

SCIENCE ACTION AGENDA

2017-2021

A Collaborative Road Map for Delta Science

September 2017

Delta Stewardship Council
Delta Science Program

This document was produced by the Delta Stewardship Council,
Delta Science Program, September 2017

Please cite as: Delta Stewardship Council, Delta Science Program. 2017.
2017-2021 Science Action Agenda.

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Page 8 Native rose in Suisun Marsh by Amber Manfree

Print Date: September 28, 2017

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For anyone accessing this report after January 2021, Table 1 is now referred to as List 1 and Table 2 is now referred to as Table 1.

California Department of Fish and Wildlife researchers sort through biota collected in a summer townet survey. The survey contributes to abundance indices for species such as Delta Smelt and is part of IEP's long term monitoring program. Photo: Michelle Avila.

FOREWORD

From my perspective as the Lead Scientist of the Delta Science Program for almost six years over the period between 2008 and 2017, there are pragmatic and aspirational reasons for a Delta-wide science action agenda. Pragmatically, the Delta Science Plan (completed in December of 2013) calls for "the open and inclusive development of a science action agenda to organize, integrate, and prioritize science activities across agencies and programs to address decision-makers' grand challenges." The Delta Science Program has been working diligently to complete the many tasks in the Delta Science Plan, and finalizing the 2017-2021 Science Action Agenda is an important achievement.

> ***"My hope is that the 2017-2021 Science Action Agenda can have an organizing and catalyzing impact on Delta science."***

I also see a compelling aspirational reason for developing the 2017-2021 Science Action Agenda. This is based on insights I gained as a Program Director in the Ecosystem Studies Program at the National Science Foundation (NSF) between 1994 and 1996. At the NSF, there is a keen awareness that certain scientific disciplines are particularly well organized and forward-looking in terms of the science that needs to be done to most effectively advance the discipline. Those working in the disciplines of astronomy, oceanography, and physics, for example, are especially proficient at advancing an agenda and speaking with a unified voice. My hope is that the 2017-2021 Science Action Agenda can have a similar organizing and catalyzing impact on Delta science. Science investments are often justified and awarded to communities of scientists who are able to coalesce successfully around a clear set of priority science actions and science infrastructure needs.

Another important insight I learned at the NSF was the critical need to invest in stable long-term studies. For example, visionary program directors initiated the US Long-Term Ecological Research (LTER) network in 1980. The network is based upon the realization that ecosystem change commonly pivots on rare extreme events. The recent whiplash between record drought and record precipitation are examples of rare extreme events in the Delta watershed. The Delta and San Francisco Bay are exceptionally fortunate to have long-term data sets. Supporting the continuation of increasingly valuable long-term databases and linking new research to these foundational data sets represents an overarching goal of the 2017-2021 Science Action Agenda.

To truly advance scientific knowledge and provide the science-based tools needed to support decision-makers and resource managers tasked with addressing wickedly complex issues in the Delta, we need collective identification and ownership of science priorities. This 2017-2021 Science Action Agenda for the Delta came from the input of literally hundreds of scientists and science managers. As such, it represents a road map that can help us come together around a common set of priorities no single organization has the capacity to achieve on its own. It is my hope that this agenda will establish a clear pathway for building partnerships and securing investments to advance relevant, credible, usable, and creative science in the Delta.

DR. CLIFFORD N. DAHM
Lead Scientist for
the Delta Science Program
July 2017

OVERVIEW

Overview

This document presents 13 priority science actions that fill critical gaps in Delta science, gluing disparate pieces of this complex enterprise together to advance the vision of the Delta Science Plan: *One Delta, One Science*. The document organizes and summarizes these priorities under five thematic science action areas. These action areas and priorities were identified through an open and transparent process that gathered input from the Delta science community, the public, and major synthesis efforts; examined peer-reviewed literature; and involved review by the Delta Independent Science Board. The document details each action area and identifies ways the agenda can be used to promote collaborative science, improve efficiencies in science planning, and coordinate investments in critical science investigations and infrastructure.

UC Davis researchers sampling for fish near restored wetlands and floodplains. Photo: Amber Manfree.

List 1: Summary of Priorities

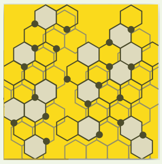
5 Action Areas and 13 Priority Science Actions

1. Invest in assessing the human dimensions of natural resource management decisions.

A. Investigate the most cost-effective methods to improve species habitat on working lands.

B. Develop tools to assist adaptive management in the Delta.

C. Initiate a research program on the Delta as an evolving place that integrates the physical and natural sciences with the social sciences.



2. Capitalize on existing data through increasing science synthesis.

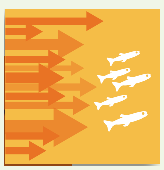
A. Strategically build the capacity to do collaborative science synthesis by implementing the science synthesis mechanisms outlined in the Delta Science Plan.

B. Identify and prioritize important data sources that should be interconnected to promote collaboration and provide the technology necessary to easily access this information.

3. Develop tools and methods to support and evaluate habitat restoration.

A. Develop methods for evaluating long-term benefits of habitat restoration based on current understanding of how species use restored areas and how use changes over time as habitats evolve.

B. Estimate and assess the system-wide effects of the location and sequence of tidal marsh habitat restoration projects in regions where sea level is rising and climate is changing.



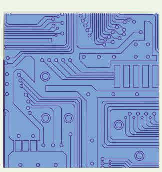
4. Improve understanding of interactions between stressors and managed species and their communities.

A. Implement studies to better understand the ecosystem response before, during, and after major changes in the amount and type of effluent from large point sources in the Delta including water treatment facilities.

B. Identify areas that act as refugia for species of concern during extreme conditions, particularly drought and flood, to inform management decisions and priorities during extreme climate events.

C. Understand mechanisms for observed relationships between flows and aquatic species.

D. Evaluate the effects of toxicity (e.g., contaminant mixtures, mercury, pharmaceutical products, HABs) on aquatic species survival including possible effects on predation.



5. Modernize monitoring, data management, and modeling.

A. Advance integrated modeling through efforts such as an open Delta collaboratory (physical or virtual) that promotes the use of models in guiding policy.

B. Explore innovative technologies and cost-effective methods for scientific monitoring and analysis of flow, water quality, and ecosystem characteristics (e.g., improved tools for fish monitoring, LiDAR, high-resolution bathymetry technology, new measurements for Delta levee hazards, and citizen scientist monitoring programs).

INTRODUCTION

Why do we need a science action agenda?

Collective actions are needed to advance scientific discoveries, sustain essential science programs, and modernize the Delta science enterprise. The 2017-2021 Science Action Agenda (SAA) is critical to achieving this goal because the SAA defines and communicates a shared set of priority actions for guiding and integrating science activities across multiple programs and agencies in the Delta. These priority science activities collectively enhance science support for achieving the coequal goals of providing water supply reliability and protecting and restoring the Delta ecosystem while protecting and enhancing the Delta as an evolving place (see Table 2, p.15).

Why is the SAA different from other strategic science efforts? The SAA identifies science actions that fall between the mission statements and priorities of a single group, program, or agency but are otherwise recognized as cross-agency and multi-group priorities, as feasible to implement and perform, and as opportunities to promote collaborative efforts. In this way, the SAA fills gaps and serves as the glue for synergistic and multi-benefit science to support important management needs.

> *"Union gives strength."*
> – Aesop's Fable, 'The Bundle of Sticks'

After collecting larval fish samples in the field, CDFW researchers sort fish from debris for later identification. Photo: Michelle Avila.

How does the agenda relate to other collaborative science initiatives?

The SAA builds on the essential activities of existing collaborative efforts such as the Interagency Ecological Program (IEP), Collaborative Science and Adaptive Management Program (CSAMP), Delta Regional Monitoring Program (DRMP), and State and Federal Contractors Water Agency's (SFCWA) Coordinated Science Program.

The SAA also furthers the vision of the Delta Science Plan [1]: *One Delta, One Science*. The Delta Science Plan itself (adopted in December 2013) is a shared document, developed jointly to guide integrated, collaborative, and transparent science in policy and management in the Delta.

Development of the SAA furthered these collaborative programs and planning efforts and brought participants of the broad Delta science enterprise together in identifying and jointly implementing a common playbook for strategically driving science and decision-making over a four-year timeframe.

What is the agenda?

The SAA is a four-year science agenda for the Delta, which prioritizes and aligns science actions to fill gaps in knowledge, achieve key objectives in the Delta Science Plan, and build science capacity to address today's management prob lems, challenges on the horizon, and anticipated long-term science needs.

The SAA is one element of a three-part Delta Science Strategy that includes the Delta Science Plan and The State of Bay-Delta Science (SBDS). These three elements build upon one another to support *One Delta, One Science*. The Delta Science Plan is the foundation that sets a shared vision for Delta science. SBDS synthesizes scientific knowledge about the Delta and provides the SAA with information to begin identifying priority science actions to address key uncertainties and fill institutional gaps. The 2017-2021 SAA identifies priority science actions for the Delta founded on SBDS 2016 and completed interim SAA efforts (i.e., the 2014 Interim Science Action Agenda and High-Impact Science Actions). This document is the first full SAA to be completed as called for in Action 2.2 of the Delta Science Plan [1].

In supporting *One Delta, One Science*, these three elements also address science needed to support achievement of the coequal goals called for in the Delta Plan. An enhanced understanding of the Delta that can be clearly shared with decision-makers and the public will be critical to informing important water and environmental management decisions.

Because the SAA serves as the "gaps and glue," it does not cover every important science action underway in the Delta. Several essential research and scientific monitoring efforts are taking place across the landscape of the Delta science enterprise (see Key Terms below). Examples of these science efforts include: long-term monitoring to comply with federal and state regulatory requirements (e.g., IEP); and scientific research and synthesis efforts that advance scientific discovery and the state of knowledge on topics like predation [3, 4], the role of harmful algal blooms [5], and groundwater supply and demand [6].

How was the agenda developed?

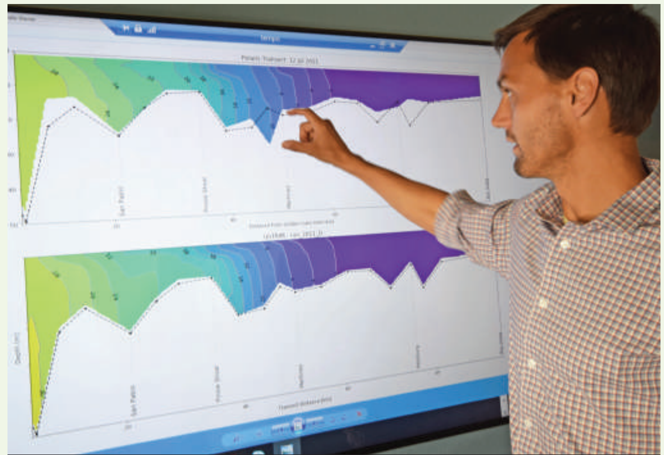
The SAA emerged out of a transparent and open process. Public comment played an important role in refining the priority science actions. Diverse input helped ensure that the Delta science community supports these actions to be of high importance. The process by which the SAA was developed resulted in the identification of 13 science actions as the highest priority actions to initiate between 2017 and 2021. Should additional resources become available, an additional 12 science actions are recognized as important (see Appendix A).

Key Terms

Science Actions include research, monitoring, data management, modeling, analysis, synthesis, communication, and building science capacity.

Science Enterprise is not interchangeable with "science program." Instead, it refers to the collection of science programs and activities that exist to serve managers and stakeholders in a regional system. The elements of an enterprise range from in-house programs within individual agencies or other organizations to large-scale collaborative science programs funded by governments. Included in this definition is academic research, recognizing that academic researchers often operate independently of management and stakeholder entities. Science enterprises can vary greatly in the degree to which resources are concentrated in collaborative programs and produce publicly-available results. The differences among regional systems can reflect historical factors, depth and persistence of conflicts regarding resource issues, governmental guidance and engagement, the range of agencies and interests involved, and other factors [2].

One Delta, One Science refers to 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.



Researcher examines hyrodynamic model outputs. Photo: Amber Manfree.

The priority science actions were organized and prioritized by the Delta Science Program with several engagements with the Delta science enterprise under the leadership of the Delta Science Program's Lead Scientist and the IEP Lead Scientist (See Appendix B for complete methods). The 13 science actions emerged as the highest priority based on applying the prioritization criteria to 158 science actions. These 158 science actions were collated from over 550 science actions sourced from scientific reports, work plans, synthesis efforts, surveys, and targeted outreach to the Bay-Delta science community. The criteria used to prioritize science actions included scientific merit, level of impact, timeliness, and the relative cost of inaction.

What are the thematic priorities in this agenda?

The 13 priority science actions are organized into five thematic science action areas:

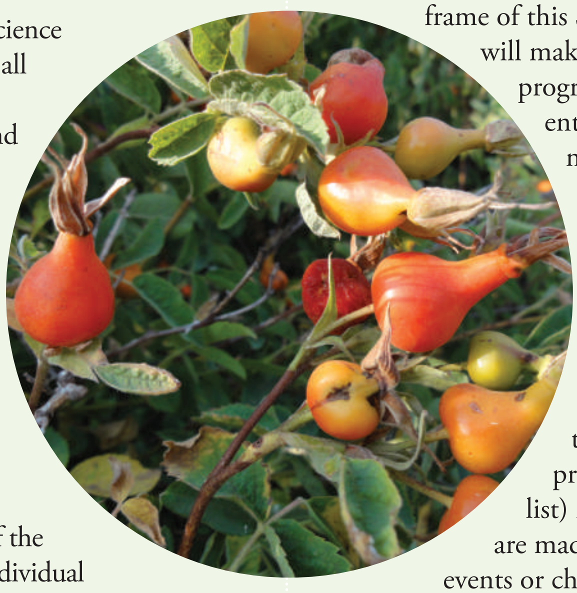
1. Invest in assessing the human dimensions of natural resource management decisions.
2. Capitalize on existing data through increasing science synthesis.
3. Develop tools and methods to support and evaluate habitat restoration.
4. Improve understanding of interactions between stressors and managed species and their communities.
5. Modernize monitoring, data management, and modeling.

These five action areas are naturally and purposefully integrative to support the complexity of Delta water and environmental management challenges. For example, managing Delta water and environmental resources affected by major stressors such as climate change, increases in temperature, altered flow regimes, loss of habitat, and evolving contaminant and nutrient compositions will require portfolio investments in science and infrastructure. These investments will modernize the way we collect and share information, build capacity to test novel hypotheses, and systematically synthesize current understanding. They are also important to address cross-cutting science gaps. Such gaps include identifying thresholds in system dynamics, determining the effects of climate change on resources, managing land-water interfaces, and improving approaches used in evaluating the costs and benefits of resource management actions.

How should the agenda be used?

The SAA should be used to guide science planning and marshal funding across all science endeavors in the Delta. This includes agency, academic, private, and non-governmental institutions. Specific uses of the SAA include informing competitive solicitations for science proposals, agency budget change proposals, coordinated multi-agency efforts, and strategic planning efforts for individual science programs.

The SAA also serves as a tool for communicating collaborative Delta science priorities within and outside of the system. The SAA can guide existing individual and collaborative science organizations to collectively advance scientific insights and ensure a robust science infrastructure for supporting management and policy decision-making.



When will the agenda be updated?

The SAA will be updated every four years. The five action areas and the 13 prioritized science actions in this SAA are intended to be responsive to current and future management and policy needs. However, if a major catastrophe or rare event (e.g., damaging earthquake, severe flood, prolonged drought, changes in major conveyance infrastructure) occurs that transforms the Delta landscape and/or infrastructure during the timeframe of this SAA, the Delta Science Program will make adjustments. In this case, the program will work openly and transparently with the Delta science, management, and policy communities to adjust the prioritized actions. This update approach enables the SAA to be nimble and responsive to new conditions without compromising the near-term investments necessary to yield desired long-term dividends. Science actions that were not given immediate priority in this agenda (see master list) may also be revisited if adjustments are made to the SAA as a result of unusual events or changes in conditions.

Action Areas and Priority Science Actions

ACTIONS

In the following pages this document presents five action areas, each of which include both priority science actions and associated management needs. Appendix D takes this a step further, by identifying examples of more specific management and science questions.

Although these five action areas represent priorities, their order, and the order of the actions within them, is not sequential. When implementing the actions, it may be appropriate to consider the sequencing of actions. However, this agenda does not reflect decisions about sequencing, as this format offers fewer limitations in terms of opportunities to pursue a variety of pathways and resources for implementing the actions.

CDFW crew cast the net for the Fall Midwater Trawl Survey. The trawl originally targeted age-0 striped bass, but currently helps calculate annual abundance indices for Delta Smelt, and other open-water species. Photo: Michelle Avila.

Native plant hedgerow being installed at Stone Lakes National Wildlife Refuge by the Sacramento Tree Foundation. Photo: Brett Milligan.

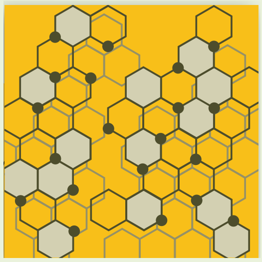
1. Invest in assessing the human dimensions of natural resource management decisions.

Humans are inextricably linked with the Delta ecosystem. Investments in social and behavioral sciences (e.g., economics, sociology, and psychology) that assess the human aspects of natural resource management have been minimal when compared to investments in the physical and biological sciences in the Delta. Despite increasing awareness of the importance of integrative and transdisciplinary research, the Delta is not alone in its struggle to integrate social sciences with physical and biological science programs. Other large estuarine and coastal systems in the United States are engaged in similar struggles [2]. There is a growing recognition that investments in science to understand human responses to management actions, to evaluate value-based tradeoffs among alternatives, and to balance limited resources among human and wildlife uses are important for creating effective policies and durable natural resource management solutions.

Investments in science that explore the human dimensions of management actions are especially important in the Delta because of the Delta Reform Act's goals. The Act directs California to provide a reliable water supply and protect, restore, and enhance the Delta ecosystem, while also protecting the unique cultural, recreational, natural resources, and agricultural values of the Delta as an evolving place (CA Water Code §85054). A review by the Delta Independent Science Board recommends establishing ongoing research on the Delta as an evolving place that is substantial and integrated with Delta research in other areas such as habitat restoration, flow requirements, or water quality [7]. The following priority actions aim to address these recommendations.

Management Needs	Priority Science Actions
A. Consider human behaviors and stakeholder concerns when developing policy alternatives and potential incentives for improving species habitat conditions [8, 9].	A. Investigate the most cost-effective methods to improve species habitat on working lands [9, 15].
B. Determine how to coordinate and assist adaptive management in the Delta [10-12].	B. Develop tools to assist adaptive management in the Delta [11, 12, 16].
C. Understand human responses to policy and management actions regarding common pool resources in the Delta [13, 14].	C. Initiate a research program on the Delta as an evolving place that integrates the physical and natural sciences with the social sciences [13, 14, 17].

2 . Capitalize on existing data through increasing science synthesis.



Science synthesis is critical to providing a reliable knowledge base for decision-making in the Delta's dynamic and wickedly complex environment. Science synthesis involves the distillation of existing data drawn from many sources across multiple fields to accelerate the generation of new scientific knowledge at a broad scale [18, 19]. Science synthesis can help manage conflict over data interpretation [1], maximizing support for decision-making.

The science actions presented in this action area emphasize implementation of the Delta Science Plan's mechanisms and protocols for making ongoing synthesis more relevant to management issues. These recommendations for strengthening integrative synthetic thinking throughout the Delta science and management community include both multi-year endeavors such as the SBDS and short-term endeavors such as workshops, peer-reviews, and white papers that accelerate understanding of the system [1]. Several existing efforts serve as prime examples of strategic synthesis. These include the IEP Management, Analysis, and Synthesis Team (MAST) and Salmon and Sturgeon Assessment of Indicators by Life stage (SAIL) groups, and the nutrient research plan science workgroups. The information synthesized by these groups serves as an important reference for recent management initiatives such as the Delta Smelt Resiliency Strategy, Sacramento Valley Salmon Resiliency Strategy, Nutrient Research Strategy, State Water Resources Control Board's Phase I Substitute Environmental Document for the Water Quality Control Plan, and draft Biological Opinions related to the California WaterFix.

Management Needs	Priority Science Actions
A. Improve access to legitimate, credible, and relevant summaries of best available science [1, 8].	A. Strategically build the capacity to do collaborative science synthesis through implementing the science synthesis mechanisms outlined in the Delta Science Plan [1, 8, 20].
B. Improve data and information exchange [8].	B. Identify and prioritize important data sources that should be interconnected to promote collaboration and provide the technology necessary to easily access this information [21].

Modelers review digital outputs and mapping. Photo: Amber Manfree.

3 . Develop tools and methods to support and evaluate habitat restoration.

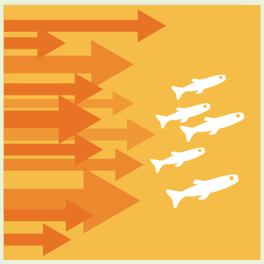
For more than 150 years, management actions and human alterations to the landscape have reduced large areas of native and migratory species habitat in the Delta to small fragmented parcels [21]. This loss of habitat, coupled with stressors described in the fourth action area, has severely compromised the historical Delta ecosystem and its native species. In response to declining species populations and overall ecosystem health, there have been increased efforts to restore natural processes and improve the ecological functions of the Delta as called for in the Delta Reform Act (e.g., Delta Plan, Ecosystem Restoration Program, EcoRestore, CA Department of Fish and Wildlife's Delta Conservation Framework, and Delta Conservancy's Strategic Plan). In addition, regulatory actions, such as the U.S. Fish and Wildlife Service's 2008 Biological Opinion and National Marine Fisheries Service's 2009 Biological Opinion, mandate habitat restoration to improve current conditions for threatened and endangered fish species and their communities. Advanced tools and methods including protocols to measure baseline pre-project conditions are needed to plan and implement projects in an integrated, consistent, and systematic way. These tools and methods also need to be developed within the context of the adaptive management framework called for in the Delta Plan.

Management Needs	Priority Science Actions
A. Evaluate performance of restored areas on a landscape scale [20, 22].	A. Develop methods for evaluating long-term benefits of habitat restoration based on current understanding of how species use restored areas and how use changes over time as habitats evolve [20, 23].
B. Effectively plan restoration, enhancement, and mitigation projects to meet project and/or system-wide goals and objectives [22].	B. Estimate and assess the system-wide effects of the location and sequence of tidal marsh habitat restoration projects in regions where sea level is rising and climate is changing [8].

Scientist sets minnow traps in Suisun Marsh as part of the UC Davis Arc of Habitat study assessing the aquatic ecology of the Cache-Lindsey Slough area, the lower Sacramento River corridor, and Suisun Marsh. Photo: Amber Manfree.

Researchers pull in a beach seine for the UC Davis Suisun Fish and Invertebrate Study. Photo: Amber Manfree.

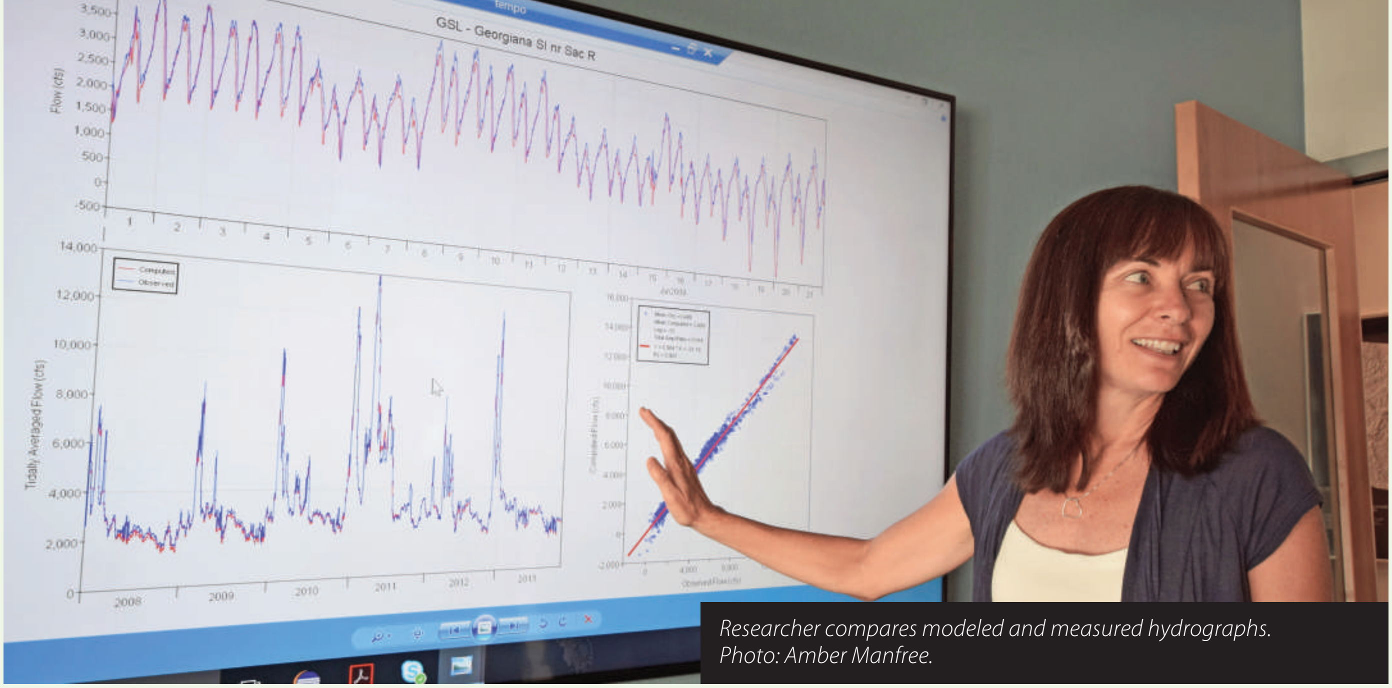
4. Improve understanding of interactions between stressors and managed species and their communities.



In the Delta, stressors are factors that negatively affect species and their communities, with the most notable impact manifesting in the often precipitous decline of populations of native species[24, 25]*. Prominent stressors include increasing climate variability; increasing water and air temperatures; habitat loss; invasive species; and changes in flows, contaminants, and nutrient concentrations. The negative role stressors play in the Delta is well acknowledged* [24, 26-28]*, but it is very difficult to design and implement management actions that holistically address multiple and interacting stressors on species and their communities. Research and monitoring approaches focused on single stressors should be updated to recognize this complexity and take into account system-wide impacts, including thresholds, at multiple spatial scales. Such improvements will help shed light on the simultaneous effects of multiple constituents stressing the ecosystem*[29]*.*

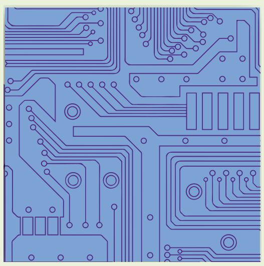
While attempting to address multiple stressors, it is also important to recognize the Delta as a coupled human and natural system, and to support current regulations structured around single species or chemical constituents (e.g., federal and state Endangered Species Acts and the federal Clean Water Act). Existing collaborative research and monitoring groups (e.g., IEP, DRMP) will be instrumental in gathering data and providing a comprehensive overview of the status and trends of stressors to address multiple management questions.

Management Needs	Priority Science Actions
A. Develop conceptual and numeric models to enhance current understanding and inform nutrient management questions [5, 30, 31].	A. Implement studies to better understand the ecosystem response before, during, and after major changes in the amount and type of effluent from large point sources in the Delta including water treatment facilities [21].
B. Quantify the effects of climate change on species, Delta ecology, and potential impacts on water and natural resource management [8].	B. Identify areas that act as refugia for species of concern during extreme conditions, particularly drought and flood, to inform management decisions and priorities during extreme climate events [20].
C. Determine how water operations and restoration actions will affect native fishes to adaptively guide management decisions and restoration design [20].	C. Understand mechanisms for observed relationships between flows and aquatic species [8, 23].
D. Identify and forecast which water quality contaminant sources and processes are most important to understand and quantify [20, 32-34].	D. Evaluate the effects of toxicity (e.g., contaminant mixtures, mercury, pharmaceutical products, HABs) on aquatic species survival including possible effects on predation [8, 9, 23, 32].



Researcher compares modeled and measured hydrographs. Photo: Amber Manfree.

5. Modernize monitoring, data management, and modeling.



A robust science enterprise requires a comprehensive monitoring program paired with infrastructure that supports an intuitive, streamlined system for accessing data to support management actions [2, 35]*. In the Delta, this concept is especially relevant given the rapidly evolving nature of the region* [19]*. The region needs tools and systems that allow it to be nimble and well-coordinated in the face of growing uncertainty.*

Existing computational models (e.g., DSM2, RMA2, and CASCaDE 2) have been instrumental in informing management actions (e.g., temperature plans for the Sacramento River; ecosystem effects of the Emergency Drought Barrier on False River) by improving understanding of monitoring data and conceptual thinking about the Delta [36, 37]*. New efforts under The Open and Transparent Water Data Act (AB 1755) aim to promote more timely access to information that supports these models. The Act requires the development of a "statewide integrated water data platform that … [will] integrate existing water and ecological data information from multiple databases." In addition, established monitoring programs (e.g., IEP and DRMP) that collect continuous, comprehensive, and long-term data sets will be critical for continued optimal model performance and enhanced tool development. Supporting existing collaborative monitoring groups and developing "data stewardship"* [34] *that provides wide access to information is critical for forward thinking, nimble, and coordinated decision-making* [35, 36]*.*

Management Needs	Priority Science Actions
A. Utilize models of the Delta and visualization tools that are widely accessible and sustained by multiple sources to predict and assess the likely outcomes of management actions and environmental change (preferably in real-time) [8].	A. Advance integrated modeling through efforts such as an open Delta collaboratory (physical or virtual) that promotes the use of models in guiding policy [38].
B. Increase capacity to be nimble, prepared, and responsive to new demands, including emerging and opportunistic science needs [8].	B. Explore innovative technologies and cost-effective methods for scientific monitoring and analysis of flow, water quality, and ecosystem characteristics (e.g., improved tools for fish monitoring, LiDAR, high-resolution bathymetry technology, new measurements for Delta levee hazards, and citizen scientist monitoring programs) [9, 23, 38-40].

Table 1: Intersection of Priority Science Actions with Chapters in the Delta Plan

1: Invest in assessing the human dimensions of natural resource management decisions.

Science Action	*Relevant Delta Plan Chapters*	
A. Investigate the most cost-effective methods to improve species habitat on working lands.	**Chapter 3:**	A More Reliable Water Supply for California
	Chapter 5:	Protect and Enhance the Unique Cultural, Recreational, Natural Resource, and Agricultural Values of the California Delta as an Evolving Place
	Chapter 6:	Improve Water Quality to Protect Human Health and the Environment
B. Develop tools to assist adaptive management in the Delta.	**Chapter 3:**	A More Reliable Water Supply for California
	Chapter 4:	Protect, Restore, and Enhance the Delta Ecosystem
	Chapter 5:	Protect and Enhance the Unique Cultural, Recreational, Natural Resource, and Agricultural Values of the California Delta as an Evolving Place
C. Initiate a research program on the Delta as an evolving place that integrates the physical and natural sciences with the social sciences.	**Chapter 3:**	A More Reliable Water Supply for California
	Chapter 5:	Protect and Enhance the Unique Cultural, Recreational, Natural Resource, and Agricultural Values of the California Delta as an Evolving Place
	Chapter 6:	Improve Water Quality to Protect Human Health and the Environment

2: Capitalize on existing data through increasing science synthesis.

Science Action	*Relevant Delta Plan Chapters*	
A. Strategically build the capacity to do collaborative science synthesis through implementing the science synthesis mechanisms outlined in the Delta Science Plan.	**Chapter 3:**	A More Reliable Water Supply for California
	Chapter 4:	Protect, Restore, and Enhance the Delta Ecosystem
	Chapter 5:	Protect and Enhance the Unique Cultural, Recreational, Natural Resource, and Agricultural Values of the California Delta as an Evolving Place
	Chapter 6:	Improve Water Quality to Protect Human Health and the Environment
	Chapter 7:	Reduce Risk to People, Property, and State Interests in the Delta
B. Identify and prioritize important data sources that should be interconnected to promote collaboration and provide the technology necessary to easily access this information.	**Chapter 3:**	A More Reliable Water Supply for California
	Chapter 4:	Protect, Restore, and Enhance the Delta Ecosystem
	Chapter 5:	Protect and Enhance the Unique Cultural, Recreational, Natural Resource, and Agricultural Values of the California Delta as an Evolving Place
	Chapter 6:	Improve Water Quality to Protect Human Health and the Environment
	Chapter 7:	Reduce Risk to People, Property, and State Interests in the Delta

3: Develop tools and methods to support and evaluate habitat restoration.

Science Action	*Relevant Delta Plan Chapters*	
A. Develop methods for evaluating long-term benefits of habitat restoration based on current understanding of how species use restored areas and how use changes over time as habitats evolve.	**Chapter 4:**	Protect, Restore, and Enhance the Delta Ecosystem
	Chapter 6:	Improve Water Quality to Protect Human Health and the Environment
B. Estimate and assess the system-wide effects of location and sequence of tidal marsh habitat restoration projects in regions where sea level is rising and climate is changing.	**Chapter 4:**	Protect, Restore, and Enhance the Delta Ecosystem
	Chapter 6:	Improve Water Quality to Protect Human Health and the Environment

4: Improve understanding of interactions between stressors and managed species and their communities.

Science Action	*Relevant Delta Plan Chapters*
A. Implement studies to better understand the ecosystem response before, during, and after major changes in the amount and type of effluent from large point sources in the Delta including water treatment facilities.	**Chapter 3:** A More Reliable Water Supply for California **Chapter 4:** Protect, Restore, and Enhance the Delta Ecosystem **Chapter 6:** Improve Water Quality to Protect Human Health and the Environment
B. Identify areas that act as refugia for species of concern during extreme conditions, particularly drought and flood, to inform management decisions and priorities during extreme climate events.	**Chapter 3:** A More Reliable Water Supply for California **Chapter 4:** Protect, Restore, and Enhance the Delta Ecosystem **Chapter 6:** Improve Water Quality to Protect Human Health and the Environment
C. Understand mechanisms for observed relationships between flows and aquatic species.	**Chapter 3:** A More Reliable Water Supply for California **Chapter 4:** Protect, Restore, and Enhance the Delta Ecosystem **Chapter 6:** Improve Water Quality to Protect Human Health and the Environment
D. Evaluate the effects of toxicity (e.g., contaminant mixtures, mercury, pharmaceutical products, HABs) on aquatic species survival including possible effects on predation.	**Chapter 3:** A More Reliable Water Supply for California **Chapter 4:** Protect, Restore, and Enhance the Delta Ecosystem

5: Modernize monitoring, data management, and modeling.

Science Action	*Relevant Delta Plan Chapters*
A. Advance integrated modeling through efforts such as an open Delta collaboratory (physical or virtual) that promotes the use of models in guiding policy.	**Chapter 3:** A More Reliable Water Supply for California **Chapter 4:** Protect, Restore, and Enhance the Delta Ecosystem **Chapter 5:** Protect and Enhance the Unique Cultural, Recreational, Natural Resource, and Agricultural Values of the California Delta as an Evolving Place **Chapter 6:** Improve Water Quality to Protect Human Health and the Environment **Chapter 7:** Reduce Risk to People, Property, and State Interests in the Delta
B. Explore innovative technologies and cost-effective methods for scientific monitoring and analysis of flow, water quality, and ecosystem characteristics (e.g., improved tools for fish monitoring, LiDAR, high-resolution bathymetry technology, new measurements for Delta levee hazards, and citizen scientist monitoring programs).	**Chapter 3:** A More Reliable Water Supply for California **Chapter 4:** Protect, Restore, and Enhance the Delta Ecosystem **Chapter 5:** Protect and Enhance the Unique Cultural, Recreational, Natural Resource, and Agricultural Values of the California Delta as an Evolving Place **Chapter 6:** Improve Water Quality to Protect Human Health and the Environment **Chapter 7:** Reduce Risk to People, Property, and State Interests in the Delta

Science Infrastructure

Critical infrastructure underpins the science enterprise in the Delta. Long-term support for the current infrastructure, along with investments in new tools and capacity, will guarantee a vibrant Delta science enterprise. Many of the priority science actions identified in this agenda require continued or new investments in the form of physical, computational, virtual, and human infrastructure. Examples of valuable physical infrastructure include:

- Acoustic doppler current profilers – networks of instruments to measure three-dimensional water current velocities and Delta flows
- Continuous real-time water quality stations – real-time telemetered sensor networks for measuring Delta temperature, specific conductance (salinity), pH, turbidity, dissolved oxygen, chlorophyll, nitrate, phosphate, ammonium, and fluorescence
- Acoustic telemetry tags and receivers – networks for tagging and remote tracking of fish in 3D throughout the Delta
- Environmental genomics and environmental DNA monitoring – rapid monitoring of aquatic distributions and abundance directly from Delta water samples
- Tide and water level gauges and other infrastructure to support restoration planning, track sea level rise, and environmental monitoring [41]

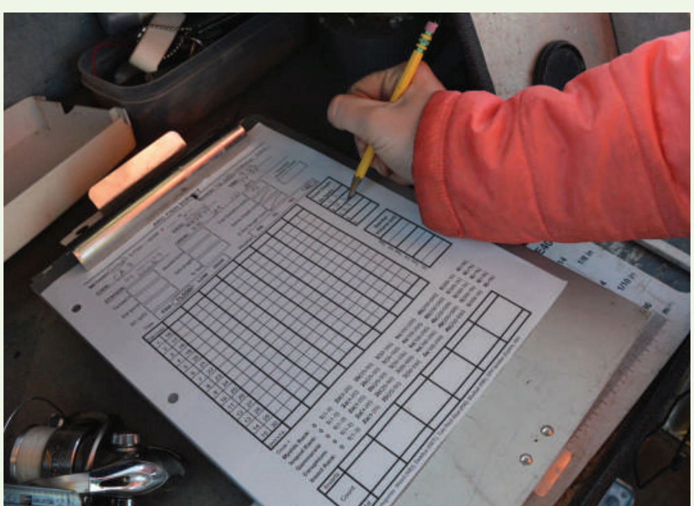
Such infrastructure provides critical tools for informing real-time operations and water quality management. In addition, supporting virtual infrastructure for open and transparent sharing of water and environmental data increases the capacity for collaborative science synthesis, facilitates innovative ways to share data across agencies and organizations, and sets the stage for a federated data sharing system.

These examples underscore how even single one-time investments in long-term infrastructure can be the catalyst for moving multiple priority science actions forward. Future funding for science infrastructure deserves to be promoted as high priority and should facilitate meeting multiple needs that broadly serve the Delta science enterprise.

Next Steps

The 2017-2021 Science Action Agenda spans the gaps and provides the glue necessary to advance science usable for Delta decision-making. The success of the agenda relies on the dedication of the Delta science enterprise to work intentionally and collectively to support and fund these 13 priority science actions. Example mechanisms include, but are not limited to, joint competitive solicitations for science proposals and coordinated agency budget change proposals.

The following measures may be used to evaluate the Delta community's collective success in implementing the 2017-2021 Science Action Agenda:



Researcher logs results in the field. Photo: Amber Manfree.

- Use of the action areas and priority science actions to inform proposal solicitation packages, requests for proposals, or other mechanisms for selecting and funding science activities
- Reference to the 2017-2021 SAA in communications regarding regional science priorities
- Evidence of management and policy decisions being founded on scientific information gained as a result of implementing the 2017-2021 SAA
- Modernization of science infrastructure to allow rapid response and capacity to learn from novel and opportunistic events (e.g., levee failures, severe floods, earthquakes, prolonged droughts, introductions of new invasive species, chemical spills).

Through collaborative advancement of this agenda on the part of the Delta science enterprise, and a joint commitment to its promotion and accomplishment, this agenda will help fill scientific knowledge gaps and modernize science-based tools to support decision-makers and resource managers addressing the wickedly complex issues of the current and future Delta.

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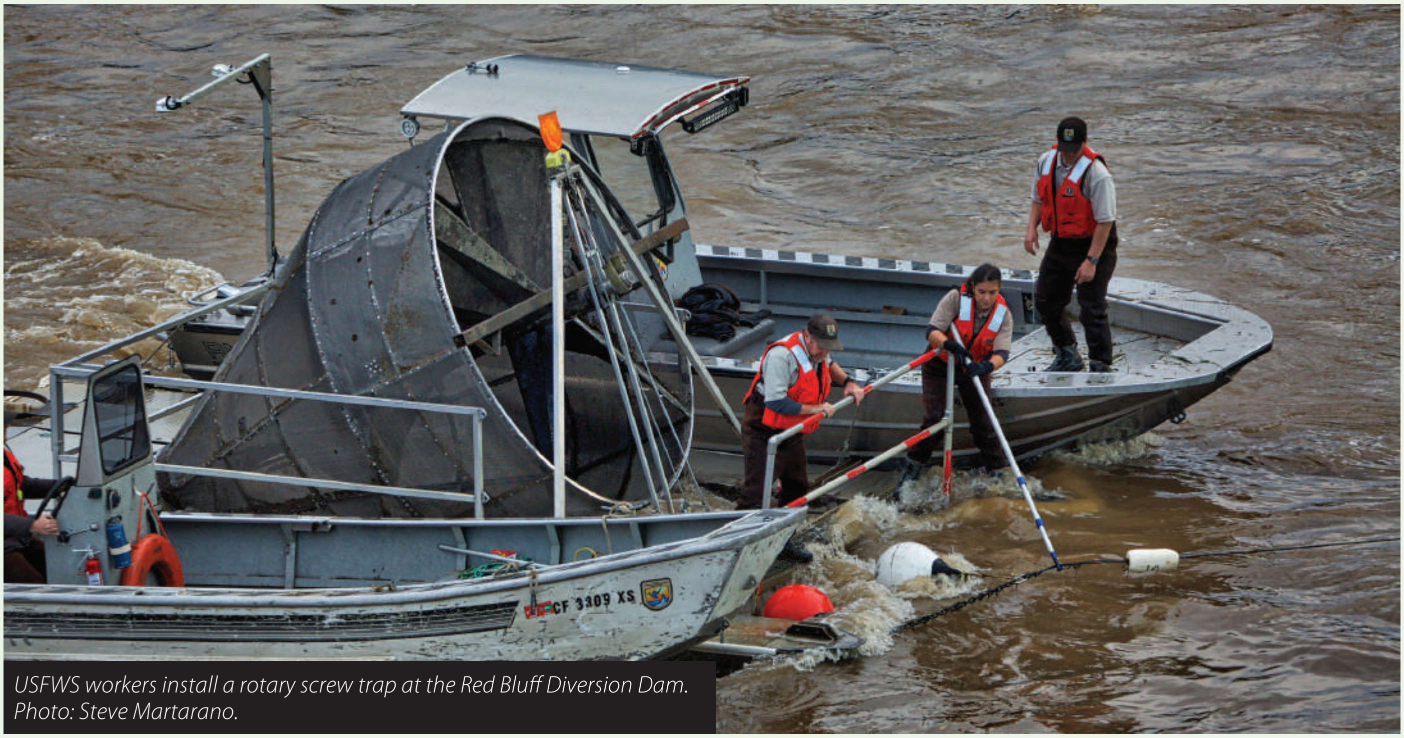
GUIDE TO ACRONYMS

AB	Assembly Bill
ASC	Aquatic Science Center
CAMT	Collaborative Adaptive Management Team
CASCaDE2	Computational Assessments of Scenarios of Change for the Delta Ecosystem 2
CECs	Constituents of Emerging Concern
CSAMP	Collaborative Science and Adaptive Management Program
CVPIA	Central Valley Project Improvement Act
DASW	Delta Agency Science Workgroup
Delta ISB	Delta Independent Science Board
DSM2	Delta Simulation Model II
DSP	Delta Science Program
DRMP	Delta Regional Monitoring Program
ESA	Endangered Species Act
HAB	Harmful Algal Bloom
IEP	Interagency Ecological Program
ISAA (2014)	Interim Science Action Agenda
LiDAR	Light Detection and Ranging
LTER	Long-Term Ecological Research
MAST	Management, Analysis, and Synthesis Team
NSF	National Science Foundation
QA/QC	Quality Assurance/ Quality Control
RMA2	Resource Management and Associates Hydrodynamic Model II
SAA	Science Action Agenda
SAC	Science Advisory Committee (for the Delta Science Program)
SAIL	Salmon and Sturgeon Assessment of Indicators by Life stage
SBDS	The State of Bay Delta Science
SFCWA	State and Federal Contractors Water Agency



USFWS workers install a rotary screw trap at the Red Bluff Diversion Dam.
Photo: Steve Martarano.

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APPENDICES

Researcher tests turbidity with secchi disk. Photo: Michelle Avila.

Appendix A: Additional Science Actions

These additional science actions are recognized as important actions that should be taken on as funds become available and higher priority science actions are addressed.

1. Invest in assessing the human dimensions of natural resource management decisions.

Management Need	*Science Action*
A. Obtain data that can quantify the effects of climate change and extreme events on agriculture and economy to inform adaptation strategies (e.g., potential for flood risk, how will increasing temperatures affect regional crop mixes, water pricing, and employment?) [1, 2].	A. Implement studies to understand socio-economic adaptations to climate change (e.g., human behavioral response in the agriculture sector to changes in water prices) [2, 3].
B. Evaluate success of restored areas on a landscape scale (e.g., do the habitat benefits of managed wetlands and ponds outweigh potential costs to native species and out of production agricultural land?) [2, 4].	B. Develop a methodology for assessing the long-term costs and benefits of managed wetlands and ponds [2, 3].
C. Identify new measurements of Delta levee hazards (e.g., areas prone to liquefaction, subsidence risk, etc.) [3, 5].	C. Initiate Delta levee risk assessment studies that address individualized levee fragility curves, identify levee sections most subject to earthquake-induced liquefaction, clarify attenuation of ground motions from Bay Area earthquakes, monitor land-level changes adjacent to levees post-earthquakes, hydrodynamic studies to project magnitude of levee breaches, duration, and severity of disruption [3, 5].

2. Capitalize on existing data through increasing science synthesis.

Management Need	*Science Action*
A. Obtain population abundance estimates and trends for Green and White Sturgeon (e.g., use model outputs to evaluate trends in Green Sturgeon abundance) [6, 7].	A. Develop improved sturgeon abundance estimates through modeling and synthesizing data from cohort abundance studies, surveys, and report cards [6].
B. Enhance knowledge of predator-prey relationships and how changes in flow, climate, and habitat may affect these relationships (e.g., would predator reduction techniques be feasible, effective, and have acceptably low impacts on listed species?) [8, 10].	B. Produce a system-wide analysis of existing telemetry results to provide an understanding of fish movement and predation [3].

3. Develop tools and methods to support and evaluate habitat restoration.

Management Need	*Science Action*
A. Understand how species use restored areas (e.g., how does tidal marsh restoration affect production of food suitable for listed fish species both within and outside of restored sites?) [2, 9].	A. Review efforts to examine effectiveness of habitat restoration [2].
B. Evaluate success of restored areas on water quality on a landscape scale (e.g., to what extent does intertidal wetland restoration result in changes in contaminants such as mercury and photochemically active organic compounds that could affect listed fishes?) [1, 2].	B. Collect environmental, social, and economic baseline data and develop a database of pre-project habitat conditions at the landscape scale (e.g., native species presence/condition, water quality, current food and predator densities, conditions in adjacent channels, and socio-economic valuations of management practices and environmental stewardship) [2, 11].

4. Improve understanding of interactions between stressors and managed species and their communities.

Management Need	*Science Action*
A. Predict how environmental stressors will affect the health condition of salmonids in the Bay-Delta, migratory corridors and natal tributaries (e.g., what is the relative importance of temperature mortality in the salmon life cycle?) [2,12].	A. Better understand salmonid temperature tolerances in streams and rivers [3, 12].
B. Improve ability to prevent, conduct early detection, rapid response, eradication and control of non-native and potential invasive species [3].	B. Identify effective mechanical and biological control strategies for established non-native clams and potential invasive mussels, including developing effective prevention measures for potential invaders [3].

5. Modernize monitoring, data management, and modeling.

Management Need	*Science Action*
A. Determine how water project operations affect salmon population dynamics and survival within the Delta's complex channel network to guide water operations timing, provide early warning, and accelerate recovery efforts and habitat restoration design (e.g., quantitatively understand salmon distribution and movement for real-time water operations) [12].	A. Build on existing models to integrate fish and water quality monitoring data to report, simulate, and forecast distribution of salmon runs in time and space. These actions should be coordinated with tagging studies and other monitoring data to provide accurate and consistent interpretation of information to support decision-makers (e.g., coupling 3-D hydrodynamic modeling of the Delta with juvenile salmon behavior and survival) [12, 13].
B. Identify anadromous fish habitat usage and attributes to guide resource allocations for their protection, conservation, and recovery (e.g., what is the potential effect of flow and temperature on Green and White sturgeon spawning?) [7].	B. Conduct baseline surveys throughout spawning habitat, map egg collection and larval rearing habitat, and quantify availability using various characteristics identified through egg sampling (water temperature, depth, velocity, substrate, etc.) [6, 7].
C. Improve monitoring to include more relevant information about health, distribution, and abundance of wetland species in light of climate change uncertainty (e.g., what opportunities exist for joint implementation of Regional Water Quality Control Board regions 5 & 2 monitoring plans?) [2, 4].	C. Develop and implement a Bay Area and Delta regional wetland monitoring program [14].

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CDFW researchers dissect fish to learn more about their diet. Photo: Michelle Avila.

Appendix B: Science Action Agenda Development Process

Introduction and Background

Delta Science Plan Action 2.2 calls for the development, implementation, and update of a Science Action Agenda that organizes, integrates, and prioritizes science activities across agencies and programs to address decision-makers' needs in an efficient manner. The Interim Science Action Agenda (ISAA), completed in November 2014, took an initial step toward achieving this action while also providing the foundation for the High-Impact Science Actions, a list of high-impact, multi-benefit science actions for immediate implementation in 2015-2016.

The following is a record of the methods used to identify a draft list of priority science actions for inclusion in the SAA. Science activities for the SAA were identified and updated through an open process led by the Delta Science Program. The process included outreach efforts to communicate the SAA's purpose and to solicit recommendations for science actions and management needs, a brainstorming session to incorporate social science perspectives in the current list of science actions, and review of the refined list by the Delta science community. Methods used to prioritize these science actions are explained in Appendix C.

Initial List Development (May 2016 – November 2016)

An initial list of key management actions and associated science actions were compiled from 1) science actions identified in the ISAA, 2) documents listed in Tables B.1, and B.2) outreach efforts described in the section below. To minimize redundancies in sources gathered while developing the ISAA, the literature review was limited to the ISAA and documents related to collaborative groups in the Delta. This provided a good representation of management needs and science actions shared by Delta-wide communities. A list of 557 combined management needs and associated science actions were compiled from these sources. A copy of the master list of compiled management needs and science actions can be found here:
https://deltacouncil.box.com/s/kzkt0thqu4cjnd9pmd7fxb89cldofkxc

Outreach for Advice on Initial List (June 2016 – February 2017)

The development of the Science Action Agenda is designed to be an open process: the master list of management needs and science actions was compiled through meetings with collaborative groups and by referencing relevant documents (see Tables B.1 and B.2). To ensure a wide range of Delta science interests, collaborative federal and State groups, stakeholders, and academics were contacted. Outreach meetings consisted of providing the respective organizations with the Science Action Agenda's purpose and development process, and a request for individuals to provide recommendations for sources of management needs and associated science actions to add to the initial list.

During the Bay-Delta Science Conference (November 2016), a Town Hall was held to receive input from the broad Delta community. Prior to the Town Hall, an online survey was posted on the Delta Stewardship Council website to receive input on any key science actions and management needs not included in the current list. The survey was also distributed through the Bay-Delta Science Conference and Delta Stewardship Council listservs. Questions in the survey ranged from asking the user to identify science actions that help fill knowledge gaps, to highlight emerging tools and technology that would help inform management decisions, and to describe how the SAA would be useful to the user. Recurring science actions and themes included increased monitoring efforts, integrated modeling, and continuous water quality sensors.

The Science Enterprise Workshop, which took place in November 2016, emphasized the importance of integrating the social sciences in research and monitoring to inform management needs. To ensure social science was well represented in the SAA, UC Davis faculty with expertise in studying the human dimensions of natural resource management were contacted to provide input on the draft list. A meeting took place in December 2016 at UC Davis, where the faculty members provided thoughtful input including suggestions about where and how social sciences could be better incorporated in the draft list of science actions. As a result, questions and actions were broadened to better integrate the social sciences with the physical and natural sciences in multiple action areas.

Refining the List of Management Needs and Associated Science Actions (June 2016 – March 2017)

Once the master list was stable, science actions and management needs with similar messages or goals were merged while actions already completed or well underway were removed. The remaining 158 science actions and management needs were compiled into a spreadsheet, initially grouped by the 17 action areas identified in the ISAA (organized by Delta Plan chapters and topics related to science infrastructure and capacity). Both the screening and prioritization criteria were applied to this set of 158 science actions (see Appendix C for more details). This resulting list of 28 science actions was presented to the Delta Science Program and IEP Lead Scientists for review. Based upon the lead scientists' suggestion, this list of science actions was further re-organized into five thematic science action areas. During the thematic reorganization of the actions, one action was further merged with other actions. This draft "short list" of 27 actions served as a starting point for further review and prioritization.

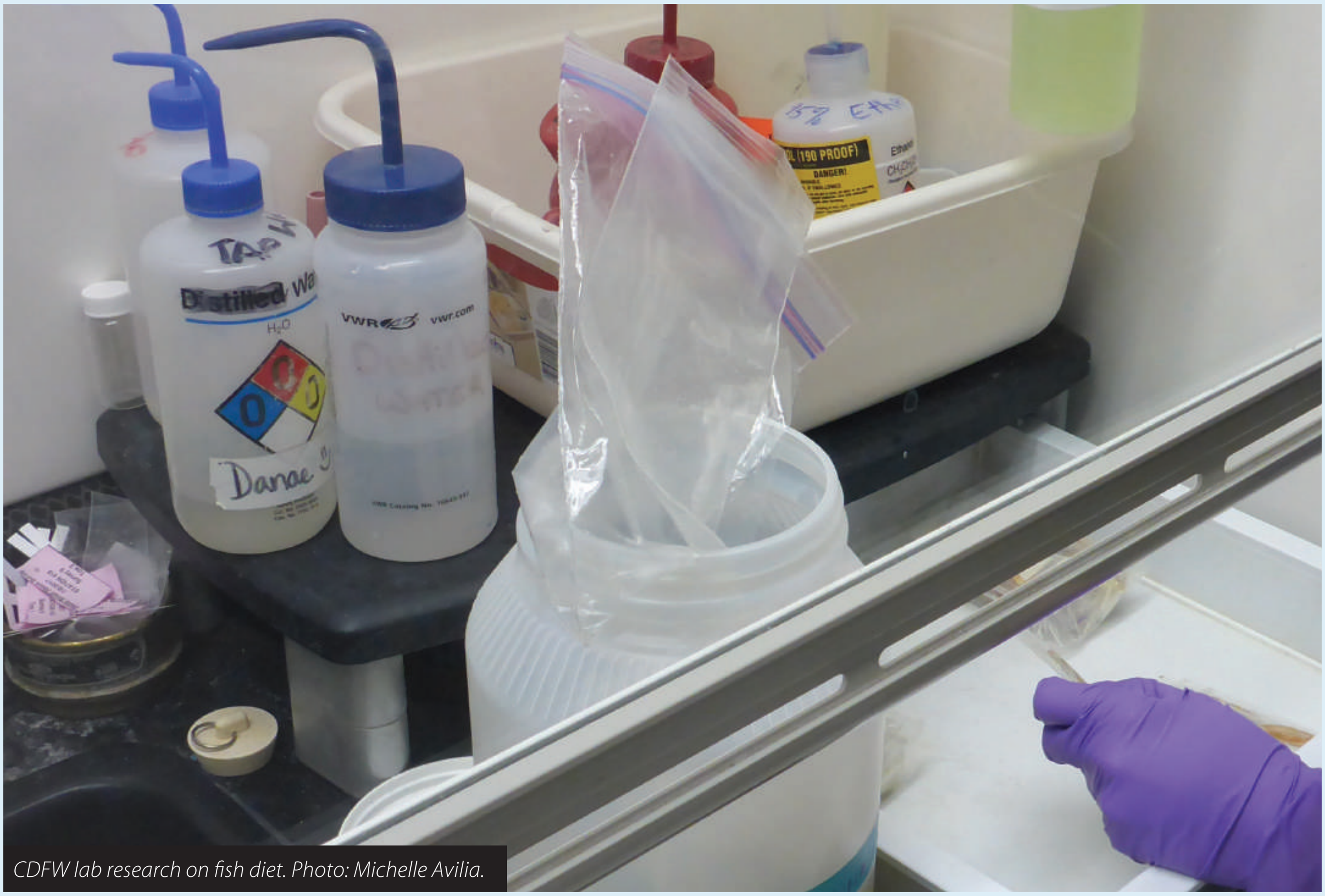
The list of 27 science actions was presented to the Science Advisory Committee for the Delta Science Program, the Delta Science Program and IEP Lead Scientists, and leading scientists from other agencies and stakeholder groups for input on whether the list was comprehensive or still missing key science actions. Comments from these groups were compiled and addressed.

At the Delta Agency Science Workgroup meeting in March 2017, the list of 27 science actions incorporating input from the groups noted above was presented for further refinement and prioritization (please see Appendix C for details on the prioritization process). The DASW provided input to ensure all the science actions were indeed not fully addressed and some wordsmithing suggestions were received. Based on suggestions from the DASW, two of the 27 science actions were merged and one dropped resulting in a final list of 24 science actions. The 12 priority science actions were included in the draft SAA (April 2017), while the remaining 12 science actions were placed in Appendix A of the draft document.

Public Comment on Draft Science Action Agenda (April – June 2017)

The draft science action agenda was posted on the Delta Science Program web page on April 10, 2017 for public comment. As mentioned above, a public survey was posted during the collating of priority science actions to receive input from a wide audience for initial input. In addition, both the Interim Science Action Agenda and High Impact Science Actions, on which many of the science actions in the SAA are based, were also open to public review and comment, enabling input from a wide range of interests.

Twelve public comment letters and emails were received. The comments and recommendations provided valuable input for improving the science actions and the relevance of the SAA to the wider Delta community. Public recommendations generally included feedback emphasizing the need to address Delta as a place, climate change, and



CDFW lab research on fish diet. Photo: Michelle Avilia.

organization of the science actions (see section below for more details). Copies of the comment letters and email can be viewed here: https://deltacouncil.box.com/s/nj27hsht9t2ahq92y2ijneurlur02268

Delta Independent Science Board Comments on Draft Science Action Agenda (June 2017)

Several changes were made to the draft SAA based on overall, general, and specific comments from the Delta ISB. Major comments included the need for science actions that addressed Delta as an evolving place, levees, and water supply reliability; clarification of the methods; and suggestions for better wording of the science actions. In response to these recommendations, science action wording was adjusted and sections of the document were clarified.

Modifying the Science Actions Based on Comments (June – July 2017)

The following is a description of key changes made to the list of Priority Science Actions and Actions in Appendix A in response to comments and suggestions received from the public, Delta ISB, and Delta Science Program Lead Scientist. Based on public comment and guidance from the Delta Science Program Lead Scientist, the ordering of science action areas 1 and 4 were changed. In attempts to minimize confusion, action area 1 (action area 4 in the April 2017 draft) will be termed the "human-dimension action area", while action area 4 (action area 1 in the April 2017 draft) will be termed the "stressor action area".

Modifications to Priority Science Action List (July 2017)

Based on recommendations from the public and Delta ISB, a science action to integrate more social science in Delta research was added to the human-dimension action area. There were several suggestions to merge science actions 2B and 5A in the April 2017 SAA draft, as they both related to integrating data. In response, science action 2B was reworded, while science action 5A was removed. General rewording was also applied to various science actions to improve clarity. Specific examples of management needs and science actions were moved to Appendix D to further emphasize that these examples are only select examples and are not an exhaustive list.

Modifications to Appendix A (July 2017)

In response to public comment, both science actions A and C from the stressor action area were moved to the priority list. With guidance from the Delta Science Program Lead Scientist, a science action from the master list was added to the stressor action area in Appendix A. A science action related to increasing levee-related research was added under the human-dimensions action area in response to comments from the public and Delta ISB.

Delta Stewardship Council Acceptance (July – August 2017)

The Delta Stewardship Council was asked to receive and accept the proposed final draft SAA at its July 2017 meeting. At the meeting, the Delta Science Program Lead Scientist and staff provided a summary and presented the proposed final draft SAA to the Council, while also providing additional opportunities for public comment.

The final editorial completion in August 2017 was presented as part of the Lead Scientists' Report. The final SAA will be presented to both the DASW and DPIIC during their respective meetings, scheduled for fall 2017, to seek participation in jointly implementing the SAA.

Table B.1: List of Documents Used in Compiling Science Actions and Management Needs

Title of Document	*Associated Organization*
Adaptive Management Framework for the California Water Fix and Current Biological Opinions on the coordinated operations of the Central Valley and State Water Projects (2016)	California Department of Fish and Wildlife
Effects of Fish Predation on Salmonids in the Sacramento River - San Joaquin Delta and Associated Ecosystems (2013)	California Department of Fish and Wildlife, Delta Stewardship Council, National Marine Fisheries Service
California Water Action Plan (2016)	California Natural Resources Agency
Increasing efficiency and effectiveness through collaboration: First triennial audit of implementing A Comprehensive Monitoring Program Strategy for California 2011-2014 (2014)	California Water Quality Monitoring Council
Central Valley Improvement Plan 2017 Work plan Attachment 1: Memo on CVPIA Core Team Priorities (2016)	Central Valley Project Improvement Act
Central Valley Improvement Plan 2017 Work plan	Central Valley Project Improvement Act
Calendar Year 2015 Annual Progress Report to the Collaborative Science Policy Group (2016)	Collaborative Science and Adaptive Management Program/ Collaborative Adaptive Management Team
Key Management Questions Regarding South Delta Salmonid Survival and Water Project Exports (2017)	Collaborative Science and Adaptive Management Program/ Collaborative Adaptive Management Team
Effects of Water Project Operations on Juvenile Salmonid Migration and Survival in the South Delta (2017)	Collaborative Adaptive Management Team Salmonid Scoping Team
Habitat Restoration in the Sacramento-San Joaquin Delta and Suisun Marsh: A Review of Science Programs (2013)	Delta Independent Science Board
Flows and Fishes in the Sacramento-San Joaquin Delta: Strategic Research Needs in Support of Adaptive Management (2015)	Delta Independent Science Board
Improving Adaptive Management in the Sacramento-San Joaquin Delta: A Review by the Delta Independent Science Board (2016)	Delta Independent Science Board
Workshop report—Earthquakes and High Water As Levee Hazards in the Sacramento-San Joaquin Delta (2016)	Delta Independent Science Board
Review of Research on the Sacramento-San Joaquin Delta as an Evolving Place (2017)	Delta Independent Science Board
Interim Science Action Agenda (2014)	Delta Science Program
Delta Regional Monitoring Program Monitoring Design 2015 (2015)	Delta Regional Monitoring Program
Challenges Facing the Sacramento-San Joaquin River Delta: Complex, Chaotic, or Simply Cantankerous? (2015)	Delta Science Program
High Impact Science Actions (2015)	Delta Science Program
SBDS Chapter—An Overview of Multi-Dimensional Models of the Sacramento-San Joaquin Delta (2016)	Delta Science Program
SBDS Chapter—Anadromous Salmonids in the Delta: New Science 2006–2016 (2016)	Delta Science Program
SBDS Chapter—Climate Change and the Delta (2016)	Delta Science Program
SBDS Chapter—Contaminant Effects on California Bay-Delta Species and Human Health (2016)	Delta Science Program
SBDS Chapter—The Delta as Changing Landscapes (2016)	Delta Science Program
SBDS Chapter—Delta Smelt: Life History and Decline of a Once-Abundant Species in the San Francisco Estuary (2016)	Delta Science Program
SBDS Chapter—Nutrient Dynamics in the Delta: Effects on Primary Producers (2016)	Delta Science Program
SBDS Chapter—Perspectives on Bay-Delta Science Policy (2016)	Delta Science Program
SBDS Chapter—Predation on Fishes in the Sacramento–San Joaquin Delta: Current Knowledge and Future Directions (2016)	Delta Science Program
SBDS Call Out Box: Climate Change (2016)	Delta Science Program
SBDS Call Out Box: Contaminants (2016)	Delta Science Program
SBDS Call Out Box: Delta Smelt (2016)	Delta Science Program
SBDS Call Out Box: Flow (2016)	Delta Science Program
SBDS Call Out Box: Food Web (2016)	Delta Science Program

Table B.1 (continued)

Title of Document	*Associated Organization*
SBDS Call Out Box: Modeling (2016)	Delta Science Program
SBDS Call Out Box: Nutrients (2016)	Delta Science Program
2016 Bay Delta Science Conference Town Hall Survey (2016)	Delta Science Program
Delta Plan (2013)	Delta Stewardship Council
Risk Analysis Methodology Delta Levees Investment Strategy (2016)	Delta Stewardship Council
Science Enterprise Workshop: Supporting and Implementing Collaborative Science (2016)	Delta Stewardship Council
Interagency Ecological Program 2016 Annual Work Plan (2015)	Interagency Ecological Program (IEP)
IEP Science Strategy—Needs for Near-term Science in Five Areas of Emphasis: Responses to Drought and Climate Change, Understanding Estuary Food Webs, Ecological Contribution of Restored Areas, Restoring Native Species and Communities, and Impacts of Non-native Species (2016)	Interagency Ecological Program (IEP)
An updated conceptual model of Delta Smelt biology: Our evolving understanding of an estuarine fish (2015)	IEP Management, Analysis, and Synthesis Team (MAST)
Diagnosis of a drought syndrome in the San Francisco Estuary (submitted, 2016)	IEP Management, Analysis, and Synthesis Team (MAST)
Review of the IEP Delta Juvenile Fishes Monitoring Program and Delta Juvenile Salmonid Survival Studies (2013)	IEP Scientific Advisory Group
Increasing the management value of life stage monitoring networks for three imperiled fishes in California's regulated rivers: case study Sacramento Winter-run Chinook salmon (2016)	IEP Salmon and Sturgeon Assessment, Indicators, Life Stages (SAIL)
Increasing the management value of life stage monitoring networks for three imperiled fishes in California's regulated rivers: case studies Southern Distinct Population Segment 2 of the North American Green Sturgeon and Sacramento-San Joaquin River White Sturgeon (2016)	IEP Salmon and Sturgeon Assessment, Indicators, Life Stages (SAIL)
Factors Affecting Growth of Cyanobacteria With Special Emphasis on the Sacramen-to-San Joaquin Delta (2016)	Nutrient Research Strategy Science Work Group
Factors Controlling Submersed and Floating Macrophytes in the Sacramento-San Joaquin Delta (2016)	Nutrient Research Strategy Science Work Group
Recommendations for a Modeling Framework to Answer Nutrient Management Questions in the Sacramento-San Joaquin Delta (2016)	Nutrient Research Strategy Science Work Group
Draft Research Plan 2015 (2015)	State and Federal Contractors Water Agency's coordinated science program
SFCWA Draft Salmon Questions (2016)	State and Federal Contractors Water Agency's coordinated science program
Comprehensive Conservation and Management Plan (2016)	San Francisco Estuary Partnership
Multi-Year Plan 2016 Annual Update (2016)	San Francisco Regional Monitoring Program
Primary Production in the Sacramento-San Joaquin Delta (2016)	San Francisco Estuary Institute/Delta Science Program
Wetland Status and Trends Program Implementation Proposal (2014)	Southern California Coastal Water Research Project
Monitoring of Constituents of Emerging Concern (CECs) in California's Aquatic Ecosystems - Pilot Study Design and QA/QC Guidance (2015)	Southern California Coastal Water Research Project
Past, Present and Future Approaches to Incidental Take (2015)	US Fish and Wildlife Service
Integrated Modeling for Adaptive Management of Estuarine Systems (2015)	UC Davis Center for Watershed Sciences
Delta Region Area-wide Aquatic Weed Project (website, accessed June 2016)	UC Division of Agriculture and Natural Resources
Wildlife Corridors for Flood Escape on the Yolo Bypass Wildlife Area (2016)	Yolo County Conservation District

Table B.2: List of Organizations that Provided Input on Management Needs and Science Actions to Include in the Science Action Agenda

- Collaborative Adaptive Management Team
- Delta Agency Science Workgroup
- Delta Independent Science Board
- Delta Plan Interagency Implementation Committee
- Delta Regional Monitoring Program
- Interagency Ecological Program
- Scientific Advisory Committee
- UC Davis Social Science Faculty
- Town Hall at the Bay Delta Science Conference

Appendix C: Developing and Applying Science Action Prioritization Criteria

The following is a description of 1) the screening approach for the initial set of management questions/needs and science actions that promote science-support for Delta decision-making relevant to achieving the coequal goals and implementing multi-agency and organizations' actions, and 2) the criteria and approach for prioritizing science actions. Prioritizing science actions is complicated and challenging; however, with limited resources, it is an essential task. No single prioritization approach exists across other major complex systems or disciplines. The approach outlined here is a hybrid of various prioritization processes from different groups and efforts listed in Table C.1.

Draft Screening and Prioritization Criteria (May – June 2016)

Two sets of criteria were developed to identify priority science actions to achieve the vision of *One Delta, One Science*: 1) screening criteria, which were applied to refine the master list, and 2) science prioritization criteria, used to prioritize the refined list of science actions. These criteria were developed with input from others and using examples from several sources found in Table C.1, which included various collaborative research programs around the United States and NSF.

Outreach and Advice on the Draft Prioritization Criteria (June – November 2016)

Draft prioritization criteria and draft science actions were presented at the various outreach efforts described in Appendix B. In advance of each of these meetings, the draft list of prioritization criteria was provided for review and input at the outreach events. Comments received were mostly related to clarifying some of the criteria language and their ordering. The final set of screening and prioritization criteria are listed below:

Screening Criteria

1. Science Topics Not Fully Addressed

    a. The science action will contribute to forthcoming decisions that require information to evaluate the best alternatives. Currently, this information is only partially supported, or alternatives and their associated uncertainties have not been fully explored.

    b. The management need is only partially addressed by an agency, set of agencies, or groups and thus requires further attention from the broader Delta community.

    c. The science action is only being partially funded or addressed by an agency or group and requires cross-agency support or is currently not being addressed by any group. Science actions that are well supported or in the final stages of implementation do not fall under this criterion.

2. Cross-Agency and Multi-Group Priority

    a. The management need is relevant to multiple agencies and organizations throughout the Delta and/or fulfills the mission of multiple groups.

    b. The science action is not site specific or single-agency focused and integrates the research and science goals of the larger Delta science community.

    c. The science action is linked to a high-priority policy issue that has cross-agency implications such as the California Water Action Plan, EcoRestore, WaterFix, the Delta Plan, or a new Governor's initiative.

    d. Executing the science action will help address achievement of the coequal goals in the Delta Plan.

    e. The outputs of the action will be directly used in water management or ecosystem management; the action has broad agency and stakeholder support.

    f. The science action is included in multiple priority lists by science programs that carry out research and monitoring in the Delta.

3. Feasible

    a. The science action can likely proceed given legal, fiscal, and institutional considerations.

    b. The capacity to carry out the research successfully is well established and described.

4. Promotes Collaborative Efforts

    a. Implementing the science action will provide opportunities to serve the needs of multiple agencies and organizations.

    b. The science action is synergistic with existing efforts and will support multi-agency collaboration.

Prioritizing the Refined List

Once the management needs and science actions list was refined, the science actions within each management need were prioritized using the following criteria.

Science Prioritization Criteria

1. Scientific Merit

    a. The science action is based on a sound rationale (e.g., has a high degree of support from relevant science communities and has high potential to advance knowledge).

    b. The science action is recommended by the Delta Lead Scientist, IEP Lead Scientist, Delta Independent Science Board, or an independent peer review panel.

2. High-Impact

    a. The science action is usable by one or more key agencies within a four-year time frame.

    b. The science action identifies and addresses current or anticipated gaps in knowledge relevant to multiple agencies.

    c. Implementing the science action involves integrating existing data from individual agencies spanning various geographical locations.

    d. The science action identifies emerging issues requiring a rapid Delta-wide assessment to develop management needs.

    e. The science action supports synthesis activities that cross multiple existing programs or agency missions.

    f. The science action supports science infrastructure needs (the action supports the Delta science enterprise, and provides tools, facilities, or professional development for scientists).

    g. Outcomes of the science action have a high potential to address and resolve areas of scientific conflict.

3. Timeliness/ Need

   a. The science action is ready for further development and the opportunity for progress is high.

   b. The project has partial support and commitments that can be greatly enriched by focused short-term attention.

4. Risk Assessment/ Opportunity Cost

   a. Not taking this action today would pose a severe risk to core scientific, technical and organizational capabilities to address management needs today and in the future.

   b. Addressing this scientific topic is an immediate opportunity for innovation and scientific advancements with high potential for critical new knowledge of the Delta.

Applying the Screening and Prioritization Criteria to Identify the Draft List of Priority Science Actions (December 2016 – April 2017)

The master list was refined by Delta Science Program staff by applying the screening criteria with ongoing guidance from the Science Advisory Committee for the Delta Science Program and representatives of the Delta policy, management, science, and social science community. As described in Appendix B, the initial list of over 550 was refined to 158 after merging science actions and management needs with similar messaging and removing science actions already completed or well underway. Both the screening and prioritization criteria were applied to this set of 158 science actions; those with the highest scores using the prioritization criteria were retained for a draft list of 28. Based on the criteria, the 28 science actions were determined to be: not fully addressed, cross-agency and multi-group priorities, partially or fully feasible, and opportunities to promote collaborative efforts. All actions included scored high on scientific merit, high-impact, timeliness/need/ready to proceed, and risk assessment/opportunity cost. Scores generated during the screening and prioritization exercise can be found in the master list matrix. The 28 science actions were further refined to 27 science actions following input received from the Delta Science Program and IEP lead scientists (see Appendix B for more details).

At the Delta Agency Science Workgroup meeting in March 2017, the list of 27 science actions was presented for a ranking activity. The goal of this ranking activity was to identify the two highest-priority science actions to address in each of the five priority science action areas. A preliminary ranking was conducted through an online form prior to the March meeting to get a sense of what actions rose to the top. At the meeting, the science actions were presented in the order determined from the online survey. The DASW members were then requested to vote, by sticker method, on their top two science actions in each action area. Results of the scoring can be found in the master list matrix. As mentioned in Appendix C, based on suggestions from the DASW, two of the 27 science actions were merged and one dropped resulting in a list of 24 science actions. The 12 priority science actions were included in the draft SAA (April 2017), while the remaining 12 science actions were placed in Appendix A of the draft document.

Table C.1: List of Sources Investigated to Guide Development of Prioritization Criteria

Collaborative Adaptive Management Team

Great Lakes Commission

Interagency Ecological Program Decision Making Criteria

Interagency Ecological Program Science Agenda Prioritization and Implementation Strategy

Interim Science Action Agenda Criteria

National Science Foundation Proposals and Award Guidelines

NOAA Alaska and Southwest Fisheries Science Centers

Puget Sound Partnership

South Florida Ecosystem Restoration Task Force

Research boat for Suisun Marsh Study, with rare Mason's lilaeopsis (mudflat quillplant) at Rush Ranch in foreground. Photo: Amber Manfree.

Appendix D: Example Management and Science Questions

1. Invest in assessing the human dimensions of natural resource management decisions.

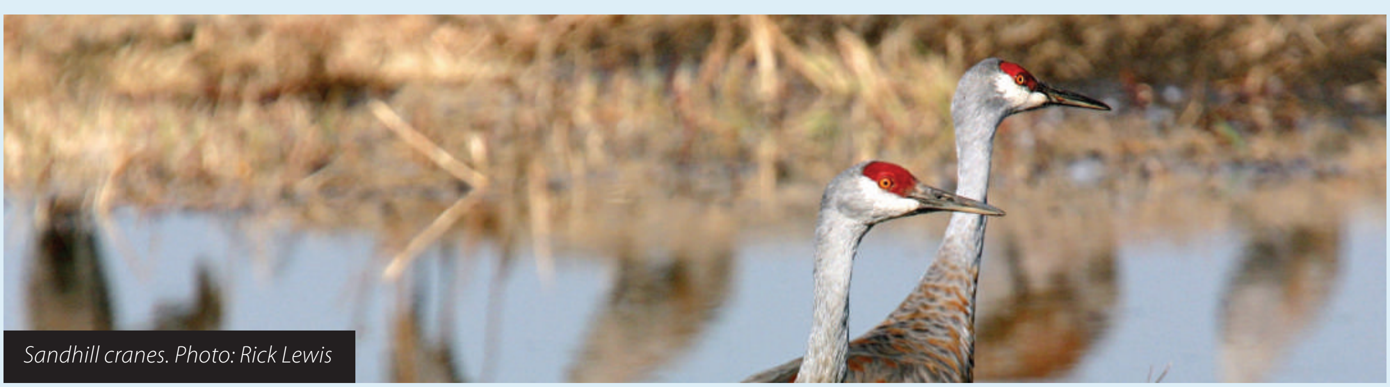
Management Needs	*Priority Science Actions*
A. Consider human behaviors and stakeholder concerns when developing policy alternatives and potential incentives for improving species habitat conditions. *Example question:* Are financial subsidies effective in increasing wildlife-friendly agriculture on private lands?	A. Investigate the most cost-effective methods to improve species habitat on working lands. *Example question:* What are the behavioral responses associated with various incentive programs to create wildlife-friendly agriculture and which of these programs is the most cost effective?
B. Determine how to coordinate and assist adaptive management in the Delta. *Example question:* How can we improve the way we share lessons learned, communicate ideas and information on adaptive management, and provide a networking venue for project implementers, managers, and scientists?	B. Develop tools to assist adaptive management in the Delta. *Example question:* How can we best design monitoring protocols to fit the magnitude of management actions and the timing of important ecosystem processes that make the value of adaptive management more readily apparent?
C. Understand human responses to policy and management actions regarding common pool resources in the Delta. *Example question:* How are people in the Delta adapting to climate change?	C. Initiate a research program on the Delta as an evolving place that integrates the physical and natural sciences with the social sciences. *Example question:* How can we better incorporate the human dimension in habitat restoration efforts in the Delta?

2. Capitalize on existing data through increasing science synthesis.

Management Needs	*Priority Science Actions*
A. Improve access to legitimate, credible, and relevant summaries of best available science. *Example question:* What format is most useful to communicate scientific lessons that can be learned from past drought management actions coupled to fish migration and survival studies to inform future management efforts?	A. Strategically build the capacity to do collaborative science and science synthesis through implementing the science synthesis mechanisms outlined in the Delta Science Plan. *Example question:* What are the abundances and relative distributions of Delta Smelt and Longfin Smelt in different Bay- Delta habitats (i.e. shallow water, tidal wetland, open water) and at different life stages?
B. Improve data and information exchange. *Example question:* How can we collaborate among various agencies to negotiate sharing of data and improve data accessibility, building on efforts such as Sacramento Prediction and Assessment of Salmon, to create a publicly available web-based query system that provides real-time information?	B. Identify and prioritize important data sources that should be interconnected to promote collaboration and provide the technology necessary to allow this information to be easily accessed. *Example question:* How can we best integrate data that focuses geographically on the Cache Slough Complex into a dashboard accessible by data users and decision makers?

3. Develop tools and methods to support and evaluate habitat restoration.

Management Needs	*Priority Science Actions*
A. Evaluate performance of restored areas on a landscape scale. *Example question:* How do size, location, and connectivity of restored areas affect native species and non-native species?	A. Develop methods for evaluating long-term benefits of habitat restoration based on current understanding of how species use restored areas and how use changes over time as habitats evolve. *Example question:* How can we apply approaches developed elsewhere (such as Diefenderfer et al. 2016 [1]) for evaluating benefits of multiple restoration projects? Benefits may include use by native species, effects on wetland functions, and food web subsidies.
B. Effectively plan restoration, enhancement, and mitigation projects to meet project and/or system-wide goals and objectives. *Example question:* What are the most effective designs for tidal restoration sites to deter establishment of invasive aquatic vegetation?	B. Estimate and assess the system-wide effects of location and sequence of tidal marsh habitat restoration projects in a region where sea level is rising and climate is changing. *Example question:* How do large-scale tidal wetland restoration actions affect tidal excursion, bathymetry, the low salinity zone, and sediment dynamics in the estuary?



Sandhill cranes. Photo: Rick Lewis

4. Improve understanding of interactions between stressors and managed species and their communities.

Management Needs	*Priority Science Actions*
A. Develop conceptual and numeric models to enhance current understanding to inform nutrient management questions. *Example question:* How will the large scale nutrient loading change resulting from the Sacramento Regional County Sanitation District wastewater treatment plan upgrade affect nutrient cycling, primary production, and important food webs within the Delta?	A. Implement studies to better understand the ecosystem response before, during, and after major changes in the amount and type of effluent from large point sources in the Delta including water treatment facilities. *Example question:* Where are the 'hot spots' for nutrient transformations and uptake in the Delta that traditional monitoring methods miss?
B. Quantify the effects of climate change on species, Delta ecology, and potential impacts on water and natural resource management. *Example question:* How far will species suites move in response to changes in climate that affect sea-level and regional temperature?	B. Identify areas that act as refugia for species of concern during extreme conditions, particularly drought and flood, to inform management decisions and priorities during extreme climate events. *Example question:* What are the physical and biological characteristics of areas that have served as drought and flood refugia for affected species?
C. Determine how water operations and restoration actions will affect native fishes to adaptively guide management decisions and restoration design. *Example question:* Will augmented spring outflow be required to maintain Longfin Smelt abundance?	C. Understand mechanisms for observed relationships between flows and aquatic species. *Example question:* What hydrological, ecological or biological mechanisms (or combination thereof) underlie the relationship between aquatic species abundance and outflow (or X2)? [2]
D. Identify and forecast which water quality contaminant sources and processes are most important to understand and quantify. *Example question:* What are the three most important toxins contributing to Delta Smelt impairment, mortality, or physiological stress?	D. Evaluate the effects of toxicity (e.g., contaminant mixtures, mercury, pharmaceutical products, HABs) on aquatic species survival including possible effects on predation risk. *Example question:* How can we better incorporate bioanalytical screening and non-targeted analysis in determining effects of constituents of emerging concern on fish species ability to evade predators [3]?

5. Modernize monitoring, data management, and modeling.

Management Needs	*Priority Science Actions*
A. Utilize models of the Delta and visualization tools that are widely accessible and sustained by multiple sources to predict and assess the likely outcomes of management actions and environmental change (preferably in real-time). *Example question:* How can landscape changes in the Delta under various earthquake scenarios be best visualized?	A. Advance integrated modeling through efforts such as an open Delta collaboratory (physical or virtual) that promotes the use of models in guiding policy. *Example question:* What is the most optimal way to convene community modelers to develop decision-support tools to address management questions (e.g., those identified in the Effects of Water Project Operations on Juvenile Salmonid Migration and Survival in the South Delta; Volume 1: Findings and Recommendations)?
B. Increase capacity to be nimble, prepared, and responsive to new demands, including emerging and opportunistic science needs. *Example question:* What should we invest in to slow and contain the spread of invasive species in the Delta?	B. Explore innovative technologies and cost-effective methods for scientific monitoring and analysis of flow, water quality, and ecosystem characteristics (e.g., improved tools for fish monitoring, LiDAR, high-resolution bathymetry technology, new measurements for Delta levee hazards, and citizen scientist monitoring programs). *Example question:* What are the effects of altered hydrology and seismicity on levee integrity and the interaction between Delta levees and ecosystem function?

References for Appendix D

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2. Interagency Ecological Program, Science Strategy– Needs for Near-term Science in Five Areas of Emphasis: Responses to Drought and Climate Change, Understanding Estuary Food Webs, Ecological Contribution of Restored Areas, Restoring Native Species and Communities, and Impacts of Non-native Species. http://www.water.ca.gov/iep/docs/2016_IEP_Science_Strategy_FINAL_02-21-2017.pdf. 2016.

3. Mehinto, A.C., K.A. Maruya, and S.B. Weisberg, Incorporating Bioanalytical Screening and Non-targeted Analysis for CEC Monitoring (http://www.swrcb.ca.gov/water_issues/programs/swamp/cec_aquatic/cec_workshop_2017may.shtml). 2017: Constituents of Emerging Concern in Aquatic Ecosystems Workshop, May 1-2, 2017.

Delta Stewardship Council
Delta Science Program