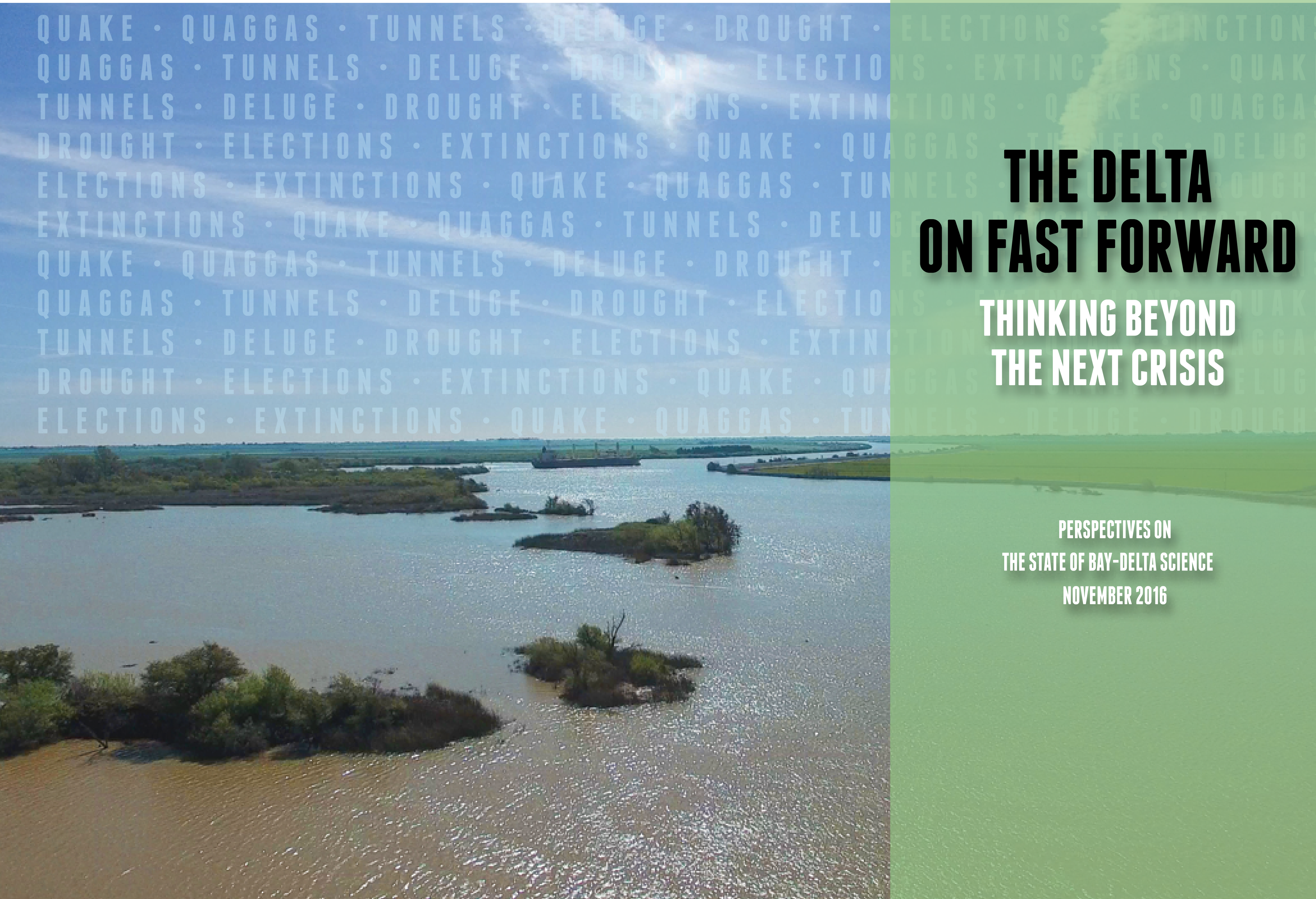
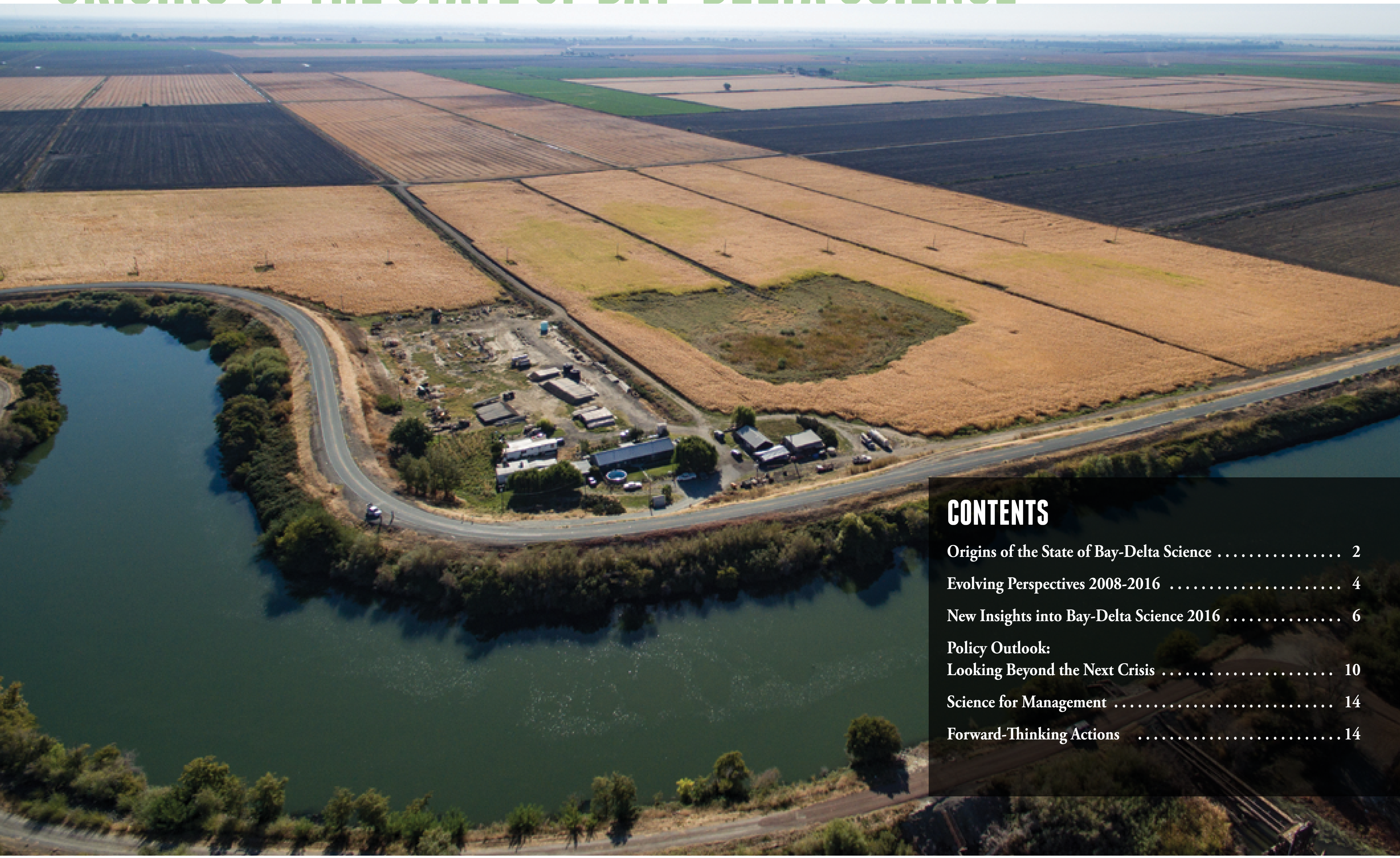



# THE DELTA ON FAST FORWARD

## THINKING BEYOND THE NEXT CRISIS

PERSPECTIVES ON
THE STATE OF BAY-DELTA SCIENCE
NOVEMBER 2016

# ORIGINS OF THE STATE OF BAY-DELTA SCIENCE



## CONTENTS



*Farms, levees, sloughs, shipping channels and subsidence co-exist on 1,600-acre Prospect Island, where restoration for fish benefits is also planned. Photo: Bird's Eye View*

## AN UNCERTAIN FUTURE

Planning for the future based on the past is the way we've always done things. Even when that didn't work, we often had the time, space, or ecological options to adjust. Or we were simply fortunate that responding on a crisis-by-crisis basis worked — at least for a while.

Global climate change is disrupting historic weather patterns. Likewise, stresses on both the human and natural world are mingling and mounting in ways that are pushing all living things to various brinks. Where in the past there might have been room to maneuver, or adapt, scientists agree that our window of opportunity is now compressed.

In the Delta — where so much is at stake in terms of water supply for millions of people, farms and food crops, fisheries, recreation, and habitats for threatened and endangered species — the sense of game change is palpable. For those who've spent their careers studying Delta species, tracking the movements of water parcels or plankton blooms or pesticides in sediments, trying to pinpoint this or that cause of this or that problem, the complexity of interrelated stresses on the ecosystem seems more apparent than ever. In a recent report on Delta challenges, scientists confirmed that the Delta is "a wicked problem" that cannot be solved but only managed.


In this 2016 review of what we've learned in Bay-Delta science since our review eight years ago, no one is mincing words. In a reality check, three top scientists reviewing a series of new journal articles on the state of Bay-Delta science — articles covering everything from the vulnerability of levees to nutrient dynamics to contaminant effects on ecosystem health — have come to one overarching conclusion: the Delta has changed irreversibly; in this context, we have to envision desirable possible futures and work to steer change in that direction.

## HISTORY OF THE SCIENCE

The first State of Bay-Delta Science (SBDS) report was published in 2008 by the CALFED Science Program. It synthesized the latest research and provided an emerging understanding of the estuary to inform policymaking. The report is now an established baseline of scientific understanding against which future findings and reports can be compared.

In 2009, the Delta Reform Act established the Delta Stewardship Council and named the Delta Science Program as the successor to the CALFED Science Program. With passage of the Act, the legislature implicitly acknowledged the multifaceted and complex nature of the Delta management problem. They further acknowledged the importance of "…providing the best possible unbiased scientific information to inform water and environmental decision making in the Delta."

This document highlights what Bay-Delta scientists have learned since the publication of the SBDS 2008. It explores the impact of the seven science perspectives put forward in the 2008 report, and how they may have contributed to the achievement of the Delta Reform Act's coequal goals of a reliable water supply and a healthy ecosystem in the context of protecting the Delta as a unique and evolving place.

In preparing the 2016 report, an editorial board chose topics based on science priorities identified by senior managers, policymakers, and scientists familiar with the Delta. The resulting SBDS 2016 comprises 15 peer-reviewed papers published in the journal *San Francisco Estuary and Watershed Science* (see back page).

Some of the papers update issues examined in 2008, such as water supply, levees, and food webs; others tackle issues that have since come to the fore, including increasing recognition of the influence of nutrients, contaminants, and predation on species declines, and new tools for measuring the interactions of multiple stresses.

One paper, a synthesis written by the editorial board entitled *Perspectives on Bay-Delta Science and Policy*, offers seven perspectives from SBDS 2016 and provides a related policy outlook. This document — *The Delta on Fast Forward: Thinking Beyond the Next Crisis* — summarizes the *Perspectives* paper for a general audience and also provides a list of forward-thinking actions for the future.

## EXECUTIVE SUMMARY

Delta science needs to push beyond its tendency to focus on short-term policy mandates and near-term crises. Taking a longer, 50-100 year viewpoint has been part of various planning exercises including Delta Vision. That kind of long-range thinking now needs to be more strongly incorporated into the whole Delta science and management endeavor. An appreciation of the changes that are coming, particularly those associated with climate change, needs to inform all our research and planning.

In the meantime, despite management actions that in some instances appear heroic, native fish continue to decline in the Delta. The food web has changed dramatically, new stressors are added daily to existing ones, and several native species are virtually extinct. While we must continue to try to shore up the Delta smelt, for example, it is time for serious debate about more radical alternatives to habitat restoration, including assisted relocation, assisted evolution, even perhaps cryopreservation (freezing of genetic materials). Agency mandates based on the past should not prevent us from taking actions that prepare us for a very different future.

The capacity of the Delta to absorb extremes of all kinds is declining. In the future, water managers will have to adjust to reduced and more variable inflows to the Delta and to less predictable sources of water supply. Sustaining a Delta ecosystem hospitable to native species will be much more difficult. In that case, it may become necessary to refocus on managing for novel plant and animal communities that provide desirable ecosystem services. Delaying action until the next crisis is upon us will greatly increase the risk and costs of failure.

# EVOLVING PERSPECTIVES 2008–2016


*Water primrose, the latest invasive plant to clog Delta waterways and alter the ecosystem. Photo: Bird's Eye View. Delta cartoon key page 9.*

## 2008 PERSPECTIVES
### State of Bay Delta Science 2008

| | |
|---|---|
| 1 | The Delta is a **continually changing ecosystem**. Uncontrolled drivers of change (e.g., population growth, changing climate, land subsidence, seismicity) mean that the Delta of the future will be very different from the Delta of today. |
| 2 | Because the Delta is continually changing, we cannot predict all the important consequences of management solutions. The best solutions will be robust but provisional, and will need to be **responsive and adaptive** to future changes. |
| 3 | It is neither possible nor desirable to **freeze the structure of the Delta** in its present or any other form. Strengthening levees is only one element of a sustainable solution and is not applicable everywhere. |
| 4 | The **problems** of water and environmental management **are interlinked**. Piecemeal solutions will not work. Science, knowledge, and management methods all need to be strongly integrated. |
| 5 | The capacity of the Sacramento-San Joaquin **water system** to deliver human, economic, and environmental services is likely at **its limit**. To fulfill more of one water-using service we must accept less of another. |
| 6 | **Good science** provides a reliable knowledge base for decision-making, but for complex environmental problems, even as we learn from science, new areas of uncertainty arise. |
| 7 | Accelerated climate change means that **species conservation** is becoming more than a local habitat problem. Conservation approaches need to include a broad range of choices other than habitat protection. |

## 2016 PERSPECTIVES
### State of Bay Delta Science 2016

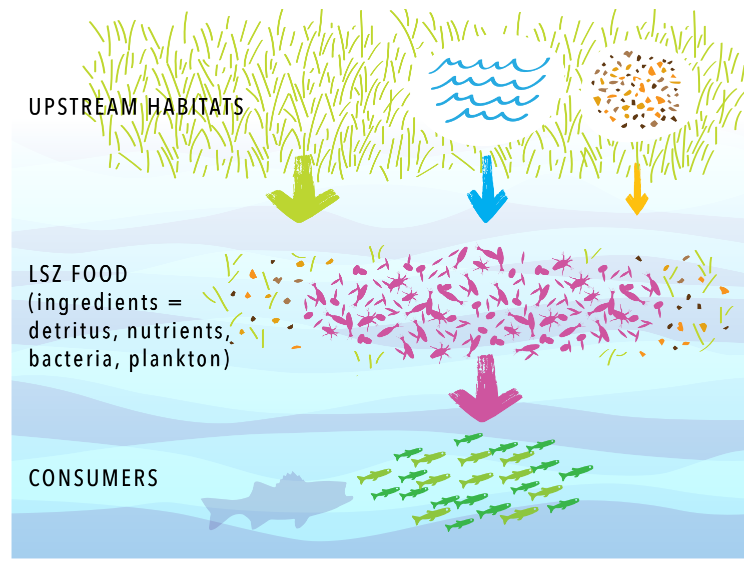
| | |
|---|---|
| 1 | **Nutrients** are important. Whereas in the past we considered nutrients to be relatively unimportant in Delta productivity, we now understand that the absolute and relative concentrations of different nutrients in the Delta can be drivers of Delta ecology, including inhibition of phytoplankton growth by ammonium and promotion of the expansion of invasive *Microcystis* and waterweeds. |
| 2 | Delta waters are contaminated. The complex **cocktail of contaminants** that enters the Delta from agriculture, urban, and industrial discharges has the potential to cause serious damage to the ecosystem and human health. |
| 3 | Aquatic food webs no longer sustain native species. **Food webs** in the Delta now bear little resemblance to those that supported communities of native organisms prior to European colonization. Driven by physical and chemical changes in the Delta and invasions by alien species, the aquatic ecosystem has gone through a regime shift that probably cannot be reversed. The present food web appears stable but is much less able to support native fishes than in the past. |
| 4 | Species declines are a result of **multiple stressors** acting together. There are few instances in which a single stressor can be identified as the primary cause of any species' decline. Effective conservation of aquatic species requires a holistic approach to improve habitat quantity and quality. |
| 5 | Future water management will be driven more by extreme events (of all types) than by long-term averages, even as those averages change. As California's climate changes due to global greenhouse gas emissions, more frequent and more **extreme storms and droughts** will occur. Management will have to restructure to respond to these changes. |
| 6 | Delta habitats work together as a landscape scale mosaic. The success of local restoration is dependent on what happens in adjacent habitats and vice versa. Any habitat restoration, therefore, has cascading effects that propagate far beyond the restored habitat. **Landscape ecology** provides a set of tools and concepts for identifying and taking account of these cascading effects. |
| 7 | The **situation for native species is dire.** The ecological regime shift coupled with the emerging effects of climate change in the Delta are creating conditions that will likely accelerate the current downward spiral of native species. This situation makes it urgent that the scientific foundations for new management responses be developed. |

# NEW SCIENCE INSIGHTS 2016

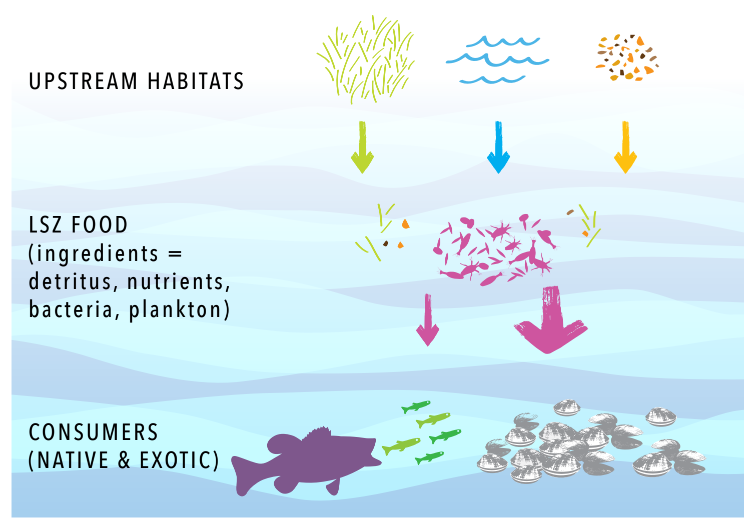
Chinook salmon fry, one endangered species present in many West Coast estuaries. Photo: Michael Wigle
INSET: A favorite food item of Delta smelt and other small fish, a copepod (about 1 mm in length) present in zooplankton. Photo: Robert Vogt

## FISH FOOD IN THE ESTUARY'S LOW SALINITY ZONE

### PRESUMED CONDITIONS 1900



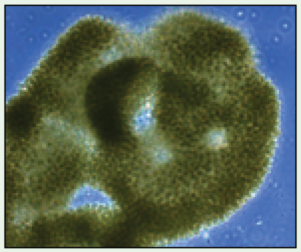

### OBSERVED CONDITIONS 2016



# NEW SCIENCE INSIGHTS

The following section expands on what we've learned since 2008 as described in the 2016 *Perspectives* paper and on page 4.

**NUTRIENTS GAIN IMPORTANCE** Nutrients in the water can spark or inhibit the growth of phytoplankton at the base of the Delta food web, depending on their type and concentration. Of particular interest now is discovering if and how nutrients may be promoting the development of blooms of cyanobacteria, especially *Microcystis*, and fueling the spread of waterweeds. High nutrient loads coupled with long water residence times may contribute to growth of these toxic and nuisance species.



*Microcystis. Photo: Kudela Lab*

Until recently, scientists thought other factors exerted more control over the Delta food web including grazing by the invasive overbite clam, water residence time, and turbidity. This view is now giving way to a more complex narrative that considers the various chemical forms of nitrogen, the sources of nutrients that enter the Delta largely via agricultural runoff and wastewater treatment plant discharges, and the roles of declining turbidity, changing hydrodynamics, and invasive species. A recent focus has been the presence or absence of high levels of ammonium and how this particular nutrient and other pollutants in wastewater affect blooms and the food web. Ongoing upgrades to the Sacramento Regional Wastewater Treatment Plant offer an opportune experiment for deepening this understanding.

**CONTAMINANT COCKTAILS** Delta waters are contaminated by agricultural, urban, and industrial discharges. Recent research has shown that Delta water is often acutely or sublethally toxic to a range of aquatic organisms. Contaminants likely played an important role in the rapid decline of several native fish species that began in the early 2000s (referred to as "pelagic organism decline," or POD). Contaminants alone or in combination with other variables can cause not only direct effects on organisms but also make them more vulnerable to predation or interfere with reproduction.

One focus of recent research has been the impacts of changes in pesticides used in agriculture in response to concerns about toxicity. The latest pyrethroid pesticides are highly toxic to invertebrates, notably to the very bees on which agriculture relies. New research suggests that pyrethroids, thought to be less persistent in the environment than the chemicals they replaced, persist longer in waterways when attached to sediments.

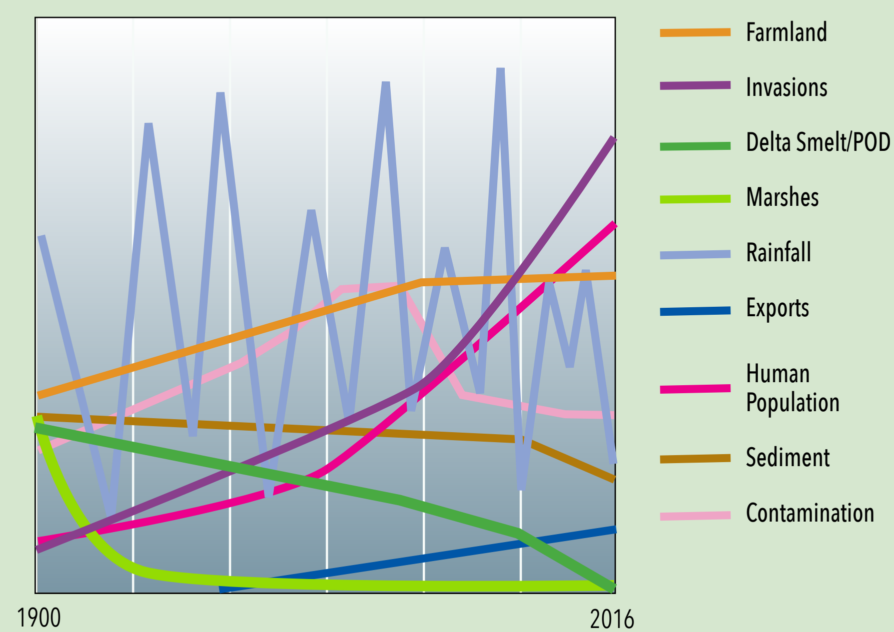
Contaminants such as pesticides aren't the only variable with impacts on organisms in the Delta, and scientists have been working to pinpoint the extent of influence of each variable. New research examining the relationship between POD species abundance and a range of flow and water quality variables, for example, found that pyrethroid use explained 21-73% of the variability of species abundance. This analysis suggests that contaminants are one of several factors influencing abundance.

**IRREVERSIBLE FOOD WEB CHANGES** The Delta food web today bears little resemblance to that which existed prior to 1850 and no longer sustains native species. When humans began draining, farming, and engineering the Delta, the base of the food web shifted from high quality organic detritus from the marshes and flood basins to phyto–plankton produced in the open waters of the channels. By the late 1980s, the invasive overbite clam had co-opted the majority of phytoplankton production, resulting in a Delta in which native fishes are severely food limited. The low salinity zone, once a food-rich region of the Delta, now provides little food for native fish, and its foragers are sustained by inputs from upstream and downstream (see diagram above).

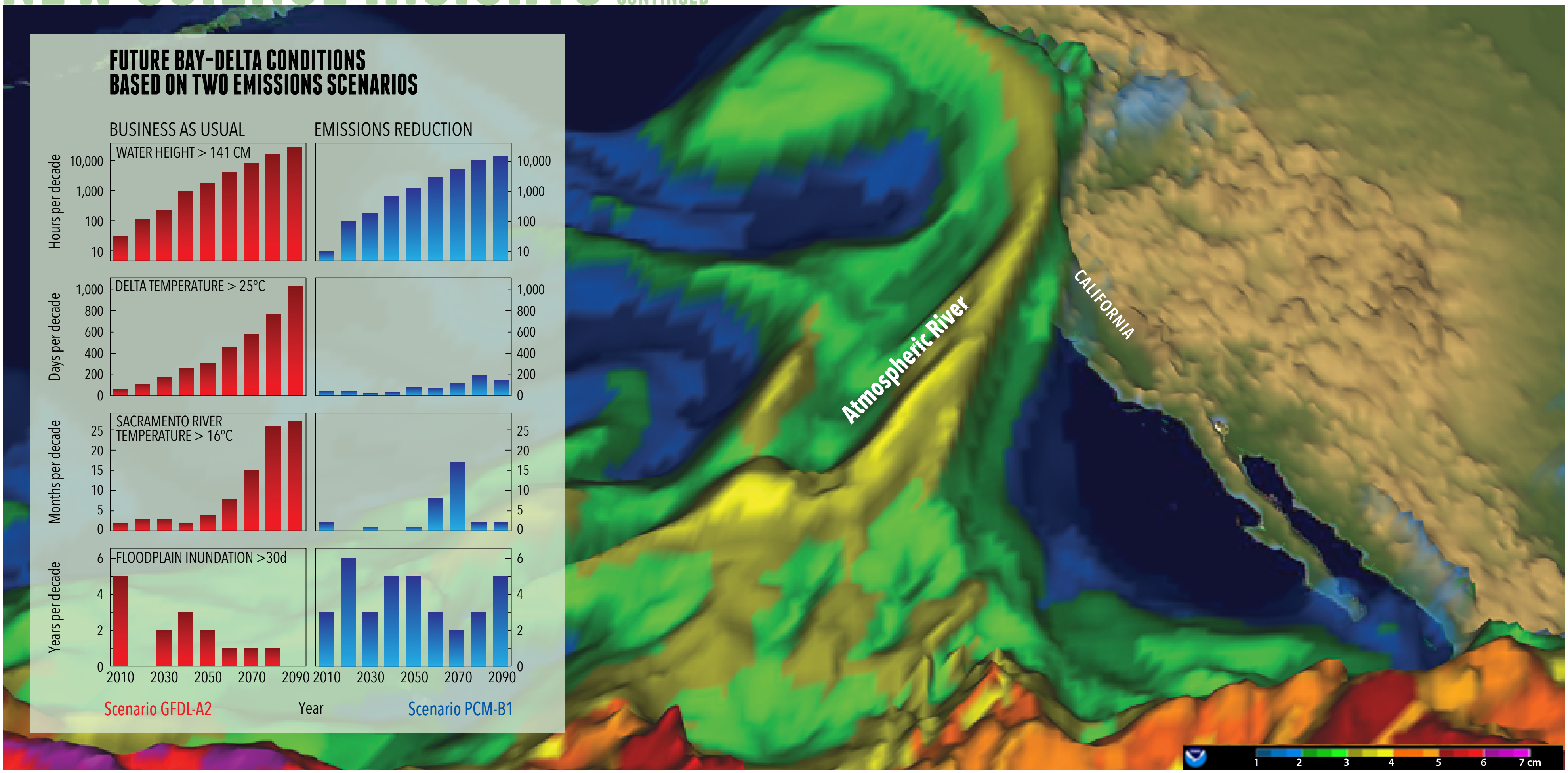
Recent research suggests the food web has been relatively stable for the past 15 years, but new stressors including climate change, increasing contaminants, further changes in hydrology, and new invasions could push the system in undesirable directions.

Delta smelt will likely be the first native fish species to succumb to these changes. Others have only tenuous holds on survival. Improving conditions for listed species in the Delta remains a major challenge. Any actions to improve conditions must be undertaken in the light of this new food web structure.

## DELTA TRENDS



# NEW SCIENCE INSIGHTS CONTINUED




*INSET: Projected 2010-2099 changes in the occurrence of extreme environmental conditions in the San Francisco Estuary and Delta watershed system under two scenarios of human response to climate change: the A2 scenario (red) which assumes increasing greenhouse-gas emissions throughout the 21st Century, and the B1 scenario (blue), assuming emissions that level off by late century. Indicators show number of hours per decade of extreme water height 141 centimeters above historic sea level; number of days each decade when projected water temperature in the Delta exceeds 25°C, and is unhealthy for Delta smelt; number of months per decade when water temperatures in the Sacramento River are over 16°C, and lethal to Chinook salmon; and number of years per decade in which spring floods inundate the Yolo Bypass for at least 30 consecutive days, a minimum threshold for successful spawning of Sacramento splittail. (Source: Cloern et al, PLoS ONE 2011)*

*ILLUSTRATION: Microwave depiction of total amount of water vapor in a February 2015 atmospheric river making landfall on the West Coast. These rivers of water vapor over the Pacific often bring California's warmest and wettest storms. Atmospheric rivers are projected to become more common and more intense under climate change. Adjusting to this enhancement of our largest storms will be important to water managers in the future. (Source: Dettinger, USGS in https://eos.org/meeting-reports/setting-the-stage-for-a-global-science-of-atmospheric-rivers; data derived from NOAA Global Forecast System)*

## MULITIPLE STRESSES ON NATIVE SPECIES

Many species in the Delta are listed as threatened or endangered. Conservation actions for these species have focused on improving hydrodynamics and restoring habitat. It is now apparent, however, that no single stressor can be singled out as the "cause" of Delta species' declines. Rather, numerous stressors acting together are increasing the vulnerability of each species to the point that the Delta can no longer sustain viable populations.

The Delta smelt illustrates this complexity very well. When this species first began to decline, attention focused on changes in Delta flows and smelt being lost at the export pumps. A precipitous decline in Delta smelt and three other fish species beginning around 2002 triggered more analysis, which concluded that water export was only one cause of the declines. Still more research implicated limits on food, exposure to toxic chemicals, interactions with exotic predators, shrinking habitat, and the artificial geometry of the Delta. Today, a workable approach for saving this tiny estuarine native fish continues to elude scientists.

Indeed, for many native species it is unclear which combinations of stress reductions would lift enough of the burden to allow their persistence. Any viable solution must address multiple stressors. The current emphasis is on reestablishing marsh and flood basin habitats in the northwestern part of the Delta, as well as on reestablishing a more supportive hydrograph. These are worthwhile experiments, but they could be derailed by invasive species and contamination in the Delta.

**EXTREME CONDITIONS** Climate projections suggest that instead of planning for gradual change in hydrologic and climatic conditions, managers should be preparing for an increase in extremes. Average precipitation may not change much, but more will fall as rain than snow. Wet events will be wetter and dry periods drier, increasing the threat of both floods and drought. Sea level will rise 60 centimeters or more by the end of the century, challenging managers' ability to control salt intrusion into the Delta through freshwater outflows, particularly during extended droughts. Rising temperatures and more frequent extremes, combined with declining water supplies, will make it difficult or impossible to maintain water temperatures tolerable to native species.

All of these changes will challenge reservoir managers already making tough choices between maintaining storage space as a hedge against higher flood risk or storing more winter streamflow for summer irrigation and stream-temperature management. In addition, rising sea level and higher flood flows will increase the risk of levee failure.

With various species on the precipice, with nutrients and foodwebs modified far beyond their natural ranges, with lethal and sublethal cocktails of contaminants in the Delta's waters, with alien species dominating all biological communities, and with water resources pushed to their limits, the capacity of the Delta to absorb extreme events of all kinds without showing dramatic and undesirable change is declining. Fortunately, there is time for the water management system to evolve so as to mitigate some of these effects.

## RESTORATION BEYOND INDIVIDUAL SITES

The Delta is a mosaic of landscape patches that are interconnected geographically, hydrologically, and ecologically. As a consequence, the success or failure of any habitat restoration is only partially determined by what is done at the restoration site itself. Where a particular patch of restored habitat is located in relation to other habitat patches in the landscape and how it interacts with other patches, both nearby and distant, are also important to the success of a restoration project.

Research suggests a number of reasons habitat restoration may fail in a landscape context, ranging from being surrounded by unsuitable habitat to only being suitable for one life stage of a target species. Alien species may be the first to colonize new habitat, and their presence may preclude successful colonization by target species. Likewise, disturbances such as local land use change and global climate change can compromise the success of local restoration. Even the scale of a restoration may be inappropriate for the target species.

The science of landscape ecology provides concepts and tools for designing habitat restoration that addresses these factors. As yet, however, these concepts and tools have not been fully integrated into Delta restoration planning.

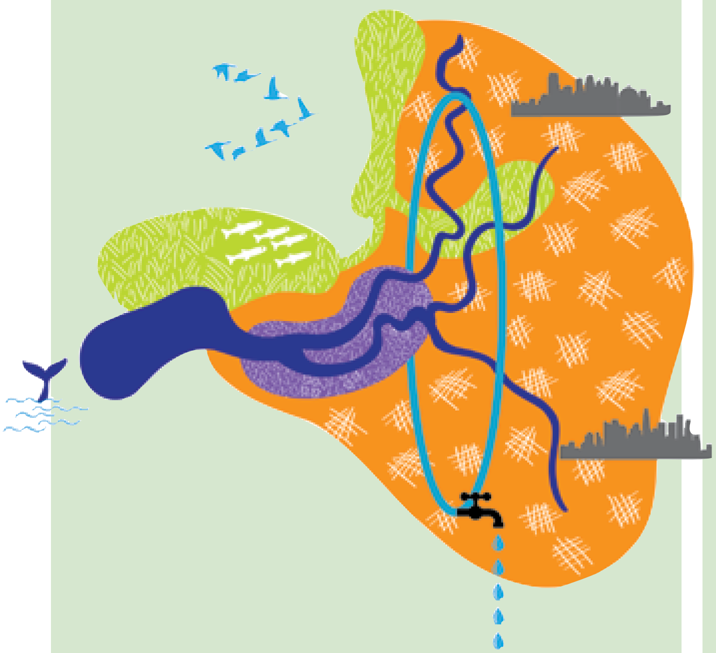
**DIRE STRAITS FOR NATIVES** Despite management actions that in some instances appear heroic, native fish species continue to decline in abundance in the Delta. Some scientists now envision three possibilities for the imperiled Delta smelt that may also apply to other declining species. The first scenario is extinction. The second scenario requires the establishment of intensively managed remnant populations in restricted habitats such as flooded islands or upstream reservoirs. The third scenario involves development of a semi-natural refuge for smelt by creating an arc of suitable habitat from the Yolo Bypass, through the Cache-Lindsay Slough complex and the lower Sacramento River, and into Suisun Bay and Marsh.

The latter will likely be a first step, because it is consistent with habitat restoration and enhancement projects planned in the Delta. In their 2008 SBDS *Perspectives*, scientists suggested serious debate on another step, assisted relocation. This debate is now much more urgent (see pp 10-11).

*Endangered Lange's metalmark butterfly with damaged wing. Photo: USFWS*

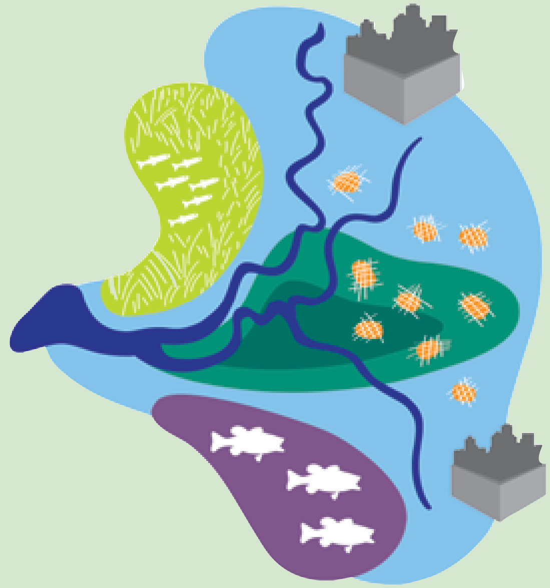
# POLICY OUTLOOK: LOOKING BEYOND THE NEXT CRISIS

## SUSTAINABLE DELTA?



*FAST FORWARD I: Sustainable Delta presented in the 2008 Delta Vision. This long-term vision includes interconnected habitats, careful control of urban growth and invasive species, select levee upgrades, stronger connection to the lower estuary, and a new "dual conveyance" water delivery system emphasizing reduced exports, conservation, and conjunctive use.*

## WETTER DELTA?



*FAST FORWARD II: Inexorable sea level rise and levee failures flood most of the Delta except isolated farms and walled cities. Native ecosystems survive in the north due to early interventions and restoration while a warmwater bass fishery offers recreation and a novel ecosystem in the south Delta.*

## CONCRETE DELTA?

*FAST FORWARD III: Uncontrolled urbanization and crisis-by-crisis engineering and flood control fixes add acres of hardscape and miles of concrete levees and flood control channels to the Delta.*

## LEGEND

- Native fish habitat, marshes and shallows
- Farms and agriculture
- Warmwater habitats invaded by exotic bass and aquatic weeds
- Flooded by rising sea levels or levee failure
- Subsided and flooded by rising sea levels or levee failure
- Urbanization
- Engineered flood defense
- Water diversion via dual conveyance system, and conservation

# POLICY OUTLOOK

The *Perspectives* paper synthesizing SBDS 2016 scientific findings also offers a number of perspectives on various policy questions.

## CAN WE GET BEYOND CRISIS MANAGEMENT?

Delta science and management need to push beyond their tendency to focus on short-term policy mandates and near-term crises. Taking a longer, 50-100 year viewpoint has been part of various planning exercises including Delta Vision. That kind of long-range thinking now needs to be more strongly incorporated into the whole Delta science and management endeavor.

The Delta has been changing physically and ecologically for millennia, but the rates of human alterations of the Delta, its watershed, and the planet are accelerating. In light of this accelerating change, two policy-relevant facts are evident. First, many aspects of the Delta ecosystem may have been destined to fade away even if there had been no human-caused transformation. Second, the Delta has always been a changing place and, looking to the future, further dramatic change is inevitable.

Scientists, managers, and policymakers now need to address some tough questions: What kind of a Delta ecosystem is feasible 50 or 100 years from now? What actions would allow the Delta to evolve in desirable directions?

An appreciation of the changes that are coming, particularly those associated with global climate change should more strongly inform our planning. Even if current efforts to reduce global greenhouse-gas emissions are successful, the climate will still change dramatically over the coming century or two. In the short to medium term, skillful water management may mitigate some impacts and allow the Delta to remain more or less as it is. Ultimately, however, and within the lifetime of today's younger generations, higher sea levels, more intense rainfall, longer droughts, and other changes will transform the Delta as we know it. Scientific, policy, and management frameworks need to be developed now to minimize the negative and maximize the positive consequences of these inevitabilities.

## HOW CAN WE HELP GOVERNMENT AGENCIES ADAPT?

Major obstacles to integrating forward-looking science and policy are the common constraints on science within government agencies. Agencies tend to focus narrowly on immediate policy and management issues, leaving their scientists and policy thinkers with little freedom to investigate more broadly or look far into the future. Conflicting mandates can also put agency-supported science at cross purposes.

If science is the key to developing forward-looking policy, then we need more forward-looking science. Governments at all levels need to invest more in exploratory science, science not linked to any current policy. We also need closer integration of short-term basic and applied research with forward-looking research.

*Endangered salt marsh harvest mouse. Photo: Bjorn Erickson, USFWS*

This will not be an easy transition for government agencies struggling to keep on top of multiple, immediate problems. The *Delta Science Plan* provides a collaborative framework for bringing research and policy to the table, but there also needs to be a willingness to shift emphasis from the immediate to the longer-term future. Short-term science cannot be expected to lay the groundwork for addressing long-term change.

Fortunately, the Delta has an exceptional science community that has vigorously engaged with the complex problems of water and environmental management. New tools, particularly remote sensing, new analytic approaches and modeling opportunities, and new sensors for real-time measurement of water quality offer Delta science more powerful machinery for looking forward (see p. 13).

Indeed, advances in modeling technology and computing power now offer the opportunity to develop fully integrated models of the wider Delta ecosystem extending from the Sierra to the sea. Like global climate models, this kind of integrated ecosystem model should be designed to look ahead to develop plausible future scenarios that can inform policy and management.

## WHAT ARE THE ALTERNATIVES TO EXTINCTION?

Many native species are likely doomed in the Delta but this is not a signal that they should simply be abandoned. They are not going to disappear from the Delta tomorrow. All reasonable efforts are required by endangered species laws to provide for them. The increasing likelihood of extinctions is instead a signal that we should begin exploring alternatives to conservation in place. These alternatives involve relocating, genetically selecting or cyropreserving near-extinct species so they aren't lost forever, with a view to future re-establishment under more hospitable conditions (see page 11).

Some endangered Delta species, like the Delta smelt, Lange's metalmark butterfly, and the saltmarsh harvest mouse, are endemic and restricted to small patches of habitat in the Delta. When these species go extinct in the Delta, they will be gone forever. Such species might be prime candidates for the creation of refuge populations or assisted relocation. Delta smelt have already been successfully cultured in hatcheries at Byron and UC Davis, providing a source of potential colonists as well as a captive refuge population.

Some listed Delta species such as Chinook salmon, steelhead trout, and green sturgeon are widely distributed and their disappearance from California would not constitute extinction. These species are threatened by climate change from British Columbia to California. As Arctic ice recedes, new habitat suitable for salmonids is opening up. It might be prudent for California to begin discussions with Canada and Alaska to ensure that suitable habitats for colonization are not compromised by other forms of development.

Decisions to pursue these options will benefit from a strong scientific foundation that does not yet exist, and require wide-ranging discussions by scientists, policymakers and the general public. Many of the alternatives discussed here are hotly debated, in terms of ecological ethics and viability, or divisive and problematic for government agencies mandated to undertake conservation in place. It is not too early to begin such discussions and experimentation with alternatives. If we wait for the crisis to be upon us, it will be too late.

## OPTIONS FOR TOMORROW'S ORPHAN SPECIES

### Conservation in Place

Protecting, restoring and maintaining habitats within the Delta where endangered species evolved naturally and already live and reproduce.

### Refuge Populations

Providing "refuges" outside or within the larger Delta system where populations can be captive or free-living in constructed or appropriated habitats. To some extent, any Delta refuges would have to be isolated from hydrodynamic exchange with their surroundings.

### Assisted Relocation

Moving vulnerable species to new locations outside the ecosystem of origin. If climate change is the primary driver of extinction, then recipient ecosystems need to be chosen that will remain within species tolerances for decades or longer.

### Assisted Evolution

Helping species to evolve tolerance to changing local conditions. In the case of Hawaii's coral reefs, for example, scientists are already experimenting with selecting individuals with higher temperature tolerance.

### Genetic Conservation

Preserving or freezing genes (cryopreservation). Though little used to date in conservation, this technology is fairly well developed for plant species. The appropriate tissue and method depend on the physiology and genetics of reproduction, which are unknown for many species, posing important research questions in the Delta context.

*Clifton Court fish screens, one early crisis response to native fish losses at the pumps. Despite these and other measures, native fish species continue to decline. Photo: Bird's Eye View*

## COULD INVADED HABITATS AND EXOTIC SPECIES BE MANAGED FOR HUMAN BENEFIT?

The Delta ecosystem is now dominated by alien species. To date, our conservation focus, enshrined in the UN Convention on Biodiversity, has been to prevent, eradicate, or contain species invasions. A growing contingent of conservation ecologists worldwide, however, is now calling for active management of invasive species for human benefit.

In the Delta, too little attention has been given to how best to utilize the habitats that are no longer suitable (and that cannot be made suitable) for native species. Without downplaying the substantial economic and ecological impact of invasive species, it may be time to accept that many of these species are here to stay.

Scientists, managers, and policymakers should be asking themselves these questions: What ecological, recreational, and economic value can alien species provide? What management actions could help us increase these values?

For example, FISHBIO, a consulting firm focused on fisheries research, monitoring, and conservation, ranked the south Delta largemouth bass fishery ninth out of the 100 best bass fishing waters in the United States. Largemouth bass, a species that invaded in the early 20th Century, joins other introduced fish in contributing to a diverse, warm water sports fishery in the Delta. These species will likely fare better under global warming than most fish in the Delta. So while native species and ecosystems shouldn't be written off in the face of extreme challenges to their survival, nor should new species and novel ecosystems be written off. Understanding the potential benefits of these novel ecosystems and species is important.

## IS SCIENCE NEGLECTING THE DELTA AS A SPECIAL PLACE?

The term "Delta as a Place" derives from the Delta Reform Act of 2009, which requires that the coequal goals "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" (CA Water Code §85054). The Act charged the Delta Protection Commission with developing a proposal to do just that. Indeed, a plan is also underway to establish a state and federal designation of the Delta as a National Heritage Area.

Although policymakers have been quick to adopt the concept of the "Delta as a Place," the Delta science community has largely missed this important legislative condition. Though existing science programs often uncover information related to the "Delta as a Place," and though acting on existing science to achieve the coequal goals can affect the Delta's unique values, these effects are often incidental to research design, rarely mentioned in the interpretation of results, and are not being effectively communicated through policy channels. Reasons for this deficiency likely include the lack of specificity around the "Delta as a Place" or of a specific research program with a dedicated budget, or even of clear pointers to the natural sciences aspects of the "Delta as a Place."

In terms of cultural aspects, the Delta Protection Commission is sponsoring new portrayals of the history of the Delta and the organization of a Delta cultural bibliography, among other actions. But in reviewing Delta science related to the *Delta Plan*, the Delta Independent Science Board is still grappling with how to provide guidance around the term "Delta as a Place." In the meantime, Delta science, across the agencies, should evaluate how better to include the "Delta as a Place" in its planning and results.

*Discovery Bay, home to many who enjoy the recreational boating and fishing benefits of Delta life. Photo: Bird's Eye View*

# SCIENCE FOR MANAGEMENT


*USGS scientists adjusting a new water quality sensor before deploying in the water. Photo: Bryan Downing, USGS*

## NEW TOOLS

Forward-thinking science will benefit from the following new tools, as well as from the integration of the information they provide into ever more sophisticated models. Scenarios created by these models will prove invaluable to policymakers making decisions about the Delta's future.

**MINIATURIZED ACOUSTIC TAGS** allow detailed measurement of migratory pathways of salmon and steelhead through the Delta, including rates of travel and rates of mortality in different Delta channels.

**REAL-TIME FIELD SENSORS,** deployed in the water, provide almost continuous measurements of nutrients, carbon, and other water quality variables (see photo).

**ADVANCES IN 2- AND 3-DIMENSIONAL HYDRODYNAMIC MODELING** allow much more detailed understanding of water and suspended particle movements in the Delta.

**REMOTE SENSING TOOLS,** combined with borehole measurements, provide more reliable mapping of the internal structure and vulnerability of levees.

**IMPROVED DOWNSCALING OF GLOBAL CLIMATE PREDICTIONS** allows more informed predictions of local climate changes and their impacts.

**NEW ANALYTIC TOOLS** use liquid chromatography and high-resolution mass spectrometry to screen water samples for a very broad spectrum of potential contaminants.

## MANAGEMENT CONTEXT

In their 2016 *Perspectives* paper, the editorial board assessed the level of influence of SBDS 2008 on the Delta Stewardship Council and other Delta management initiatives. They found that the 2009 Delta Reform Act, the 2013 *Delta Plan*, and the 2013 *Delta Science Plan* are all consistent with the seven 2008 perspectives (see p. 4). Though the latter two plans are still in the early stages of implementation, some progress has already been made to match management to the 2008 perspectives.

An important recent action, consistent with SBDS 2008, is the establishment of the Delta Regional Monitoring Program (RMP) by the Central Valley Regional Water Quality Control Board. The program (modeled on a similar regional effort in the lower estuary) will sample mercury, pesticides, nutrients, and pathogens at a number of Delta locations, both routinely and in response to events such as seasonal storms and dry periods. The Delta RMP is a landmark step to provide much more comprehensive water quality monitoring for management.

Other recent actions, consistent with SBDS 2008, include increasing efforts by water management and fish agencies to embrace adaptive management.

## FORWARD-THINKING ACTIONS

In the interests of summarizing recommended and transformative next steps, the editorial board extracted the following forward-thinking actions from their 2016 *Perspectives* paper.

1. Incorporate long-range (50 year) thinking into Delta science and management. Acknowledge the accelerating rates of change ahead, and the inability to return to past conditions, in evaluating and planning feasible options for the future.
2. Incorporate more exploratory and forward-looking science into government science programs at all levels, including science not tied to any current policy or crisis. Start planning now for about 15% of the overall Delta science budget to transition into more forward-thinking science.
3. Widen science career paths in state agencies so that scientists are not forced to abandon science to advance their careers.
4. Plan for variability and extremes in the decades ahead, as well as long-term change. Bolster the ecosystem's capacity to absorb both drought and deluge by continuing to reduce the state's demand for water supply from the Delta, as required by the Delta Reform Act of 2009. Replenish Central Valley groundwater reservoirs and promote agricultural practices more resilient to drought. Adjust water management practices to accommodate less predictable sources of supply and more variable inflows.
5. Adapt management practices to take advantage of any ecological, recreational, and economic values to be gained from various invasive species in habitats no longer suitable for native species. Manage current plant and animal communities to increase ecosystem services.
6. Begin the scientific and societal groundwork needed to seriously explore alternatives to conservation in place for endangered species. Continue all reasonable efforts to provide for them, including reducing water demand on the Delta, but recognize that the time has come to develop the science and policy foundations for more radical approaches, including assisted relocation, assisted evolution, and cryopreservation.
7. Invest now to develop models of the Delta system, analogous to global climate models, that more fully integrate physical, ecological, and social sciences. Use these models to forecast likely outcomes from changing climate and other external forces acting on the Delta, as well as likely effects of various management policies.
8. Weave "Delta as an Evolving Place" into all science, planning and management programs.

## LOOKING AHEAD

Science identified in SBDS 2016 will be incorporated into planning by the Delta Stewardship Council. The *Delta Plan* is required to be reviewed at least every five years, with the next comprehensive review planned for 2018. In the meantime, the Council is considering amendments related to ecosystem restoration as well as conveyance, storage and related operations. These potential amendments, as well as the comprehensive review, will benefit from the perspectives and policy questions raised by SBDS 2016. By the time of the Council's next comprehensive *Delta Plan* review, improvements in multidimensional modeling of how water and sediment move through the estuary, coupled with modeling of various physical, chemical, and ecological processes, could help us identify specific endpoints that will constitute positive environmental and water supply outcomes.

SBDS is one element of a three-part Delta Science Strategy for achieving the vision of One Delta, One Science — an open Delta Science community that works collaboratively to build a shared body of scientific knowledge with the capacity to adapt and inform future water and environmental decisions. The three elements of the Strategy are:

1. *Delta Science Plan,* a shared vision for science in the Bay-Delta system.
2. Science Action Agenda, priorities for science activities (research, modeling, and synthesis) that address decision-makers' most challenging issues for a four-year period.
3. State of Bay-Delta Science papers, periodic updated analysis and synthesis of the rapidly growing knowledge base to guide science priorities and planning.

As we enter a period of great change and uncertainty, science is all the more important as a source of reliable, verifiable information on which to base policy.

# STATE OF BAY-DELTA SCIENCE 2016

The State of Bay-Delta Science is a compilation of 15 papers published in the July, October, and December 2016 issues of the journal *San Francisco Estuary and Watershed Science* (SFEWS). One paper published in the September 2015 issue of SFEWS is also included in the compilation:

***Challenges Facing the Sacramento–San Joaquin Delta: Complex, Chaotic, or Simply Cantankerous?***
Sam Luoma, Cliff Dahm, Michael Healey, Johnnie Moore
*doi: http://dx.doi.org/10.15447/sfews.2015v13iss3art7*

A synthesis of SBDS 2016 findings can be found in the forthcoming paper entitled *Perspectives on Bay-Delta Science and Policy* by Michael Healey, Michael Dettinger, and Richard Norgaard. These authors also served as the editorial board for SBDS 2016.

This brochure, entitled *The Delta on Fast Forward: Thinking Beyond the Next Crisis*, is a concise version of the synthesis paper for a general audience by Michael Healey, Richard Norgaard, and Ariel Rubissow Okamoto.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## SFEWS, SBDS Part 1 – July 2016

***The State of Bay-Delta Science 2016 – An Introduction***
Michael Healey, Peter Goodwin, Michael Dettinger, Richard Norgaard
*doi: http://dx.doi.org/10.15447/sfews.2016v14iss2art5*

***Delta Smelt: Life History and Decline of a Once Abundant Species in the San Francisco Estuary***
Peter Moyle, Larry Brown, John Durand, James Hobbs
*doi: http://dx.doi.org/10.15447/sfews.2016v14iss2art6*

***Anadromous Salmonids in the Delta: New Science 2006–2016***
Russ Perry, Rebecca Buchanan, Pat Brandes, Jon Burau, Josh Israel
*doi: http://dx.doi.org/10.15447/sfews.2016v14iss2art7*

***Predation on Fishes in the Sacramento – San Joaquin Delta: Current Knowledge and Future Directions***
Gary Grossman
*doi: http://dx.doi.org/10.15447/sfews.2016v14iss2art8*

***The Delta as Changing Landscapes***
John Wiens, Letitia Grenier, Robin Grossinger, Michael Healey
*doi: http://dx.doi.org/10.15447/sfews.2016v14iss2art9*

## SFEWS, SBDS Part 2 – October 2016

***Food Webs of the Delta, Suisun Bay, and Suisun Marsh: An Update on Current Understanding and Possibilities for Management***
Larry Brown, Wim Kimmerer, J. Louise Conrad, Sarah Lesmeister, Anke Mueller-Solger
*doi: http://dx.doi.org/10.15447/sfews.2016v14iss3art4*

***Climate Change and the Delta***
Michael Dettinger, Jamie Anderson, Michael Anderson, Larry Brown, Daniel Cayan, Edwin Maurer
*doi: http://dx.doi.org/10.15447/sfews.2016v14iss3art5*

***California's Agricultural and Urban Water Supply Reliability and the Sacramento – San Joaquin Delta***
Jay Lund
*doi: http://dx.doi.org/10.15447/sfews.2016v14iss3art6*

*Sandhill cranes. Photo: Rick Lewis*

## SFEWS, SBDS Part 3 – December 2016. Forthcoming.

***Recent Advances in Understanding Flow Dynamics and Transport of Water-Quality Constituents in the Sacramento-San Joaquin River Delta***
David Schoellhamer, Scott Wright, Stephen Monismith, Brian Bergamaschi

***An Overview of Multi-dimensional Models of the Sacramento-San Joaquin Delta: What They Can Tell Us About the Distribution and Movement of Fish and Food Organisms and How Future Delta Conditions Will Affect Fish and Water Supply***
Michael MacWilliams, Eli Ateljevich, Stephen Monismith, Chris Enright

***Factors and Processes Affecting Delta Levee System Vulnerability***
Steven Deverel, Sandra Bachand, Scott Brandenberg, Cathleen Jones, Jonathan Stewart, Paolo Zimmaro

***Nutrient Dynamics of the Delta: Effects on Primary Producers***
Clifford Dahm, Alexander Parker, Anne Adelson, Mairgareth Christman, Brian Bergamaschi

***Contaminant Effects on California Bay-Delta Species and Human Health***
Stephanie Fong, Stephen Louie, Inge Werner, Jay Davis, Richard Connon

***Perspectives on Bay–Delta Science and Policy***
Michael Healey, Michael Dettinger, Richard Norgaard