic failure of the levee system. The physical configuration of the Delta is both fragile and critical to the present program of water exports. It may also be a serious obstacle to conserving and restoring native species in the Delta.

## THE ECOLOGICAL DELTA

The Delta ecosystem and the surrounding region supports more than 750 species of plants and animals. It is one of 25 international biodiversity hot spots listed as highest priority for conservation (Myers et al. 2000). The Delta provides year-round habitat for some species and important feeding and nursery habitat for others. Most ecological studies of the Delta have focused on the aquatic ecosystem, because of the obvious conflict between water exports and conservation of this ecosystem. Delta Smelt (*Hypomesus transpacificus*), has been a focal species in conflicts over water exports and, despite major changes in water allocation intended to benefit them, smelt are nearing extinction (Moyle et al. 2016). Four races of Chinook Salmon (*Oncorhynchus tshawytscha*) and Steelhead Trout (*Oncorhynchus mykiss*) move through the Delta on their seaward and spawning migrations. Acoustic tagging of smolts is revealing important details of where and when young salmon suffer mortality


**Figure 1** Map of California with Delta inset showing major water redistribution infrastructure and key landmarks



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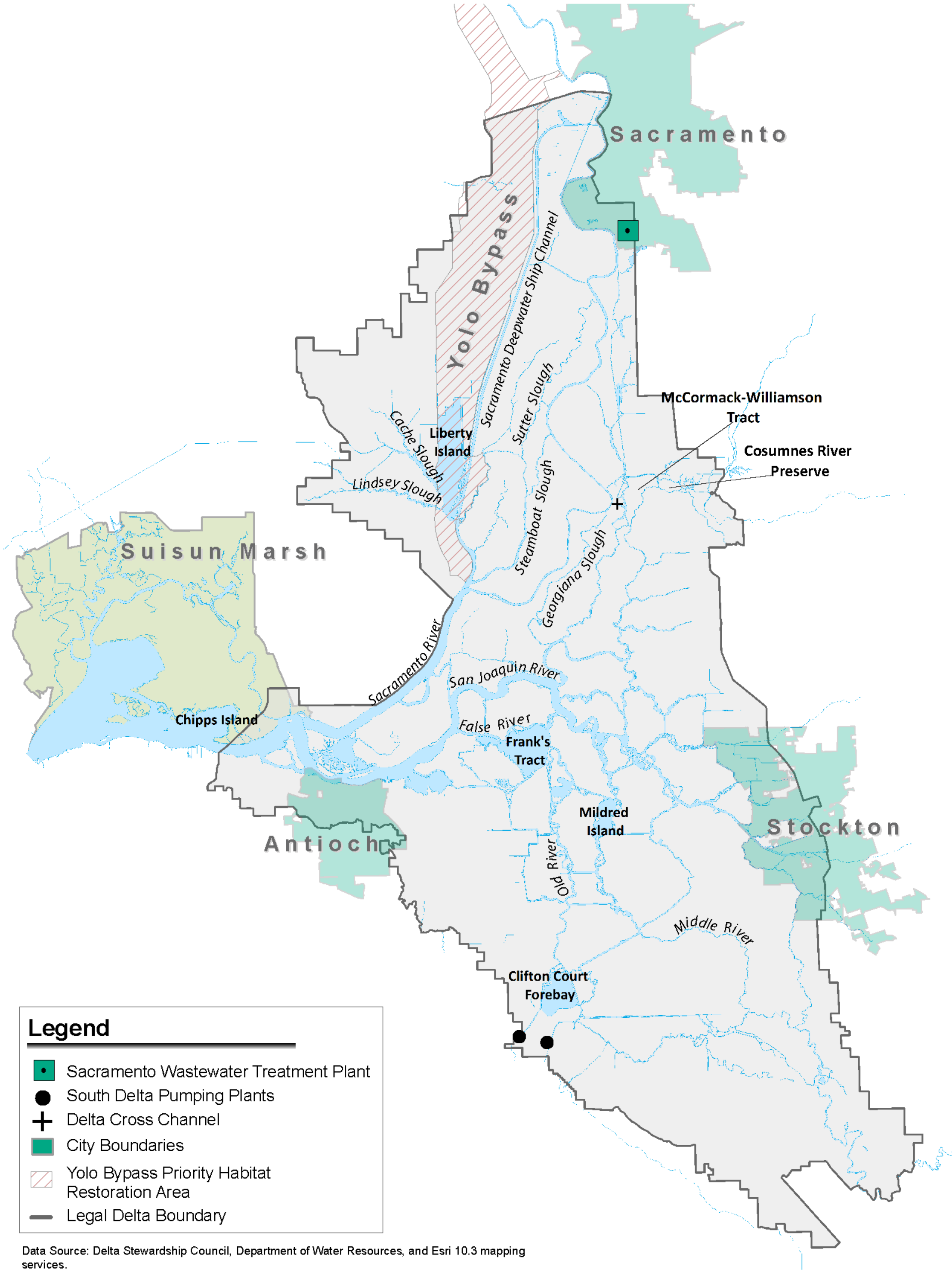


**Figure 2** Map of the Delta showing the principal river channels, important landmarks, and major cities on the Delta margin

in the Delta (Perry et al. 2016). Yet these species continue to decline. There has also been considerable study of wetland ecosystems and some study of upland ecosystems (e.g., Whipple et al. 2012; Golet et al. 2003), which further emphasizes the dramatic changes in ecosystem structure and function that have occurred in the past 200 years (Wiens et al. 2016). Conservation concern is focused on native species and more than 102 species in the Delta are of special concern.[1] All Delta ecosystems are highly invaded by alien species so that the majority of individuals or biomass found in any location are alien (Luoma et al. 2015; Brown et al., forthcoming). Cohen and Carlton (1998) described the Delta as the most heavily invaded estuary in the world, and Orsi and Ohtsuka (1999) described the zooplankton community of the Delta as essentially East Asian. A number of alien species, like Striped Bass (*Morone saxatilis*), were deliberately introduced and have become important components of the recreational economy of the Delta. Others, like the invasive reed, *Arundo donax*, are mainly a nuisance. Still others, like the overbite clam, *Potamocorbula amurensis*, have profoundly affected the productivity and food webs of the Delta (Brown et al., forthcoming). The presence of so many alien species is a major obstacle to recovering native species.

Historically, aquatic food webs were probably sustained by detrital organic carbon from the extensive and highly productive tidal marshes. The construction of leveed islands together with multiple species invasions have led to dramatic changes in open water food webs. Details of these changes are still being worked out (Brown et al., forthcoming) but it appears that shortages of suitable food may be an important contributor to native species decline. Invasive submerged and floating aquatic vegetation (Brazilian waterweed, *Egeria densa*; water hyacinth, *Eichhornia crassipes*) are also beginning to play an important role in Delta food webs with, as yet, uncertain consequences (Brown et al., forthcoming; Dahm et al., submitted).

In the early 2000s, four pelagic fish species—Delta Smelt, Threadfin Shad (*Dorosoma petenense*), Longfin Smelt (*Spirinchus thaleichthys*), and Striped Bass—declined abruptly in abundance, a phenomenon that became known as the Pelagic Organism Decline, or POD (Sommer et al. 2007). Analysis of potential causes of the POD showed that multiple stressors affected each species, and it was not possible to identify which were the most important. Water exports, which historically were believed to be the cause of native species declines, could not be singled out as the primary cause. Predation was considered to be the proximate cause of a great deal of mortality, but ultimate causes may have been changes in habitat configuration, reductions in available food, or exposure to toxic pollutants that made the species more vulnerable to predation.

Toxic pollutants are, perhaps, the most complex and least understood of the stressors. Many toxic substances enter the Delta from agriculture, industry, wastewater treatment plants, urban stormwater, and atmospheric fallout. Water samples from the Delta are sometimes acutely toxic, or cause behavioral or physiological impairment in test organisms. However, it is not yet possible to determine the degree to which chemical contamination contributes to species declines, in part because toxicity in the Delta is not routinely monitored (Fong et al., submitted). Understanding the sources, effects, and interactions of contaminants in the aquatic ecosystem remains a major gap in scientific understanding of the Delta.

## THE SOCIO–ECONOMIC DELTA

The Delta is not just an ecosystem, nor a water conveyance system, nor solely an economic engine. Rather the Delta is a place where all of these services come together and are at risk (See the 2009 Delta Reform Act). As the hub of the statewide water redistribution system (Figure 1), the Delta underpins the state's economy and is a component of the much wider water network that links the seven states of the Colorado River Pact and Mexico (Luoma et al. 2015). More than 570,000 people live in the urbanizing regions around the margin of the Delta and derive their livelihoods from the Delta or use the Delta for transportation and recreation (Figure 2). The Delta is a source of water to these people and millions more (Lund, submitted). This social dimension of the Delta is a critical consideration in every decision that affects the fate of the region. The Delta exists at many scales, therefore, from the local to the regional

1 *http://www.calwater.ca.gov/delta/species/index.html*, accessed April 18, 2016.



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to the national and international, and understanding the science of the Delta is important at all these scales (Wiens et al. 2016).

## SCIENCE OF THE DELTA

The first edition of *The State of Bay–Delta Science* (*SBDS*) began with seven shifts in perspective, changes in the way that scientists understood the Delta and water supply that had emerged in the decade before its publication (Healey et al. 2008). These changes in scientific understanding have profoundly affected the long-term vision for the Delta and the way that it is managed (Delta Vision Task Force 2008; Delta Stewardship Council 2010). A similar evolution in understanding has emerged in the 8 years since publication of the first edition and we expect our understanding of the Delta and California water will continue to evolve and change as new studies are conducted. *SBDS* will be a living document, updated from time to time as sufficient new findings accumulate and, in particular, as the effects of climate change become more apparent. Meeting the new and unprecedented challenges to water supply and ecosystem conservation that climate change will bring will require both an intensification of scientific effort and much better coordination and planning of Delta science. The papers that make up the second edition of *SBDS* represent one step toward an integrated and policy-relevant compilation of science in the Delta.

## ACKNOWLEDGMENTS

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