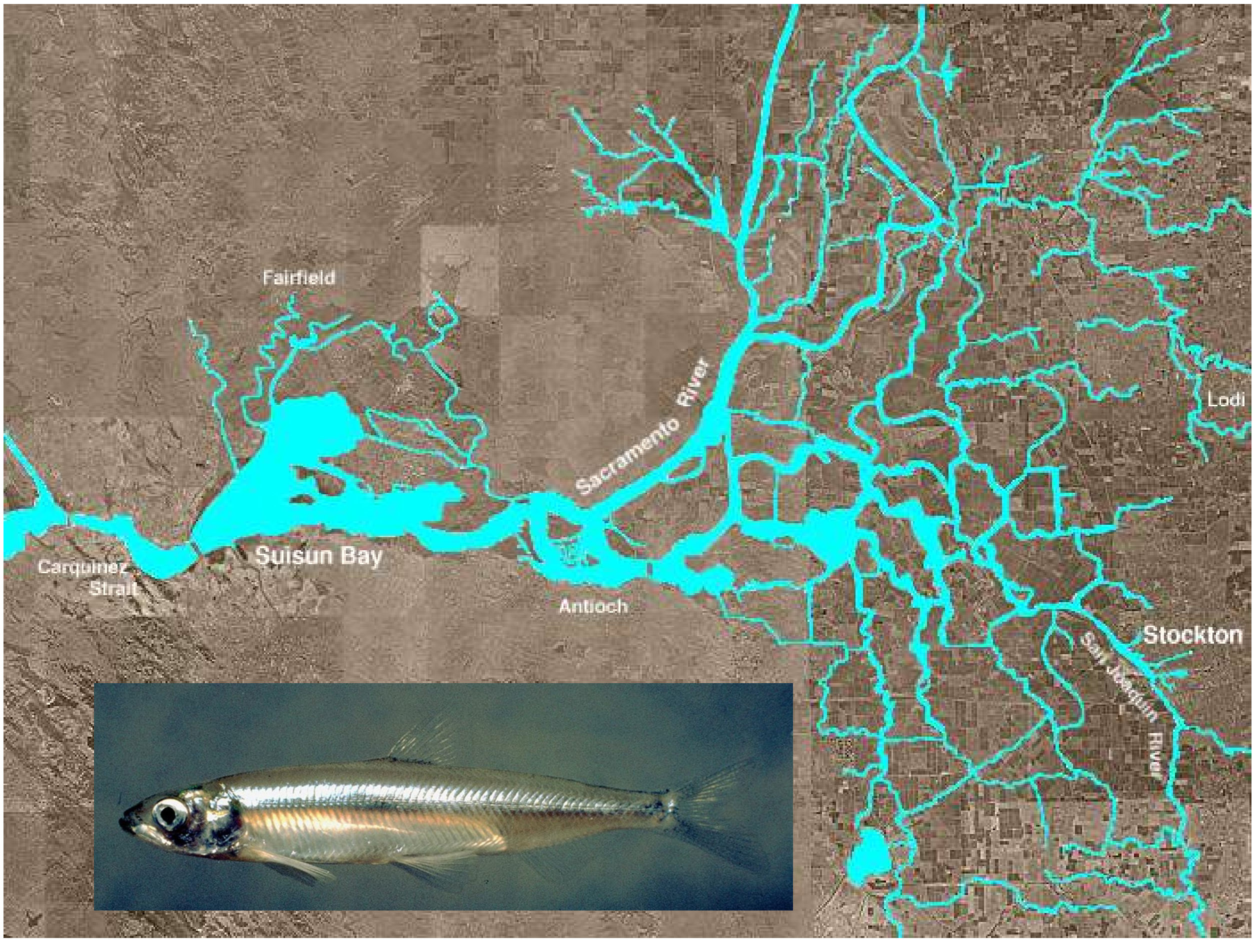
Science Plan to Assess the Effects of Ambient Environmental Conditions and Flow-Related Management Actions on Del ta Smelt



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Acronym or Abbreviation	**Definition**
AB	Assembly Bill
AHSP	Aquatic Habitat Sampling Platform
AMP	Adaptive Management Program
CAMT	Collaborative Adaptive Management Team
CASCaDE	Computational Assessments of Scenarios of Change for the Delta Ecosystem
CDFW	California Department of Fish and Wildlife
Chl	Chlorophyll
CNRA	California Natural Resources Agency
CSAMP	Collaborative Science and Adaptive Management Program
DISB	Delta Independent Science Board
DJFMP	Delta Juvenile Fish Monitoring Program
DMP	Data Management Plan
DNA	Deoxyribonucleic Acid
DO	Dissolved Oxygen
DOP	Directed Outflow Program
DSC	Delta Stewardship Council
DSM2	Delta Simulation Model II
DSP	Delta Science Program
DSRS	Delta Smelt Resiliency Strategy
DSST	Delta Smelt Scoping Team
DUWG	Data Utilization Work Group
DWR	Department of Water Resources
DWSC	Deep Water Ship Channel
eDNA	Environmental DNA
EDSM	Enhanced Delta Smelt Monitoring
EMP	Environmental Monitoring Program
EPA	Environmental Protection Agency
FCCL	Fish Conservation and Culture Laboratory
FLaSH	Fall Low Salinity Habitat
FLOAT	Flow Alteration
FMWT	Fall Mid Water Trawl
HAB	Harmful Algal Bloom
IBM	Individual Based Model
IEP	Interagency Ecological Program
IICG	Interagency Implementation and Coordination Group
IMSC	Integrated Modeling Steering Committee
IPA	Interagency Personnel Agreement
JFM	Juvenile Fish Monitoring
LCM	Life Cycle Model

LSZ	Low Salinity Zone
LTM	Long-Term Monitoring
MAST	Management, Analysis and Synthesis Team
NGO	Non-Governmental Organization
NMFS	National Marine Fisheries Service
NTU	Nephelometric Turbidity Units
PCR	Polymerase Chain Reaction
PG	Policy Group
PWT	Project Work Team
QA/QC	Quality Assurance/Quality Control
SBDS	State of Bay-Delta Science
SCHISM	Semi-implicit Cross-scale Hydroscience Integrated System Model
SDM	Structured Decision Making
SEW	Science Enterprise Workshop
SF	San Francisco
SFEWS	San Francisco Estuary and Watershed Science
SJR	San Joaquin River
SKT	Spring Kodiak Trawl
SLS	Smelt Larval Survey
SOP	Standard Operating Procedures
SSC	Suspended Sediment Concentration
STN	Summer Tow Net
UC	University of California
USFWS	US Fish and Wildlife Service
USGS	US Geological Survey
WQ	Water Quality
WY	Water Year
YBFMP	Yolo Bypass Fish Monitoring Program

Acknowledgements

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Executive Summary

This plan provides a framework for ongoing assessment and evaluation of data and research findings to increase mechanistic understanding of how Delta Smelt respond to changing environmental conditions. The plan is designed to: promote collaboration, deliver timely learning, be management relevant, build on and enhance ongoing work and established protocols, strategically advance science, and apply a system perspective.

There is scientific debate about the potential benefits that flow-related management actions provide to Delta Smelt, and many of these actions come with a high societal cost, thus there is a direct need for scientific evaluation of their effects and direct feedback to managers and decision-makers. These actions offer a unique opportunity for learning because of their recurring nature and the prospect that actions can be adjusted based on the findings from previous occurrences. While the focus here is on flow-related management actions, the recommended approaches can be applied more broadly.

Science to Understand Delta Smelt Response to Changing Environmental Conditions

Adaptive management requires scientific knowledge to support prediction of the effects of an action in advance of it being implemented, detection of change in response to the actions, and understanding of the mechanisms behind those changes. These three components are also essential to structured decision making processes. The discussion of existing scientific activities, needs and recommended next steps is framed around these components.

Predicting Delta Smelt Response: Efforts to predict the response of Delta Smelt to changing system conditions and management actions have thus far mostly focused on population status and trends and have been based on statistical analysis of long-term monitoring data. The Delta Smelt Life Cycle Model[1] can be used to quantitatively evaluate the effects of abiotic and biotic factors on Delta Smelt recruitment and life-stage specific survival. However, its focus is on population level effects and it may not be able to detect effects of management actions that do not result in a change in the population. Short-term or localized effects may also be missed. Quantitative predictions of the expected mechanistic response to changing conditions, including flow-related management actions, is a key missing link in management of this system.

- *Recommendation: Advance an integrated process-based tool to predict the effects of annual flow-related management actions and changing ambient conditions on Delta Smelt. This will require several years and dedicated resources. The first step is to develop a detailed approach and proposal to set appropriate expectations, timelines and resource needs.*

Detecting the Response: There are extensive existing field sampling programs in the Delta, many of which are directly relevant to Delta Smelt. Many of these programs collect data directly related to the expected effects of flow-related management actions on Delta Smelt.

[1] https://www.fws.gov/lodi/juvenile_fish_monitoring_program/dslcm.htm

While routinely collected information can be used as part of a larger effort to detect and understand change, it is unlikely to be sufficient to develop a full understanding of management effects. The specific scale of the effect of flow-related management actions varies depending on operational considerations. Planning for additional survey and monitoring needs to be conducted in an action-specific context. Existing surveys and monitoring could also benefit from further exploration of non-take detection approaches for Delta Smelt.

- *Recommendation: Establish an independent science advisory panel, using the guidelines in the Delta Science Plan, to provide timely advice on the potential utility of approaches to non-take detection of Delta Smelt, possible pitfalls, appropriate caveats, and useful steps to refine and test such approaches individually or in combination.*

In addition, technology that can efficiently generate data in areas and on time scales not covered by existing programs needs to be explored.

- *Recommendati*on: *Convene a* w*orkshop on new techniques for aquatic field surveys in the Delta focusing on abiotic and biotic aspects of 'dynamic habitat' in the estuarine environment.*

Understanding the Response: This report considers two main approaches to developing understanding: investigative research focused on mechanisms or the effects of stressors, and analysis and synthesis of field information and predictions in the context of the evolving knowledge base.

- **Research:** Ongoing sources of funding for research and mechanistic studies are limited.

  - *Recommendation: Explicitly request proposals relevant to understanding Delta Smelt flow-related management actions (e.g., interacting effects of dynamic and structural habitat on food availability, response of Delta Smelt and their prey to contaminant mixtures found in Delta water) as part of existing and future solicitations that include Delta-focused scientific study.*

  Several example topics are identified as areas where attention has been lacking or where specific studies could be undertaken that would provide a foundation for further mechanistic understanding. For example, multiple stable isotope analysis has become a familiar technique to determine food web pathways in aquatic, terrestrial, and marine systems and has provided initial insights into direct and indirect habitat linkages in the Bay-Delta.

  - *Recommendation: Conduct an inventory of existing information on the isotopic signatures of key potential carbon sources, including information about potential temporal and spatial variability, and where existing information is adequate.*

  The effect of contaminants on Delta Smelt under ambient conditions and when flows are adjusted as part of management actions is another outstanding question.

- *Recommendation: Engage the Contaminants PWT to plan a series of specific experiments that build on existing work, and select focus locations for water collection where Delta Smelt are often caught and where contaminants are known to be an issue.*

Synthesis: While the findings of individual studies provide valuable information, synthesis across studies or management actions can be an effective mechanism for greater insight into system dynamics and Delta Smelt response. Integration and synthesis activities need to bring together not only the findings of work conducted under this science plan, but other relevant scientific developments in the Delta and beyond. IEP has worked to increase its internal capacity for synthesizing data and information for the estuary, and the Delta Science Program has successfully coordinated periodic 'State of Bay-Delta Science' reports designed to synthesize current understanding of the Bay-Delta system.

- Recommendation*: Convene a work group incluidng managers and scientists (drawing in those outside of CSAMP participation as appropriate) that includes participation from the Delta Science Program and IEP, to develop a multi-year list of synthesis topics (e.g., issues, locations, species life stages/transitions) for which data/information is expected to be available, the types of synthesis outputs needed, and estimates of resource needs.*

Delivering Understanding to Management

The annual life cycle of Delta Smelt, and the current low population estimates, make the development and delivery of scientific understanding to users urgent. Decisions on flow-related actions are expected to be made on an annual basis and must be informed, to the extent practicable, by the most recent information and understanding. Regular updates need to be provided including: monthly short presentations on progress to CAMT/DSST, quarterly short written summaries including available information from scientific activities and other research, and annual progress summaries made available or presented to CSAMP Policy Group. One useful vehicle for reporting and dissemination of new scientific developments would be an annual or biennial State of Delta Smelt symposium. Such a symposium on a regular basis could provide an excellent venue for open discussion of management needs and how they can best be met by the scientific community.

A Programmatic Approach

Planning and executing scientific activities using a programmatic approach enables consideration of interactions among actions, and enables field surveys and monitoring, improvements in predictive modeling, and investigative research to proceed in parallel as part of a coordinated approach to building knowledge. The programmatic approach proposed, uses a three-year cycle for planning and execution of diverse scientific activities in support of understanding Delta Smelt response to changing ambient conditions and flow-related management actions. The approach includes structured processes for communicating understanding and is founded on scientific best practices, i.e., quality assurance/quality control, data management, archiving and peer review. Science leadership is critical to success. The ongoing execution of science in the context of adaptive management, including detailed science plans, communication to a variety of audiences, advocacy for constrained resources, motivating delivery of information, and championing learning, requires a dedicated leader. The proposed **Science Program Manager** works at the interface between those who generate the science and those who use the science.

At the center of the proposed approach is a **Three-Year Science Plan** for planning and executing scientific activities. **Annual Supplements** can be used to tailor plans, particularly field surveys and opportunistic studies, around flow-related management actions or ambient conditions specific to a particular year. The development of a Three-Year Science Plan involves: identifying candidate science activities, assessing resource availability, and prioritizing scientific activities on the basis of management relevance and availability of funding. The process for each of these steps is described, and it is expected that the development of the first Three Year Annual Science Plan could take 5-6 months, with future plans taking less time as foundational information would be more readily available. The Science Program Manager leads the process with direct engagement from CAMT, various science providers and science experts.

Decisions regarding the implementation of flow-related management actions will be taken in the light of expected water year conditions. An Annual Supplement process using information developed during the development of the three-year plan, and additional information developed in the intervening period, allows a nimble response to changing conditions within an ongoing progressive learning process. A series of key steps need to be taken in December – April each year. The process involves dialog with CAMT, DSST, IEP science managers, and agency 'champions' for the flow-related management actions. New information from other sources, e.g., research studies, routine monitoring not related to flow actions, should be utilized as appropriate.

The framework for identifying scientific activities to increase understanding of Delta Smelt response to changing ambient conditions and flow-related management actions is best operationalized as part of an overall adaptive management program. Even without such a program in place, steps can be taken to make progress in planning and coordination of scientific activities, advancing knowledge, and improving the availability and collaborative utilization of results and findings. The identified organizational priorities are:

- *Recommendation: Establish the position of Science Program Manager to enable collaborative, coordinated, and effective generation and delivery of scientific information around Delta Smelt response to changing ambient conditions and flow-related management action*.
- *Recommendation: Adopt a Three-Year Science Planning process, with provisions for Annual Supplements; initiating a structured approach to planning, coordinating and communicating scientific activities does not depend on any specific programmatic structure being in place.*

The Role of this Science Plan

Context

This plan has been developed to provide a framework for ongoing assessment and evaluation of data and research findings to increase mechanistic understanding of changing ambient conditions[2] and the consequences of flow-related management decisions for Delta Smelt. It is founded on an established understanding of the Delta Smelt life cycle (Baxter et al., 2015; Moyle et al., 2016), emerging information, and recent identification of a number of flow-related management actions[3] that could benefit Delta Smelt (CNRA, 2016).

There have been a number of concerted efforts to scientifically evaluate the effects of flow-related management actions including the FLaSH studies for the 2011 Fall Outflow management action (Brown et al., 2014), the FLOAT-MAST and Directed Outflow Program (DOP) studies undertaken in relation to the 2017 Fall Outflow management action, and studies of specific regional effects, e.g., (Frantzich et al., 2018). The aim here is to show how existing scientific activities[4] and new research can be leveraged and enhanced, specific research can be used to increase understanding, improve prediction capabilities and increase efficiency.

The development and execution of a scientifically rigorous research, monitoring and assessment program, combined with periodic synthesis, is essential to understand responses of the ecosystem to any management regime. The focus here is on understanding mechanisms by which abiotic and biotic conditions affect Delta Smelt including the role of ambient conditions and flow-related management actions such as seasonal flow management, Toe Drain flows, managed wetlands and Suisun Marsh water management.

There is scientific debate about the potential benefits that flow-related management actions provide to Delta Smelt, and many of these actions come with a high societal cost, thus there is a direct need for scientific evaluation of their effects and direct feedback to managers and decision-makers. Moreover, in a complex ecosystem, such as the Delta, change for any individual species must be seen in a systems context. For this plan, that means coordination with programs and initiatives focused on other aspects of the system and maintaining an awareness of how the system as a whole is changing in response to multiple management actions and changing ambient conditions.

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[2] Ambient is used here for the general state of the system within which flow-related management actions are implemented. It includes the physical nature of the system, structural habitat, and dynamic habitat conditions which would exist without additional flow management actions. Ambient conditions are defined in the context of individual flow management actions within a water year type.

[3] In this report 'actions' are deliberate, planned management measures intended to achieve a benefit to a habitat, resource or species. Flow management actions are those that involve active management of water movements through the Delta, Suisun or Yolo that would not occur under normal water operations.

[4] Scientific activities include monitoring, field surveys, data collection laboratory analysis, field and laboratory experiments, statistical analysis, synthesis, meta analysis, investigative research, conceptual modeling, numerical modeling and other applied science pursuits.

Goal and Objectives

The goal of this plan is to ***provide a programmatic framework for ongoing development, assessment and evaluation of data and research findings to increase mechanistic understanding of how Delta Smelt respond to changing environmental conditions***. While there is a focus on the response to ambient conditions and the consequences of flow-related management decisions for Delta Smelt, the approach is designed to be more broadly applicable.

The objectives are to:

- Identify approaches that can be used to predict, detect and understand the response of Delta Smelt to management actions, in the context of ambient conditions, that leverage existing programs and opportunities
- Characterize appropriate methods to progressively capture and communicate learning to a variety of users
- Demonstrate how scientific best practices can be used to promote legitimacy and credibility of scientific work
- Develop a programmatic approach for collaborative planning and execution of scientific activities to increase mechanistic understanding of Delta Smelt response to changing environmental conditions

The focus of this report evolved as work progressed and the state of scientific knowledge, existing and ongoing work, and the challenges of implementation became clear. Box 1 summarizes how the objectives of the work are reflected in the report.

Potential Use in Adaptive Management and Other Decision-Making

The linkages between decision-making, project implementation and science can be structured as parts of a formal adaptive management program. A specific adaptive management context for this Science Plan has not been provided; however, the approach presented here has been informed by adaptive management approaches used for Fall Outflow-related management actions, those developed for California Water Fix and Current Biological Opinions[5] (hereafter AMP), and in other systems such as the Missouri River[6].

Effective adaptive management requires interaction among decision-makers, managers and scientists. Figure 1 captures the ways in which the functions of these three groups intersect.

Formal processes are not yet in place for collective decisionmaking in regard to management actions to benefit Delta Smelt, or coordinated implementation of those actions (although progress is being made on advancing actions included in the Delta Smelt Resiliency Strategy). However, there are some direct ways in which a focus on advancing science can inform ongoing and evolving programs in the Delta:

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[5] http://www.californiawaterfix.com/wp-content/uploads/2017/10/App_6.A_AM_Framework_Rev.pdf

[6] https://usace.contentdm.oclc.org/utils/getfile/collection/p16021coll7/id/8070

Box 1. Meeting the Objectives

The objectives are shown in italics with accompanying text describing how they are addressed in this report.

Identify approaches that can be used to predict, detect and understand the response of Delta Smelt to management actions, in the context of ambient conditions, that leverage existing programs and opportunities

- This report includes suggestions on several areas where research and new approaches could add value. These are not prioritized but have been selected as examples of topics and issues that need to be addressed. The framework for collaborative science described here includes ways of further identifying priority research needs.

Characterize appropriate methods to progressively capture and communicate learning to a variety of users.

- Communication of science findings and learning is seen as an essential function in this report and making information available to managers and decision makers is a key part of the programmatic approach. Methods include monthly updates, quarterly summaries and annual reports.

Demonstrate how scientific best practices can be used to promote legitimacy and credibility of scientific work

- The report addresses the need for adherence to scientific best practices, e.g., quality assurance and data management, and shows how these can be operationalized as part of a three-year science planning process.

Develop a programmatic approach for collaborative planning and execution of scientific activities to increase mechanistic understanding of Delta Smelt response to changing environmental conditions.

- The report provides a framework for development and execution of scientific activities around a Three-Year Science Plan with provision for Annual Supplements to be responsive to management needs.

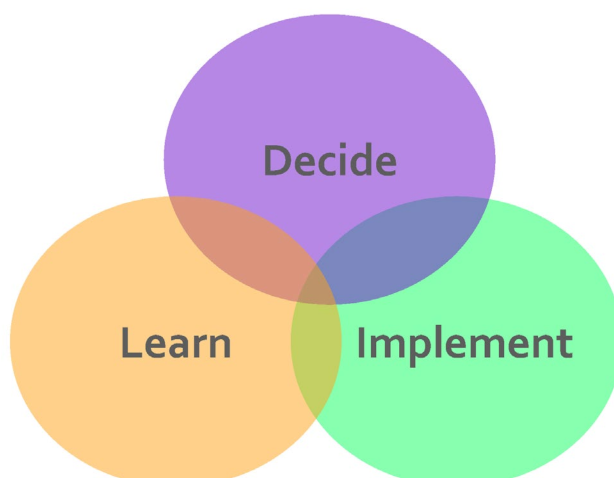

Figure 1. Intersection of key functions in adaptive management (from Compass Resource Management December 2018)

- Directly informing an adaptive management program focused on Delta Smelt by developing and packaging scientific information in a way that it can be directly used to evaluate project performance, assess progress against triggers and objectives, refine future actions, etc.
- Providing information and tools for use in structured decision making (SDM). SDM is being considered as a tool to collaboratively identify and prioritize management actions that could benefit Delta Smelt. This science plan provides a framework for the scientific activities that a) accompany and support those actions, b) build a base of knowledge necessary to effectively improve conditions for Delta Smelt and c) continuously improve the predictive models necessary to inform future SDM and other decision-making processes.

- Supporting the implementation of a larger set of actions, e.g., habitat restoration, and/or actions to benefit other species, e.g., longfin smelt. Many of the approaches laid out here are not specific to either Delta Smelt or flow-related management actions and could be readily adapted for use in other contexts.

The state of knowledge, the status of the species and environmental conditions can all change rapidly. Generating usable scientific information in a timely manner that is responsive to changing needs is the underlying purpose of this plan. If the plan is successful the institutions, entities, procedures and approaches that use that information will be many and varied.

Guiding Principles

This plan has been developed using the following principles which characterize the way in which the plan should be executed.

- **Work collaboratively.** As noted in the Delta Stewardship Council (DSC) draft Delta Science Plan update[7] science in the Delta has successfully adopted a collaborative approach that includes sharing information and resources and modifying activities based on a common interest or objective.
- **Deliver timely learning.** Delta Smelt live 1 to 2 years (Moyle et al., 2016) and are experiencing record low abundance. There is some evidence that they can respond positively to specific conditions (Brown et al., 2014), but recent low catches have stimulated discussion of extinction and supplementation (Hobbs et al., 2017; Lessard et al., 2018). Given this, information on how Delta Smelt respond to changing conditions must be delivered in a timely manner to inform management action.
- **Be management relevant.** While there is, as yet, no specific management program that is a direct 'user' of the information and learning generated by implementation of this plan, in a system like the Delta, science needs to be responsive to both changing management needs and changing environmental conditions. A framework within which science can inform management is more useful than a prescribed set of studies which may be superseded by events.
- **Build on and enhance ongoing work and established protocols**. Decades of science has contributed to the current understanding of the Bay-Delta (Cloern & Jassby, 2012). Much has been learned about vital rates and condition of Delta Smelt since the 2011 FLaSH work and knowledge is still developing. Ongoing monitoring and previous studies provide a foundation of data, tested approaches, and standard protocols which should be built on, enhanced and progressively refined.
- **Strategically advance science.** Restoration efforts in the Delta have long recognized the role of research in providing information essential to adaptive management, and it is clear that furthering our mechanistic understanding of how and why Delta Smelt respond to changing conditions will require specific investigative studies in addition to field surveys and

[7] http://deltacouncil.ca.gov/docs/delta-science-plan/draft-delta-science-plan-update-public-review-august-22-2018

monitoring. Such studies need to be directly related to management issues and be structured to test or explore specific relationships or mechanisms.

- **Apply a systems perspective**. Making progress in understanding the behavior of complex systems and their response to multiple and interacting stressors requires a new approach to thinking (Kates et al., 2001). Common attributes of a systems approach include breadth, interconnectedness and feedbacks. A systems perspective ensures understanding of aspects of that system that generate, exacerbate or are affected by the problem at hand, in this case response of Delta Smelt to flow-related management actions and ambient conditions.

Relationship to Other Delta Science Initiatives

This Science Plan has been developed with awareness of the broad range of players involved in Delta Smelt activities, as exemplified by participants in Collaborative Science and Adaptive Management Program (CSAMP) Policy Group (PG), Collaborative Adaptive Management Team (CAMT) and its subcommittees and teams, and CSAMP is seen as a key audience for this report. However, there are other established science bodies working in the Delta with which this Science Plan needs to mesh. These are described in general here with more specifics of how alignment, leveraging and coordination is expected to occur provided throughout the report.

CSAMP

CSAMP provides a vehicle for collaborative implementation of the structured scientific approach described in this report.

- PG can provide guidance on key questions and priorities for science and synthesis, receive briefing on proposed activities and findings, and support resource allocation decisions within entities
- CAMT can identify available resources, provide input on management science needs, offer approaches to meeting those needs, prioritize scientific activities, receive regular updates, and provide a mechanism for coordination with other Delta activities and interests.
- Delta Smelt Scoping Team (DSST) can provide input on appropriate scientific activities and provide a venue for detailed technical discussion of science issues.

Interagency Ecological Program (IEP)

IEP plays an important role in current efforts to understand dynamics of the Delta ecosystem. IEP provides a basis of field monitoring programs on which other activities can build, and has established procedures for many routine data collection and laboratory processes. IEP also has authorization for take of Delta Smelt, issued by USFWS, and has established guidelines and reporting processes for take. In addition, IEP supports ongoing synthesis work and there has been substantial recent progress in data management.

Delta Science Program (DSP)

The Delta Science Program's strategic objectives include supporting research, synthesizing scientific information, facilitating independent review, coordinating and communicating science. In addition, the DSP has considerable experience with planning and executing workshops on science and science-management topics and established policies and procedures for independent scientific review and independent science advisors. Leveraging the skills and reputation of the DSP for aspects of the science framework described here, to the extent this can be done without compromising their independence, provides credibility to the process.

Report Structure

This report lays out an approach to the development and application of science in the context of flow-related management actions for Delta Smelt, that inherently requires understanding their response to ambient conditions. The report describes the scientific activities needed to understand Delta Smelt response to flow-related management actions. The activities are framed around predicting the effects of management actions, detecting the system response, and understanding the response. A programmatic approach for science is described, and a process for the development of Three-Year Science Plans is proposed. An annual process of 'supplements' to the Three-Year Science Plan is described to ensure responsiveness to water year type and changing opportunities for flow-related management actions, for example. The report concludes with some suggestions on immediate next steps to advance the plan. Appendices are referenced throughout for more detailed information about specific topics or issues raised.

Science to Understand Delta Smelt Response to Changing Environmental Conditions

Recent Developments

There is a substantial amount of ongoing work on Delta Smelt. Appendix 1 includes an illustrative, rather than exhaustive, overview of some recent developments in knowledge regarding how Delta Smelt respond to flow and changing ambient conditions. The Appendix includes some established information documented in existing synthesis or review papers including the MAST report for 2011 Fall outflow (Brown et al., 2014), the updated Delta Smelt conceptual model (Baxter et al., 2015), and the recent series of 'state of the science' papers published in San Francisco Estuary and Watershed Science in 2016 (e.g., Fong et al., 2016; Moyle et al., 2016). The main purpose of Appendix 1 is to summarize information from recently published studies and reports (through mid-2018) deemed relevant to the issue. The focus was on papers published in the peer-reviewed literature but some project reports provided useful recent information.

Advances have been achieved using a variety of techniques:

- Laboratory experiments with cultured Delta Smelt have provided insight on tolerance and response to changing environmental conditions. Laboratory studies offer the ability to identify responses in a controlled way across gradients of conditions such as salinity and temperature which is difficult in the field due to low catch and spatial and temporal variability.
- Ongoing monitoring and special field studies have provided direct information about the association of fish, and food, with specific environmental conditions. The addition of information on vital rates and condition associated with Delta Smelt found at specific times and locations, shows complexity but also enables insight beyond status and trends analyses.
- Focused field studies have provided information on food web interactions, and finer spatial patterns for native fishes, included Delta Smelt, and key food resources.
- Integrative modeling that includes linkages between physical conditions and food web dynamics or Delta Smelt catch has been developed in a number of directions and provides a promising foundation for future work.

One of the overall challenges for science focused on Delta Smelt is how to deliver information on rapidly developing scientific findings in a way that is timely and accessible to managers.

Flow-Related Management Actions

Flow-related management actions provide a unique opportunity for learning because of their recurring nature and the prospect that actions can be adjusted based on the findings from previous occurrences. Challenges include the influence of varied ambient and antecedent conditions on outcomes, and the sometimes-high opportunity cost associated with changing flow patterns.

All management actions planned or implemented to benefit Delta Smelt are based on an underlying conceptual model of how the proposed action will influence the species. This could be mediated through changes in structural or dynamic habitat (Peterson, 2003) or other influences on vital rates (e.g., reducing mortality). These underlying conceptualizations can be used to identify science needs, i.e., mechanistic research, surveys, data collection, etc. needed to detect and understand associated system change, as well as the influence of potential limiting factors (Hamilton & Murphy, 2018). For flow-related management actions, existing documents were used to identify the potential effects of various flow-related management actions that could inform the planning of science needs related to those actions.

CSAMP, with support from Compass Resource Management undertook a preliminary, multi-objective analysis of the 13 actions in the Delta Smelt Resiliency Strategy to pilot approaches for developing and evaluating actions undertaken in the Delta for Delta Smelt. The report (Compass Resource Management, 2018) includes, for each management action, an 'influence diagram' which outlines the conceptual linkages between cause and effect leading to outcomes for Delta Smelt. An example of one of these diagrams for the Reoperation of the Suisun Marsh Salinity Control Gates is shown in Figure 2.

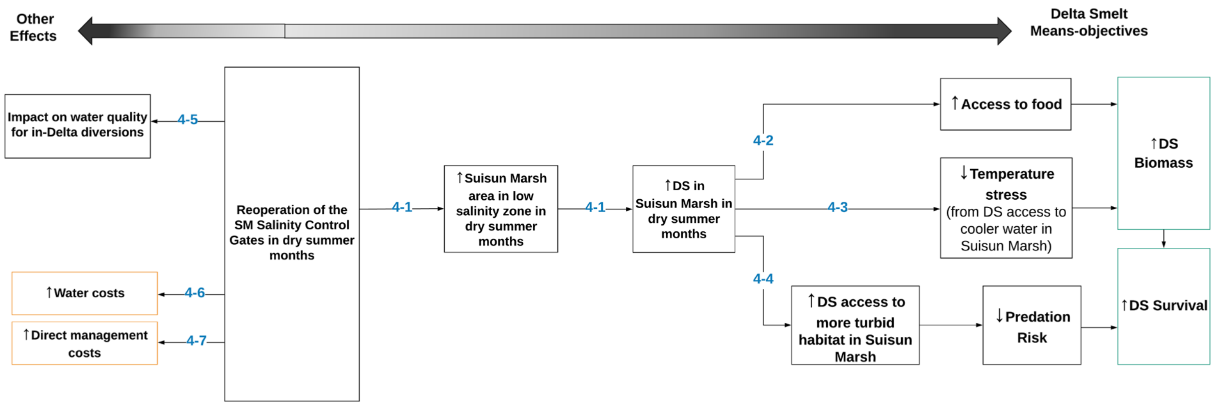

Figure 2. Influence diagram for Reoperation of the Salinity Control Gates (Compass Resource Management 2018)

Several recent IEP initiatives include qualitative predictions of expected system response, and /or specific hypotheses, related to flow-related management actions in support of Delta Smelt. The FLOAT MAST draft report includes predictions for the 2017 Fall X2 action based on response variables identified in the Fall Outflow Adaptive Management Plan The 2019 draft workplan for *Monitoring and Assessment of Proposed Suisun Marsh Salinity Control Gates Action, 2018-2020* also listed potential effects. Table 1 shows the variables or system characteristics identified by these plans and reports as being influenced by flow-related management actions or which are important modulators of the effect of flow-related management actions on Delta Smelt. While

[8]http://deltacouncil.ca.gov/sites/default/files/documents/files/Revised_Fall_X2_Adaptive_MgmtPlan_EVN_06_29_2012_final.pdf

the focus of Table 1 is on Delta Smelt, it is important to recognize that any response of Delta Smelt or other factors, e.g., food, must be seen in a systems context and examination of other system characteristics and dynamics will be useful in interpreting and explaining patterns of change in Delta Smelt.

Table 1. Expected effects of flow-related management actions. Comparative basis for the directionality of the effects: SDM Resiliency Strategy and 2018 Suisun Gates are compared to without-action condition, 2017 Fall X2 are compared to more upstream X2 position (see source documents for more detail)

	Delta Smelt Resiliency Strategy						
	Suisun Gates	Pulse through Yolo Bypass	Outflow augment.	Roaring River	Flood and drain managed wetlands	FLOAT MAST 2017 Fall X2	2018 Suisun Gates IEP Monitoring Plan
Location							
Alter LSZ position/extent	**X**		**X**			**X**	**X**
Move Delta Smelt to desirable location	**X**		**X**			**X**	**X**
Food							
Decrease clam grazing			**X**			**X**	
Phytoplankton						**X**	**X**
Zooplankton		**X**	**X**	**X**	**X**	**X**	**X**
Increase food supply		**X**		**X**	**X**	**X**	
Aquatic conditions							
Lower Temps.	**X**		**X**			**X**	
Access to turbid waters	**X**		**X**			**X**	
Avoid harmful water quality (DO)					**X**		
Decrease contaminant exposure							
Decrease exposure to HABs							
Delta Smelt response							
Decreased Predation	**X**		**X**				
Increased biomass	**X**	**X**	**X**	**X**	**X**		
Increased survival	**X**	**X**	**X**	**X**	**X**	**X**	**X***
Life history diversity						**X**	**X**
Improved Health metrics						**X**	**X***
Improved Diet & Feeding Success/Access to food	**X**	**X**		**X**		**X**	
Increased Fecundity							**X***
Increased Growth							**X***
Increased Recruitment							**X^**

*Response expected in Fall following summer action ^Response expected the year following the action

Role in Adaptive Management and Structured Decision Making

Adaptive management requires scientific knowledge to support prediction of the effects of an action in advance of it being implemented, detection of change in response to the actions, and understanding of the mechanisms behind those changes. These three components are also essential to using SDM (Murphy & Weiland, 2014):

- The need to ***predict***, in advance, the consequences of taking a management action, is essential to adaptive management. It is a key part of the planning phase (e.g., Step 3 in the Delta Plan adaptive management approach[9]) and is integral in SDM (e.g., Step 4 Consequences[10]). While structured processes have been developed enabling assessment of the outcomes of management actions using conceptual models, e.g., DiGennaro et al., (2012), models which can provide quantitative predictions of effects are preferred (Murphy & Weiland, 2014).
- Surveys and monitoring are used to ***detect*** change in the natural system. While some adaptive management approaches, e.g., The Delta Plan, link monitoring to implementation of management actions, data collection during non-action and ambient conditions can provide important additional insight into system dynamics, which is especially important context for flow-related management actions. 'Implement and Monitor' is also the final step in an SDM iterative loop, and other adaptive frameworks.
- Increased ***understanding*** and building an expanded knowledge base on which future actions can be planned and implemented is fundamental to adaptive management and iterative application of SDM. Data analysis, as well as synthesis and evaluation of findings in relation to the existing body of knowledge, is something which must be built into any restoration or management program making change in a dynamic natural system. Moreover, explicit efforts need to be made to incorporate understanding developed through investigative research and studies not directly tied to specific management actions, to advance the scientific foundation for system management.

For each of these components of a science-based adaptive management program, the following sections consider what is currently available, and identify additional work that could inform efforts to benefit Delta Smelt. Suggestions on additional work provided here have been identified from a limited set of interactions with the scientific community, and should be considered as examples which could be expanded or refined as this plan is implemented based on input from CSAMP and others.

Predicting Delta Smelt Response

What is Available?

Efforts to predict the response of Delta Smelt to changing system conditions and management actions have thus far mostly focused on population status and trends and have been based on statistical analysis of long-term monitoring data (e.g., Hamilton & Murphy, 2018; Maunder & Deriso, 2011; Polansky et al., 2018). The Delta Smelt Life Cycle Model (LCM)[11] is 'a quantitative tool designed to assess and predict the effects of management actions on the Delta Smelt population'. Recent work on the LCM has included careful adjustment of different data

[9] http://deltacouncil.ca.gov/sites/default/files/documents/files/AppC_Adaptive%20Management_2013.pdf
[10] http://www.structureddecisionmaking.org/steps/step4consequences/
[11] https://www.fws.gov/lodi/juvenile_fish_monitoring_program/dslcm.htm

sets to ensure compatibility, and the use of a Bayesian approach to consider uncertainty[12]. Indices for 'habitat quality' have also been developed linking abiotic factors and smelt abundance estimates via statistical relationships (e.g., Feyrer et al., 2011), including recent work to show spatial patterns using hydrodynamics modeling (Bever et al., 2016).

The LCM can be used to quantitatively evaluate the effects of abiotic and biotic factors on Delta Smelt recruitment and life-stage specific survival. However, its focus is on population level effects and it may not be able to detect changes in Delta Smelt vital rates (e.g., growth) unless they are reflected in a change in the population. Short-term or localized effects may also be missed due to spatial and temporal limits of data availability or averaging. An alternative approach was developed by Rose et al. (2013) who built a spatially explicit, individual-based population model of Delta Smelt. The model follows the reproduction, growth, mortality, and movement of individuals over their entire life cycle using daily values of water temperature, salinity, and densities of six zooplankton prey types (estimated from field data). The spatial grid was based on that used in DSM2, which generated hourly water velocities and water levels. This more mechanistic approach is more appropriate to predict outcomes of actions which produce conditions rarely or not previously experienced. In such cases, models that capture the underlying relationships between biological processes and environmental conditions are more useful (van der Vaart et al., 2016).

Since the development of the Rose et al. individual based model (IBM), there has been increasing application of more detailed hydrodynamic models to predict changes in abiotic conditions including velocity, water temperature and suspended sediment (e.g., Achete et al., 2017; Chao et al., 2017; MacWilliams et al, 2016a; Martyr-Koller et al., 2017; Vroom et al., 2017 among others). Such models have also been used to address ecological issues. Liu et al. (2018) linked SCHISM with a biogeochemical model to examine the effect of changes in river inputs and nutrient loading on phytoplankton biomass. Particle tracking models have recently been used to examine the effects of potential behaviors of Delta Smelt in response to abiotic conditions (Gross et al. draft report to CAMT) and have been used in combination with field data to simulate proportional movement of zooplankton from productive to less productive regions of the estuary (Kimmerer et al., 2018). The CASCaDE projects[13] link models of climate, hydrology, hydrodynamics, sediment, phytoplankton, bivalves, contaminants, marsh accretion, and fish to provide an objective basis for anticipating and diagnosing Delta ecosystem responses to planned and unplanned changes. The project has made important progress in combining both simple and detailed models into a common framework, and modeling identified some key interactions important for Delta Smelt (Brown et al., 2016b; Lucas & Thompson, 2012). Work is ongoing on a three-dimensional model of phytoplankton dynamics which links to several other CASCaDE

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[12] Polansky et al. presentation 'Delta Smelt Life Cycle Modeling: Findings and Reflections on Synthesis Efforts' at the 2018 Bay-Delta Science Conference

[13] https://cascade.wr.usgs.gov/

components including climate, hydrodynamics, water temperature, suspended sediment, and bivalve grazing models and forcings[14].

What is Needed?

In their recent review MacWilliams et al. (2016b) note 'unexploited potential' for using multi-dimensional models to advance understanding of complex coupled physical–biological dynamics (Figure 3). In addition, an Integrated Modeling Steering Committee (IMSC) has been established following the 2016 Science Enterprise Workshop (SEW) to make progress on integrated modeling. Models are increasingly used as a tool in planning and assessing the effects of flow-related management actions. The foundation is set to advance predictive modeling to become a standard tool in planning and assessing the effects of flow-related management actions on ecological processes.

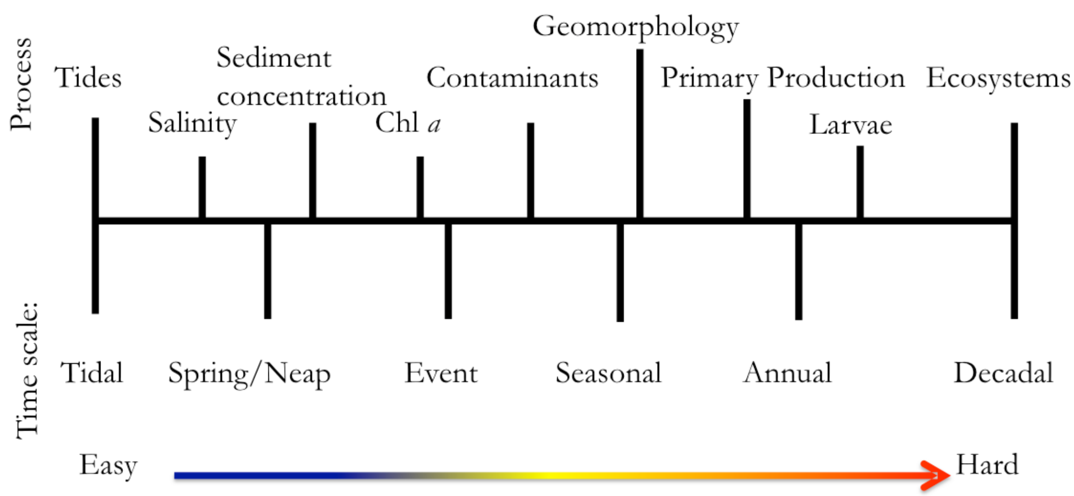

Figure 3. Schematic view of the spectrum of modeling physical and biological processes in the Delta (MacWilliams et al., 2016b)

A spatially explicit approach to provide quantitative expectations of the effects of flow-related management actions given recent and expected conditions is needed to provide:

- a basis for deciding which flow-related management actions to take in any year
- a context for the allocation of resources (e.g., flow, funding for science)
- an expectation of success relative to any management action or combination of actions in a given year
- a base against which performance of the flow-related management action can be assessed

The Rose et al. IBM and the advances in modeling described above provide a solid computational foundation for the development of a 'next generation' IBM. In addition, measurement of Delta Smelt vital rates (growth and movement), diet and condition on a large

[14] Lucas et al. 'Phytoplankton Modeling in a Strongly Tidal, High-Nutrient, Low-Light, Clam-Rich System', poster presented at the 2017 Biennial Conference of the Coastal and Estuarine Research Federation.

number of individual Delta Smelt (>1000) collected since 2011 provide a heretofore unused data set for validation of Delta Smelt modeling. Recent studies provide insight on key dynamics and relationships e.g., fecundity and fork length, foraging success, response to temperature and salinity (see Appendix 1), enabling a next generation IBM to explore how multiple factors influence Delta Smelt, and how flow-related management actions and ambient conditions interact with other aspects of the Delta ecosystem.

A focused effort to build a new individual-based predictive tool for Delta Smelt will require several years and dedicated resources. The objective is not to produce a model that provides a single prediction of the effects of a flow-related management action, or Delta Smelt response to a specific set of conditions. Given the complexity of the processes involved and the level of current understanding and data availability this is unrealistic. One way of using such a tool, especially for any biological components influenced by multiple changing and highly uncertain factors, would be to produce an *ensemble* of simulations showing a range of possible outcomes depending on assumptions that are made about different factors (e.g., weather/air temperature, bloom occurrence). This would improve on the current 'direction of change' approach (i.e., higher, lower) used to predict and assess the results of actions[15] and would provide managers an objective assessment of where and when change may occur under a range of assumptions. Such an array of predictions could be produced for different flow management options or ambient conditions.

Important considerations include:

- Dedicated resources must be made available for a core team of experts to devote time to model development
- Not all processes will likely be reflected at the same level of detail – simplification will be important to ensure progress is made. The model would use information currently available – not require new research or study.
- A modular approach could be used to ensure key components can be updated as information or insight develops.
- Computational efficiency will be an important factor. The expectation is that the simulations will be at most 1-2 years in length rather than over decades, as the goal here is predict the effects of flow-related management actions and ambient conditions[16].
- Simulations will need to be available in a timely manner to inform decisions
- Visualization of outputs will need to be accessible to non-experts and readily generated

[15] For example the draft FLOAT-MAST report

[16] Longer-term (i.e., multiple decades) simulations may be needed to explore changes in abundance, growth, and survival, etc. under different combinations of management actions (e.g., flow) and ambient conditions (salinity, water temperature, turbidity, etc.). This utility could also be investigated but it may require sacrificing spatial resolution thus the ability to predict changes resulting from local flow-related management actions.

Proposed Next Steps

Quantitative predictions of the mechanistic response to changing conditions, including flow-related management actions, is a key missing link in management of this system. A specific plan for development of the predictive tool is beyond the scope of this Science Plan. However, this can be readily developed and acted upon. Table 2 outlines a series of steps, that with resources and leadership, could be undertaken within about 9 months to develop a detailed plan of how to move forward. The IMSC, or a subcommittee of the IMSC, could be engaged to provide advice and feedback. Development of this approach could be conducted in parallel with ongoing IMSC work on challenges to integrated modeling and best practices in order not to delay progress, and the findings of those efforts woven in as appropriate as they become available.

Table 2. Steps to develop detailed proposal for predictive modeling

	Activities	Time	Resources
Step 1	Convene a small expert workgroup to discuss 'the art of the possible' and identify in outline potential approach(es) to development. This would include consideration of different model components and platforms, roles (including model development, review and guidance, project management), and resources (computational, personnel, financial, data management) - Include those who may be involved in the work - Could be convened and reported out by the Science Program Manager or a knowledgeable contractor/staff member.	Months 1-2	Staffing/leadership, possible travel support
Step 2	Discuss potential approach(es) with Integrated Modeling Steering Committee (IMSC) - Have appropriate options have been considered? - Are challenges and resource needs are appreciated? - Are approach(es) and timelines are potentially viable?	Months 3-4	Staffing/leadership, possible travel support
Step 3	Develop detailed proposal to include timelines, benchmarks, resources needed (financial and personnel). This would be developed by the small group of experts who would execute the project.	Months 5-7	Staffing/leadership, workshop support for team
Step 4	Proposal review by external experts, conducted independently (not a review panel) including members from the IMSC as appropriate.	Month 8	Staffing/leadership
Step 5	Revised proposal	Month 9	Staffing/leadership, support for team
	Decision and resource allocation.	Timing and resources dependent on the final proposal.	
	Contracting and execution.		

Detecting the Response

What is Available?

There are extensive existing field sampling programs in the Delta, many of which are directly relevant to Delta Smelt. Within the IEP, there are over 15 discrete monitoring programs that have been in place since at least the early 2000s, with several of these now spanning five decades (see Appendix 2). In addition, IEP operates a network of high-frequency water quality sensors, many of which report data in real time. Within the Suisun Marsh and the Delta alone, there are over 150 stations collecting water quality and hydrological data. The extent of these programs and their spatial and seasonal coverage has recently been collated as context for planning activities for the 2017 Fall Outflow management action (A. Schultz., pers. comm.). Appendix 2 includes a brief description of these relevant to this science plan based on the 2019 IEP Work Plan and summary tables outlining their extent. Many of these programs collect data directly related to the expected effects of flow-related management actions on Delta Smelt (Table 3).

Table 3. Surveys and monitoring programs collecting data potentially relevant to flow-related management actions (see Appendix 2 for more details).

Effect Variable	Surveys and Monitoring Programs
LSZ position/extent	EMP, SF Bay Study, USGS WQ, 20mm, STN, FMWT, SKT, EDSM, DOP
Location of Delta Smelt	20mm, STN, FMWT, SKT, EDSM, JFM Seine, SF Bay
Benthic grazers	EMP
Phytoplankton	EMP (Chl), DOP
Zooplankton	EMP, Yolo Bypass LTM, DOP
Delta Smelt food supply	DOP
Water Temperature	EMP, SF Bay Study, USGS WQ, 20mm, STN, FMWT, SKT, EDSM, DOP, SLS, Yolo Bypass LTM
Turbidity	20mm, STN, FMWT, SKT, DOP, USGS WQ, SLS
Poor Water Quality	USGS WQ, JFM Seine, EMP, EDSM
Exposure to Contaminant	DOP
Exposure to HABs	DOP
Delta Smelt Predation	
Delta Smelt Biomass	20mm, STN, FMWT, SKT, EDSM, SF Bay
Delta Smelt Survival	20mm, STN, FMWT, SKT
Delta Smelt Health Metrics	DOP
Delta Smelt Diet & Feeding Success	DOP
Delta Smelt Fecundity	SKT
Delta Smelt Growth/ Life History Diversity	DOP
Delta Smelt Recruitment	20mm, STN, FMWT, SKT

In addition to these monitoring programs, a network of sensors deployed throughout the Delta provide continuous station information on water quality and this has long focused on abiotic measures, e.g., flow, turbidity. Work continues, led by USGS, on a high frequency monitoring network, established in 2013, that also includes 15-minute sample frequency water quality measurements of temperature, conductivity, pH, dissolved oxygen (DO), nitrate, fluorescence of chlorophyll-*a*, phycocyanin (a tracer for blue-green algae such as *Microcystis*), and fluorescent dissolved organic matter (a proxy for dissolved organic carbon concentrations). Phosphate and ammonium are under development. Currently this network includes ten sampling stations in the north Delta, Sacramento River and San Joaquin-Sacramento River Confluence.

While routinely collected information can be used as part of a larger effort to detect and understand change associated with changing ambient conditions and flow-related management actions, it is unlikely to be sufficient to develop a full understanding of management effects. Table 3 shows that regular sampling programs address most of the issues identified in Table 1 but there is no routine monitoring for predation of Delta Smelt, and there is little routine documentation of contaminants in the Delta. The Delta Regional Monitoring Program[17] is making progress in that area but is focused more on status and trends for the Delta as a whole. Water sampling for contaminant analysis is included in DOP and samples are used for toxicity testing with cultured Delta Smelt.

Exploration of new approaches for field sampling is ongoing. These include:

- Smelt Cam. Substantial progress has been made with this method for non-lethal detection of smelt and it has provided insights in relation to their location on flood/ebb tides (Feyrer et al., 2013, 2017) and work continues on (a) improved species identification, (b) calibration of observations, and (c) assessment of indirect mortality[18]
- The Aquatic Habitat Sampling Platform (AHSP) is an integrated aquatic species and habitat sampling system designed to monitor aquatic organisms and explore habitat associations in shallow and off-channel habitat[19]. Development and testing are continuing.
- Environmental DNA could provide a highly sensitive sampling method to complement traditional long-term survey methods. Foundational work is being pursued through several initiatives including work on effective sampling (UC Davis) and modeling (Cramer).
- Mapping of various water quality parameters using flow through sensors mounted on boats with hull-mounted water intakes is a common tool in estuary water quality monitoring, e.g., (Buzzelli et al., 2014; Buzzelli et al., 2003). In the Delta, Downing et al., (2016) have conducted high speed mapping of various water quality parameters and have been able to demonstrate spatial patterns in, for example, phytoplankton blooms clarifying potential

[17]https://www.waterboards.ca.gov/centralvalley/water_issues/delta_water_quality/delta_regional_monitoring/wq_monitoring/

[18] 2019 IEP Workplan

[19] Anderson et al. 2016. Sampling Platform: Standardized biological sampling across habitat types. Poster presentation at BDSC.

sources (Brown, 2017). Thus far this type of mapping has been largely used in special studies rather than for routine surveys.

What is Needed?

Enhancements and additions to existing surveys and monitoring programs to enable detection of change in relation to fluctuating ambient conditions or specific management actions must be selected to address specific needs. Specific plans for monitoring and data collection must be cognizant of resource limitations (e.g., financial, personnel, take) and make tradeoffs between resources spent on data collection and those spent on analysis, as well as other studies that contrubte to understanding. Plans must also be made in recognition of the timelines expected for information delivery to managers. In the current context, two considerations are of primary importance in determining need: the nature of the management action, and limits on permited take of Delta Smelt. In addition, opportunities to efficiently extend data collection using different approaches and technologies can be useful.

Management-Action Specific Sampling Designs

Management actions focused on structural habitat modification are planned well in advance, and the footprint of the action is specified, although interaction with dynamic habitats can be complex. In contrast, flow-related management actions interact dynamically with structural habitat features, including habitat restoration projects, and the specific scale of their effect on the system varies depending on operational considerations. Identifying appropriate additional surveys and monitoring to detect effects must consider temporal and spatial dimensions of the expected effects. Thus, in any given year, the need for additional surveys and monitoring beyond that provided by routine programs needs to consider flow-related management actions either taken in the previous year for which extended effects are expected and/or those for which ambient conditions comparisons are needed. Box 2 suggests how these considerations can be

Box 2. Considerations for Identifying Management Action Specific Survey and Monitoring Needs

What management actions are to be taken this year? What is needed to document the effects? What are the unresolved issues emerging from last time the management action was taken?
What are the confounding factors that could limit the success of the management action? How can these be documented to later explain outcomes?
If more than one action is planned, how do they interact? How can such interactions be documented?
What management actions taken last year are expected to have extended, measurable effects this year?

- Do existing monitoring programs provide sufficient temporal and spatial coverage?
- If not, what else is needed?

Is this year likely to represent an interesting reference against which to assess the effects of previous year's flow-related management actions?

- Where and when is data needed for comparison? The area influenced by the flow-related management action in previous years? The part of the Delta experiencing similar environmental conditions without the flow-related management action?

framed to guide planning. Further detail on how these considerations can be used in detailed planning of scientific activities is discussed later in this report.

The extent, location, timing and duration of the expected effect of the flow-related management action(s) determines the effectiveness of existing monitoring programs in detecting response to the management action(s) and informs the planning of additional field sampling. A number of simulation tools are available (MacWilliams et al., 2016b) to predict action effects on abiotic conditions including salinity, velocity, and turbidity. The spatial and temporal extent of changes provides a template for consideration of what additional surveys could be needed. Model simulations can be used to determine:

- Interactions among flow-related management actions in space and time, including effects of upstream effects on downstream conditions, temporal lags in abiotic change both after the initiation of the flow management action and after the action has ended
- Gradients in abiotic conditions within the influence area including hot spots of potentially desirable or undesirable conditions, and how changes in abiotic conditions might interact with structural habitat features
- The magnitude and duration of change in abiotic conditions associated with flow-related management actions. While not necessarily directly related to the response of food web dynamics, for example, or any other key factors influencing Delta Smelt, in the absence of predictive tools for organism response (see Predicting Delta Smelt Response), change in abiotic conditions can provide a general guide to the magnitude of the effect of the flow management action.

In addition, the spatial and temporal extent of changes in years with flow-related management can be used to guide activity during years in which no actions are taken so as to understand response to ambient conditions. The extent of the effect can then be examined in terms of station locations for existing monitoring programs and environments or habitats which are likely to be important for Delta Smelt, and where additional surveys or opportunities for learning exist (e.g., Box 3).

Non-Take Detection

There are many reasons to explore new technologies for field sampling including safety, access the difficult environments, and efficiency in spatial and temproal coverage. Of particular concern for Delta Smelt are stringent limits on take due to extremely low abundance estimates.

Some promise has been shown in using acoustics to detect pelagic organisms, especially in highly turbid areas where optical sensors are limited[20]. Ongoing work funded by the Bureau of Reclamations on eDNA has included testing of field sampling techniques and is expected to include tidal modeling in the near future[21]. The use of eDNA to address challenging detection

[20] For example, Saenz ‘Comparison of Acoustic and Trawl-Based Estimates of Small Fish Distribution and Abundance in San Pablo Bay’ presentation at the Bay-Delta Science Conference 2018

[21] Schumer et al. ‘Delta eDNA Part 1: Investigation of eDNA Methodology to Detect Delta Smelt’, and Blankenship et al. ‘Delta eDNA Part 2: Applying eDNA Procedures to Detect Delta Smelt at Salvage’ presentations at Bay-Delta Science Conference 2018

Box 3. In-situ Experiments with Cultured Delta Smelt to Detect Patterns

Low catches of Delta Smelt in the field and limits on permitted take due to low abundance estimates, mean that framing a field study around a specific Delta Smelt response could be futile, or impossible. At the same time Delta Smelt have been cultured for over a decade, and a refuge population FCCL. Due to capacity limitations large numbers of cultured animals are culled from the population annually. Cultured fish have been valuable for researching the basic life history and biology of Delta Smelt thus far they have not been used for in situ experiments in the Delta. (Lessard et al., 2018) describes the findings of a workshop held in in 2017 that included managers and researchers. They report there was 'broad consensus' that the potential use of cultured Delta Smelt for in situ experimentation would be a valuable application for the Delta Smelt culture program. Developments in the use of natural marks to identify individual cultured smelt (Castillo et al., 2018) could allow tracking of individual fish response to field conditions. Researchers and managers are testing cages in the Delta for deployment of cultured fish. The use of tethered or caged fish and macrocrustaceans has long provided insight into habitat utilization, predator prey interactions etc. in many systems (e.g., Dahlgren & Eggleston, 2000; Heck & Thoman,1981; Rozas & Odum, 1988) in several environments. The opportunity for such response detection, especially in relation to flow-related management actions, provides an exciting opportunity to explore effects across gradients of change. This is a rapidly evolving issue for Delta Smelt and permits have recently been granted opening a whole new field of study.

and identification issues is already underway in federal agencies[22] and USGS has published sampling protocols for some freshwater environments[23]. Application in tidal and estuarine environments is more challenging as seasonal changes in fish abundance test eDNA temporal specificity (Stoeckle et al., 2017). In their work on the lower Hudson estuary Stoeckle et al. were also concerned about how daily freshwater and saltwater inflows might carry eDNA from non-resident species, challenging geographic localization of eDNA. However, they were able to demonstrate, by combining eDNA sampling over time from shore-based sampling with existing fish surveys, that eDNA amplified with PCR (see Thomsen & Willerslev (2015) for a summary of methods) correlated with fish abundance, seasonal movements, and habitat preference in an estuary with large fresh and saltwater inflows. They note that the relatively low cost of sampling, which can be 'performed by diverse persons with modest equipment' can facilitate surveys at much finer temporal and geographic scales than possible with traditional techniques.

The promise of these tools for Delta Smelt is that low catches leave questions regarding presence/absence and distribution. This technology could provide a highly sensitive sampling method to complement existing survey methods.

Increasing Effectiveness

Understanding the response of Delta Smelt to management action (next section) relies, at least in part, on documenting the changes which are occurring within the system (e.g., abiotic conditions, food web interactions and stressors) within resource limitations. The extent and complexity of

[22] For example https://research.noaa.gov/article/ArtMID/587/ArticleID/2336/NOAA-Science-Report-highlights-2017-research-accomplishments

[23] https://pubs.usgs.gov/tm/02/a13/tm2a13.pdf

the system mean that efficiency in field sampling is always an issue. Some technologies may be able to provide information slightly different from that derived from existing field programs but which could be useful in showing changes in patterns of different variables in response to changing environmental conditions. Taking a new technology or approach from concept to operation is a long process. However, there are several which have been in development for some time in other systems that could be applied in the Delta. Examples are described here to demonstrate the types of potential utility.

For environmental conditions, unmanned aerial systems are showing promise for remote measurement of turbidity in the Bay-Delta[24] and in other systems they are being used for other direct sampling of aquatic systems [25]. Development and testing of high-speed boat-based mapping of water quality parameters have demonstrated time variation in key gradients related to tidal exchanges (Downing et al., 2016). Further, Fichot et al. (2016) have shown how boat-based mapping in coordination with airborne sensors can provide high resolution mapping of important parameters such as turbidity, enabling coverage in areas beyond the limits of boat operations. Many of the flow-related management actions are relatively limited in their spatial influence and have effects in shallow areas not normally accessed by routine monitoring and between fixed stations. Novel techniques for mapping abiotic and water quality should be tested in more settings to enable a more thorough understanding of their utility, costs and limitations.

For the biotic system, metabarcoding is an example of a rapidly emerging approach because of its potential to assess efficiently community composition. Barcoding consists of taxonomically assigning a specimen based on sequencing a short, standardized DNA fragment (barcode). In the metabarcoding approach, the analysis is extended to a community of individuals (of different species) rather to a single individual (Aylagas et al., 2016). There has been some study of the use of metabarcoding for zooplankton communities in marine systems (e.g., Bucklin et al., 2016; Djurhuus et al., 2018). Standard laboratory species identification requires extensive taxonomic expertise and it is time-consuming and expensive. While metabarcoding does not provide the same information on relative abundance etc., it has promise for identification of, and change in, broad patterns of species occurrence and how they change in relation to environmental conditions and/or specific management actions.

The development and application of such techniques is advancing rapidly in many systems and application in estuaries presents many challenges. But the efficiency of the application, once developed, over large spatial scales and focused time intervals, provides opportunity for a type of information which has, heretofore, not been available in the estuary.

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[24] Fringer and Adelson 'Remote Sensing of Turbidity in San Francisco Bay Using UAVs' presentation at the Bay-Delta Science Conference 2018

[25] https://nimbus.unl.edu/projects/robotic-water-monitoring/co-aerial-ecologist-robotic-water-sampling-and-sensing-in-the-wild/

Proposed Next Steps

Furthering the approach for selection of management action specific additional surveys and monitoring is described in the proposed three-year science plan later in this report.

Non-take detection is a priority issue and many questions remain over the comparability of the data that can be produced, and what the information developed could be used for. As discussed above, non-take detection techniques have been applied in many other systems and the experiences and lessons learned from those uses need to be brought to bear in the Delta. While external experts may not be familiar with Delta Smelt or estuarine conditions in the Delta, working knowledge of the approaches and how they might be combined, e.g., hydroacoustics in combination with eDNA, will accelerate learning among Bay-Delta scientists. In addition, understanding how these approaches have been used in other systems could help managers identify the potential utility of these new data sets. ***An independent science advisory panel should be established using the guidelines in the Delta Science Plan[26] to provide timely advice to CSAMP on the potential utility of approaches to non-take detection of Delta Smelt, possible pitfalls, appropriate caveats, and useful steps to refine and test approaches individually or in combination.*** The Advisory Panel process would need to include provision of information on the current status of ongoing work, and dialog with Delta Smelt experts to enable to the local context for detection to be appreciated.

Planning management-action specific field surveys that include broader spatial and temporal coverage for some variables, or that provide different types of information in a timely manner, needs a collective understanding of what is currently available and feasible, and emerging ideas. ***A workshop on new techniques for aquatic field surveys in the Delta should focus on abiotic and biotic aspects of 'dynamic habitat' in the estuarine environment.*** The workshop would be of interest to many but should be focused in order to allow detailed presentation of benefits and challenges, and could be structured to bring in several scientists from other systems where new approaches are being applied. It could be conducted through the Delta Science Program or use a similar approach under the auspices of CSAMP.

Understanding the Response

Current Approaches

This report considers two main approaches to developing understanding: investigative research focused on mechanisms or the effects of stressors, and analysis and synthesis of field information and predictions in the context of the evolving knowledge base.

Research

Appendix 1 summarizes recent developments relevant to understanding the response of Delta Smelt to management actions, and a substantial body of research is ongoing as evidenced by presentations at the 2018 Bay Delta Science Conference.

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[26] See Appendix G of the 10/12/2018 version of the Draft Delta Science Plan Update

Several competitive programs exist to support investigative research including periodic solicitations for proposals from the Delta Science Program, Proposition 1 funds for science under the Delta Water Quality and Ecosystem Restoration Grant Program, Sea Grant, and other research funding bodies such as the National Science Foundation. Researchers often form collaborative teams across academia, agencies, the private sector and NGOs to address complex problems, or propose specific individual studies. Agencies also directly fund research work in support of their missions, and IEP has a tradition of cross-agency science and working with non-agency experts. Collectively these ‘science provider’ mechanisms have contributed to the development of an extensive body of knowledge regularly captured in reports and publications and other scholarly outlets (see Appendix 1).

Ongoing sources of funding for research and mechanistic studies are limited. The Delta Water Quality and Ecosystem Restoration Grant Program provides Scientific Studies grants to fund projects to assess the condition of natural resources, inform policy and management decisions, or assess the effectiveness of grant projects and programs. Several scientific studies have been funded in recent years relevant to Delta Smelt including studies of restored wetlands and the Cache Slough/North Delta region[27]. In 2018 a joint solicitation for scientific proposals was issued for the Delta Water Quality and Ecosystem Restoration Grant Program and the Delta Science Program, with additional funds contributed by the Bureau of Reclamation. The DSP priority areas included understand mechanisms underlying relationships between flows and aquatic species.

IEP also has the ability to fund research studies from a common, competitive pool if funding is available once the needs of the other science areas are met (i.e., Compliance Monitoring, Baseline Status and Trends, Directed Studies, & Synthesis, Modeling and Reviews). However, no funds have been available for competitive research through IEP in recent years.

Analysis and Synthesis

Advanced approaches to data analysis are increasingly common in the Bay-Delta. Statistical analyses are often focused at understanding status and trends (e.g., MacNally et al., 2010), but have also been applied to understanding Delta Smelt response to changing ambient conditions[28]. Often synthesis focuses on analysis across data sets but a broader definition includes the integration of existing, diverse datasets and knowledge to produce new insights or knowledge (Carpenter et al., 2009).

IEP has worked to increase its internal capacity for synthesizing data and information for the estuary. Since 2013, five scientist positions among three agencies have been added or redirected for dedication to synthesis work. The IEP workplan includes synthesis efforts, e.g., FLOAT-MAST, with associated project work teams to enable broader participation. The 2019 work plan for example, also includes synthesis efforts around effects of aquatic macrophyte control on

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[27] https://www.wildlife.ca.gov/Conservation/Watersheds/Restoration-Grants/Projects

[28] For example, Korman et al., 2017 Statistical Evaluation of Particle-Tracking Models Predicting Proportional Entrainment Loss for Adult Delta Smelt in the Sacramento-San Joaquin Delta. Draft report to CAMT.

Delta Smelt habitat, IEP zooplankton sample methodologies and variation in zooplankton communities across habitats, and the development of a longfin smelt conceptual model. IEP considers synthesis to include several other activities beyond integrated data analysis: 1) conducting management-relevant analysis and synthesis of ecological datasets, 2) facilitating open science practices, 3) integrating monitoring datasets, and 4) distilling IEP Science findings into cohesive narratives[29].

An important aspect of synthesis work is drawing on available relevant information to develop larger concepts and guide analysis. The Delta Science Program has successfully coordinated periodic 'State of Bay-Delta Science' (SBDS) reports designed to synthesize current understanding of the Bay-Delta system[30]. The first edition of SBDS was produced in 2008, providing a system-wide baseline for the state of scientific knowledge of the system. The 15 peer-reviewed papers that form SBDS 2016 cover issues ranging from contaminants in the Delta to levee stability, and from Delta food webs to recent discoveries about salmon migration. These include Brown et al. (2016a), Fong et al. (2016), MacWilliams et al. (2016b) and Moyle et al., (2016).

For topics of interest less driven by data and analysis, workshops have often proven to be useful venues to bring ideas together. For many of these the discussion which occurs amongst participants is a useful product as ideas are generated and linkages identified. Publications of 'essays' in SFEWS has also proven to be useful venue for dissemination of discussion topics enabling the 'state of thinking' on an issue to be documented. Recent examples related to Delta Smelt include Hobbs et al. (2017) and Lessard et al. (2018).

What is Needed?

Regular Competitive Solicitations for Research

Delta researchers have a track record of developing and conducting field and laboratory studies, computer simulations, and integrative analyses which continue to provide great insight into system dynamics and the factors influencing how Delta Smelt respond to changes in ambient conditions and flow-related management actions. While directed studies can be conducted to advance topics and answer questions which are already formed, innovative forward-looking science needs to be supported to 'address the Delta's diverse, interacting, and rapidly changing management challenges'[31]. Understanding how flow related management actions interact with the system to produce benefits for Delta Smelt relies on awareness and knowledge of changing abiotic and biotic dynamics. Rarely can studies that produce such understanding be specifically planned by managers; the research community needs opportunities to develop concepts and increase the knowledge base.

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[29] Interagency Ecological Program: Guiding framework for conducting IEP synthesis work. Draft November 2018

[30] http://sbds.deltacouncil.ca.gov/

[31] ISB letter to DPIIC 11 February 2019

The advantage of using a competitive proposal process to fund research is that it enables researchers to contribute ideas on approaches to address a particular problem area, potentially leading to innovation, and it fosters efficiency when budget is a constraint and/or an evaluation criterion. Disadvantages include the time taken for solicitation and review of proposals, the potential that no proposals will directly address the management issue of interest, and the risk that research questions cannot be addressed with the proposed approaches. Open competitions also draw new researchers to work on Delta problems and the opportunity for insight gained elsewhere to be applied to the Delta.

Existing solicitations and future solicitations that include Delta-focused scientific study could explicitly request proposals relevant to understanding Delta Smelt flow-related management actions, e.g., interacting effects of dynamic and structural habitat on food availability, response of Delta Smelt and their prey to contaminant mixtures found in Delta waters. While limited funds are available, competitive solicitations stimulate thinking in the research community and the development of ideas and approaches which can be refined and tuned to other funding opportunities.

Special Studies

Several topics are identified here as areas where attention has been lacking or where specific studies could be undertaken that would provide a foundation for further mechanistic understanding. These are examples only and have been identified through discussions with Delta scientists, awareness of approaches being used in ecosystem management in other systems and the needs of CSAMP in understanding Delta Smelt response to flow-related management actions. How they are actually advanced will vary according to the interests of scientists and researchers to pursue them collaboratively and the availability of resources.

Tracing Organic Matter Sources and Utilization

Several flow-related management actions target food production for Delta Smelt by stimulating primary production in specific areas, e.g., North Delta Food Web, or encouraging Delta Smelt movement to richer food areas, e.g., Suisun Marsh Salinity Control Gates. While monitoring of environmental conditions and smelt vital rates can provide insight into associations between beneficial responses and the consequences of a management action, mechanistic linkages often require additional studies.

Multiple stable isotope analysis has become a familiar technique to determine food web pathways in aquatic, terrestrial, and marine systems and has provided initial insights into direct and indirect habitat linkages in the Bay-Delta (Howe & Simenstad, 2011). The approach utilizes the differences in uptake of certain carbon and sulfur isotopes by different classes of producers, and changes in nitrogen isotope ratios among trophic levels. Differences in photosynthesis between riparian vegetation, emergent vegetation, and phytoplankton (both proximal within the Delta and imported subsidies) often make it possible to differentiate carbon derived from different sources in consumer tissue. Carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) have been used in several studies in the Delta examining the use of various food sources by fish e.g., Grimaldo et al. (2009) and Schroeter et al. (2015). The addition of sulfur ($\delta^{34}S$) has been used in some studies to provide additional discrimination among sources (Howe & Simenstad, 2007), especially across salinity gradients. Isotope ratios can provide information about primary production/habitat origins of organic matter, predator-prey linkages and energy flow through food webs, and Schroeter et al. note that they can be particularly helpful when diet studies are difficult both because of the small size of species and prey maceration by invertebrates. Stable isotope analysis can also provide an integrative assessment of consumption and can be scaled over the consumption-assimilation timeframe by using different organ sources, e.g., muscle for long-term (months) and kidney for much shorter term (weeks). Recently, fatty acid composition has been used as an additional biomarker of food web sources, enabling higher resolution and discrimination of food web pathways (e.g., Gonçalves et al., 2012; Meersche et al. 2009). This can be helpful for primary consumers but secondary consumers such as fish have some, still poorly resolved, ability to synthesize some fatty acids, e.g. Oboh et al. (2016), which can confuse their application.

A recent study of Liberty Island (Barnard et al., 2018) used stable isotope and fatty acid biomarkers to characterize the production base of food web support of larval fishes and their prey organisms. They found that overall phytoplankton comprised the largest proportion of Delta Smelt diets (>70%), followed by smaller contributions form benthic diatoms, emergent marsh vegetation, and SAV. Larger Delta Smelt (16 – 25 mm) depended more on phytoplankton (90%) than smaller (<16 mm) Delta Smelt (70-80%). However, there have been few stable isotope studies of Delta Smelt (or other comparable pelagic forage fishes in the Delta) and there may be life history stages when prey organisms have less phytoplankton-based stable isotope ratios. Stable isotope analysis has also been used in the Delta to trace sources of nutrients in blooms e.g., Kendall et al. (2015) and Lehman et al. (2015).

The IEP Tidal Wetlands Monitoring (Interagency Ecological Program Tidal Wetlands Monitoring Project Work Team, 2017) includes stable isotope analysis as a potential tool for making inferences about major sources of ecosystem metabolism and to provide insights into diet of consumers over longer time periods than possible using stomach analysis. Understanding linkages between carbon sources in different regions or habitats and zooplankton, microcrustaceans and Delta Smelt, and how flow and changing ambient conditions influence them is crucial to understanding how actions may influence Delta Smelt. Tools such as stable isotope and fatty acid analysis can help tease out specific mechanistic relationships and potential life history variation in the relative importance of food web sources. ***A next step to support more work in this area is an inventory of existing information on the isotopic signatures of key potential carbon sources including information about potential temporal and spatial variability, and where existing information is adequate.*** Such a catalog of information would be useful to more efficiently plan specific studies to target linkages between carbon sources in different regions or habitats and zooplankton, microcrustaceans and Delta Smelt, and would support more ready application of this tool in relation to specific actions.

Contaminant Effects

The effect of contaminants on Delta Smelt under ambient conditions and when flows are adjusted as part of management actions is an outstanding question. Fong et al. (2016) reviewed studies using ambient water and concluded that there is evidence to support that contaminants are bioavailable in Bay–Delta waters at concentrations that are affecting Delta Smelt. They also noted laboratory studies with cultured fish and contaminants at levels detected in the Delta. Findings included decreased growth, abnormal development, and altered behavior associated with exposure to pyrethroids, and effects on immune, nervous, and muscular systems from exposure to copper. Ammonium induced effects were similar, affecting immune- and muscular-system functioning, as well as development and behavior.

The Delta Independent Science Board (DISB) recently identified the need for more attention on contaminant effects in the Delta[32] (see Box 4). Brooks et al. (2012) note that lack of direct lethality in the field may have prevented consensus that contaminants may be one of the major drivers of coincident but unexplained declines of fishes. They also conclude that the greatest threat most likely occurs in the freshwater reaches of the Delta in late winter and spring when storms may greatly increase concentrations of toxicants. Opportunities exist for furthering

Box 4. Key Points from the DISB Review of Water Quality Science in the Delta

- There is a need to further assess the effects of chemical contaminants on the Delta ecosystem through holistic studies that combine toxicity testing and chemical analyses with fish and food-web monitoring.
- Little attention has been paid to interactions among chemical contaminants, as well as interactions between contaminants and other stressors.
- Interactions between chemical contaminants and other stressors require more attention. Improved understanding of the interactive effects of multiple chemicals on the ecosystem is also needed.
- An understanding of spatial and temporal variability in contaminant delivery and the role of key events (e.g., first flush, floods, and tides) will contribute to better understanding and management of contaminants.

understanding of how flow-related management actions interact with contaminant stress, and the potential consequences for Delta Smelt. Two potential avenues of investigation are suggested here.

- Routine collection of large volume water samples for use in toxicity testing during flow-related management actions and non-action conditions. DOP is currently collecting samples for specific purposes, but such sampling could be added to other field monitoring used to detect response to flow and ambient conditions. Water sampling could be informed by USGS's pesticide group, the Delta Regional Monitoring Program or the California 303 (d) list[33] of water bodies that do not meet Clean Water Act standards. Water samples can be used for toxicity testing with cultured fish with mortality and

[32] http://deltacouncil.ca.gov/docs/final-delta-isb-review-water-quality-science-chemical-contaminants-and-nutrients
[33] https://www.waterboards.ca.gov/rwqcb5/water_issues/tmdl/impaired_waters_list/#intrpt2014_2016

behavior (e.g., abnormal swimming behavior) monitored visually. Genomic techniques can also be used to document sublethal stresses (e.g., Connon et al., 2009). Standard toxicity testing could be used to get a general sense of toxicity in the water[34]. The advantage of toxicity testing is that it is not limited to specific chemicals selected for analysis, or to individual chemicals, but can detect the presence of effects from a wide range of contaminants and mixtures in field water. This could provide an overview of the relative importance of contaminant effects across areas of interest, and enable assessment of bioavailability. Note this would be in addition to studies of field collected Delta Smelt health and condition, but is not dependent on the collection of wild Delta Smelt. The detection of patterns, hot spots or associations with specific environmental conditions could guide more specific follow up studies.

- Controlled laboratory experiments. Studies of wild caught Delta Smelt have documented evidence for contaminant stress using histopathological condition and its potential interaction with other stressors (Hammock et al., 2015). Laboratory studies of cultured fish have provided insight on their response to specific stressors and gradients and thresholds within responses (e.g., Kammerer et al., 2016; Komoroske et al., 2016). Controlled laboratory experiments have provided fundamental understanding of various aspects of Delta Smelt biology (see summary in Lessard et al. (2018)). Controlled experiments can also be used to examine the sensitivity of different life stages of Delta Smelt to ambient water quality variation, in combination with other potential stressors, e.g., food limitation, high water temperatures. Such experiments would require larger volumes of ambient water than could reasonably be collected during field sampling for other purposes (e.g., studies by Hasenbein et al. (2014) utilized 700 L of water collected from field locations), but the use of ambient water provides insight into potential multiple stressor effects without the need to specify specific contaminants and concentrations.

The inclusion of contaminants within DOP has been an important step, and results from that work will be valuable in guiding future work on contaminants. ***The Contaminants PWT should be engaged to plan a series of specific experiments that build on existing work, and select focus locations for water collection where Delta Smelt are often caught and where contaminants are known the be an issue.*** The PWT could also assist with interpretation and follow up studies on specific contaminants, mixtures or stressor combinations.

Synthesis

While the findings of individual studies provide valuable information, synthesis across studies or management actions can be an effective mechanism for greater insight into system dynamics and Delta Smelt response. Integration and synthesis activities need to bring together not only the findings of work conducted under this science plan, but other relevant scientific developments in the Delta and beyond. Conceptual models are often seen as synthesis tools for capturing current

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[34] See Interagency Ecological Program Tidal Wetlands Monitoring Project Work Team (2017) for discussion of appropriate species for fresh and brackish conditions, and their SOP 2.5 for details of standard testing protocols.

knowledge in a structured manner, and numerical models can play a similar role if they are routinely updated as knowledge develops. However, reports and papers are one of the most common and accessible synthesis products.

Given the level of effort involved in synthesis activities, these should not be annual deliverables related to each management action but could periodically reflect on the effects of a suite of management actions, including those related to flow, and ambient conditions on a specific issue, e.g., food availability and use.

Over a number of years, and within the context of adaptive management and in support of SDM, a series of reports could be produced for:

- Key issues, such as food availability or the effect of contaminants
- Important locations, e.g., Cache Slough, Suisun Bay-Marsh, DWSC
- Individual Delta Smelt life stages or transitions

The concept is to go beyond the effects of an individual management action to consider the response of Delta Smelt in a systems context. Insights would be gathered from available data and emerging research, and would draw in information generated by others, e.g., the Delta Regional Monitoring Plan, National Estuarine Research Reserve.

To some extent this has been the approach used in developing SBDS. That process has been viewed as a periodic benchmark in learning. However, making these types of integrative synthetic assessments appear more regularly, but perhaps with a 4-5-year frequency for any particular issue or topic, could enable a wider array of topics to be covered. These could be submitted for publication in San Francisco Estuary and Watershed Science, e.g., as research monographs or as policy/program analyses[35]. Coordination with the Delta Science Program, the journal editor, as well as IEP MAST efforts would be important to avoid overlap with SBDS and ensure authors/editors etc. are available. Note that the Draft Delta Science Plan update includes modification to the current SBDS process in Appendix D which may provide additional opportunities for coordination.

Identifying and prioritizing synthesis efforts requires the articulation of management needs and concerns, the availability of appropriate data and information, and the interest of scientists. Accomplishing the synthesis also requires funding. The key issues surrounding Delta Smelt response to changing ambient conditions and flow-related management are already broadly identified (Table 1). ***To advance synthesis in a coordinated way, CSAMP should convene a work group includng managers and scientists (drawing in those outside of CSAMP to participate as appropriate) that includes participation from the Delta Science Program and IEP, to develop a multi-year list of synthesis topics (e.g., issues, locations, species life stages/transitions) for which data/information is expected to be available, the types of synthesis outputs needed, and estimates of resource needs.***

[35] https://escholarship.org/uc/jmie_sfews/aimsandscope

Delivering Understanding for Management

The annual life cycle of Delta Smelt, and the current low population estimates, make the development and delivery of scientific understanding to users urgent. Decisions on flow-related actions are expected to be made on an annual basis and must be informed, to the extent practicable, by the most recent information and understanding. Often the delivery of scientific findings takes place through formal and informal presentation, and the production of contract reports, synthesis products and scholarly publications. This plan links the scientific process and the 'maturity' of the information derived, with communication of that developing information to users.

Scientific Products

The scientific process – from concept to peer-reviewed publications – involves many steps, often iterative and time consuming. USGS has captured this progression into a data lifecycle that describes how data flow through a research project from start to finish (Figure 4)

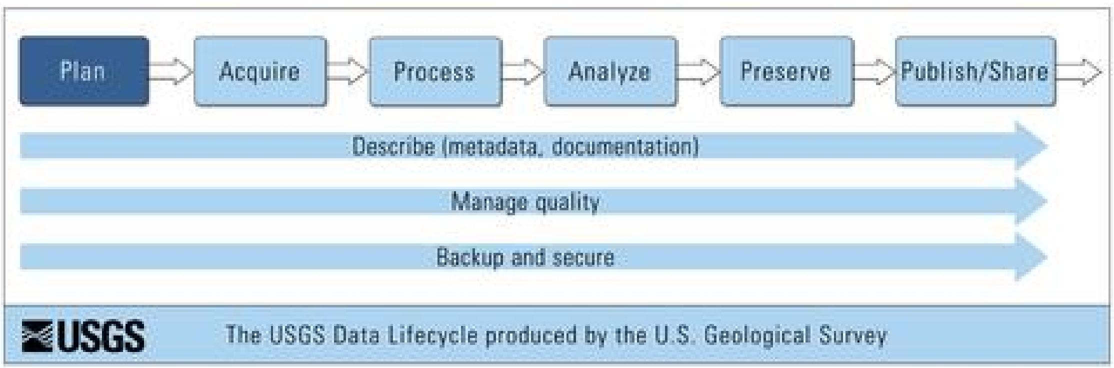

Figure 4. USGS Data Life Cycle (https://www.usgs.gov/media/images/usgs-scientific-data-lifecycle-model-plan)

Table 4 identifies stages in the development of information and outlines issues related to their use and availability. Proposals and scopes of work are an important part of the delivery of scientific delivery process as they describe what will be done, what types of analysis will be conducted and the timing for completion of each of the stages. These expectations are agreed in advance of work being conducted and provide the base against which progress can be tracked.

Raw data collection can be field observations, sensor data streams, results from laboratory sample processing or analyses, raw model outputs, etc. Although they are the fundamental product of scientific activities, raw data must undergo QA/QC procedures to ensure users can trust the accuracy of the data. Formal procedures need to be in place to ensure data are scientifically valid and comparable across efforts. The resulting 'validated' data are those which should be archived and posted to repositories[36] (see Data Management & Archiving for more on data management and access). While validated data are useful to other scientists and researchers, without further summary they are rarely of direct value to users.

[36] The concept of validation used here is similar to 'approved' data from USGS sensors for example.

Table 4. Stages in the development of information

Stage	Contents/Outcomes of Interest	Use/Distribution	Timing of Delivery
Proposals and scopes of work	Description of methods Sampling design Expectation of findings	Funded proposals available to potential users	Specifies timelines for delivery of information in stages
Raw data collection	Any methodological challenges encountered	Science team only	N/A
Validated data	Data undergoes QA/QC as specified in proposal.	Posted to data repository with appropriate metadata	Repository data maybe embargoed.
Summarized data	Summary statistics, maps, charts etc. with methods, sampling etc. from proposal (modified as appropriate). Maybe presented in comparison to previous years/existing data. No interpretation of differences/patterns.	Available to users in summary form	Timing varies for data within a study based on sample processing, etc. as specified in proposal
Individual study detailed analysis and interpretation	Scientific findings, contribution to knowledge	Final report available to users	As specified in proposal
Programmatic interpretation/synthesis	Integrative and technical Occurrence depends on actions/issues: - Periodic by management action - Periodic by 'means objective'	Accessible shorter summary documents in addition to longer reports and publications	Dependent on issue and availability of resources
Publication	Scientist's professional product	Open access?	Author discretion

Knowledge 'Updates'

The 2016 SEW noted the importance of fostering effective communication among scientists and managers, and that scientists' familiarity with agency and stakeholder cultures, interests, and individual personalities are helpful to ensuring that science provides effective, trustworthy support. Open communication among individuals is ideal but takes time and opportunity.

The Delta Science Program's initiative of 'Policy-Science Forums' has been using CSAMP as a vehicle and is making progress in communicating the findings of complex scientific studies to policy makers using short summary papers and interactive presentations. The DSC Lead Scientist also makes 'Science Update' presentations at each meeting of the Delta Stewardship Council summarizing newly available science for the Council and those present. Webinar technology has greatly increased participation in online 'seminars' and 'brown bag lunch' series held by DSP and IEP among others. These approaches have combined in-person and remote participation enabling communication between scientists and their peers and interested managers. The Delta Science Conference continues to be a hugely successful venue for formal presentations, informal discussions, and networking.

All of these mechanisms need to be leveraged to ensure common understanding of science related to Delta Smelt response to flow-related management actions and ambient conditions. In addition, as emphasized elsewhere, the annual life cycle, annual water cycle, the substantial resource allocation made to flow-related management actions, and the urgency presented by population decline, mean that scientific findings need to be disseminated widely and in a timely manner. As described in Box 5, emphasis on summary data and preliminary findings, as well as on-time delivery of reports and data, makes information on the potential effectiveness of flow-related management actions accessible as well as more rapid than traditional reliance of final reports and publications. Regular updates need to be provided including:

> Box 5. Data Summaries as Communication Tools
>
> The focus of timely information delivery for the annual science plan is summarized data. This may include graphs and charts, simple visualization of data (e.g., model outputs) that include summary statistics to characterize variability or uncertainty. The methods used to derive that data have already been described in the proposal or scope of work and notes to identify any adjustments made to the original plan provided. Summarized data may be accompanied by observations from those generating the information that might include comparison to long-term means, nuances in the patterns, or unusual results that require further examination to explain. Any observations provided should be seen as preliminary and subject to change. An example of this type of information delivery is provided in Brown (2017) which is an annual report for a multifaceted study. For each study element brief introductory material is followed by summary graphics and bullets. The information format is an example of scientists delivering something other than fully interpreted findings. An additional example is the IEP 'Status and Trends' seasonal report summary graphic (https://water.ca.gov/Programs/Environmental-Services/Interagency-Ecological-Program).
>
> The delivery of summarized data on agreed upon timelines does not preclude the need for final reporting of detailed analyses and findings. Such final reports maybe presented in the format of a manuscript as desired by the scientist(s) for their professional development but should include all pertinent information for the study conducted, perhaps in appendices. Delays in publication should not delay delivery of the final reports.

- Monthly short presentations on progress to CAMT/DSST
- Quarterly short written reports including available summary information. Development of these is based on incoming information from scientific activities (Table 4), other developments (publications or reports), etc. The development of these reports is described later in this report. These reports could also be shared with other science providers.
- Annual progress summaries would be developed in a similar manner and made available or presented to CSAMP Policy Group.
    - One useful vehicle for reporting and dissemination of new scientific developments in relation to Delta Smelt response to changing ambient conditions and flow-related management actions would be an annual or biennial State of Delta Smelt symposium.

This would enable both the presentation and discussion of emerging findings and refinement of understanding of management needs.

- Summary presentation of annual findings and science plan activities should be presented at the IEP workshop to strengthen linkages between field/bench/computer scientists and managers and users.

These specific communication mechanisms are incorporated into the three-year science plan described below (see Programmatic Planning for Science: Three-Year Cycle) and are in addition to publications and presentation made by scientists of their own findings.

Scientific Best Practices

It is expected that all work conducted to implement this plan will follow scientific best practices. Several elements are highlighted here to demonstrate how they can be tailored to the needs for science in support of understanding Delta Smelt response to ambient conditions and flow-related management actions outlined in this report.

Quality Assurance and Quality Control

Quality Assurance and Quality Control (QA/QC) procedures are designed to ensure that environmental data are of known and verifiable quality, technically valid, and appropriate for their intended purpose. Formalized quality assurance and quality control (QA/QC) procedures have been used extensively in water quality monitoring and chemical analyses, largely due to the EPA's rigorous quality assurance standards. Evaluating and documenting data quality in a systematic way is important in ensuring the data is usable, both by other entities in the near-term, and even by the entity that collected the data in the long-term. In chemical analyses, instruments and analytical methods can be calibrated with known standards, to precisely describe the accuracy and precision of the analysis. Many agencies already have their own guidance, e.g., DWR Water Resources Engineering Memo 60, EPA Guidance for Quality Assurance Project Plans, and USGS has recommended practices for quality assurance plans.

In many ecological measurements, it is not possible to know the 'true' value, e.g., against a standard. Therefore, the focus of quality assurance for many biological methods is often on comparability of measurements and the representativeness of the measurements (see IEP Tidal Wetland Monitoring Framework for the Upper San Francisco Estuary). Comparability allows use of data from across systems.

Requiring formal QA/QC procedures helps ensure consistency of data across scientific efforts, and, with appropriate oversight, can enable contractors or others to supplement existing surveys or monitoring programs (see Management-Action Specific Sampling Designs) to improve spatial or temporal resolution of field measurements, and/or relieve backlogs in laboratory sample processing.

Data Management & Archiving

Ensuring progressive learning requires that activities are documented, tracked over time and that information is readily accessible once made available.

Management and access to data generated by scientific activities initiated to support understanding of Delta Smelt response to changing ambient conditions or flow-related management actions is a crucial issue. Cross jurisdictional data management and sharing was the focus of an Environmental Data Summit Delta Stewardship Council's Delta Science Program in June 2014[37].The passage of AB1755 in 2016 renewed attention to the issue to some extent, but

[37] http://deltacouncil.ca.gov/enhancing-the-vision-for-managing-californias-environmental-information

federal requirements are also in place [38] with the common theme being that data and information are valuable resources.

Data management has long been an issue for science providers. The National Science Foundation has required data management plans (DMP) as part of proposals since 2011 and the recent Proposal Solicitation Notice jointly issues by CDFW and DSP requires that data meet certain criteria including that:

- Data are interoperable (machine readable)
- Standard data formats are used for similar data types
- Quality assurance and quality control (QA/QC) procedures are documented and followed
- Open and transparent data and metadata are accessible to the public in a reasonable time frame

CDFW, among others, have established minimum metadata standards[39] noting that 'timely capture of metadata is fundamental to the quality of the dataset as a whole in order to document what the data are intended to represent, how and when it was created, who created it and why it was created'.

IEP has made extensive progress in this area. The Data Utilization Workgroup (DUWG) activities include (1) developing data standards and best practices, including minimum standards for data descriptions, definitions, and documentation, (2) increasing efficiency and openness of data sharing and interoperability among datasets, and (3) providing support for IEP member agencies. All IEP programs are expected to have data management plans which will be a required component of IEP proposals beginning in 2019 (S. Culberson, personal communication) and guidance and a template has been developed by the DUWG to support researchers (Table 5). These procedures and approaches can be readily applied to non-IEP efforts.

Table 5. Components of IEP Data Management Plans

Program Element Number	
Year	Metadata
Date DMP Updated	Storage & backup
Start Date	Archiving & preservation
Principal Investigator	Format
Point of Contact	Quality Assurance
Data Description	Access & sharing
Related data	Rights & Requirements

The DUWG is also supporting open synthesis[40] and is using the Environmental Data Initiative as a repository, including guidance to researchers on how to prepare and upload data and metadata.

[38] https://www.whitehouse.gov/sites/whitehouse.gov/files/omb/circulars/A130/a130revised.pdf
[39] https://www.wildlife.ca.gov/Data/BIOS/Metadata
[40] https://github.com/IEP-Open-Synthesis

A further step in the recognition that data is a valued resource is publishing data as a standalone scientific product. These citable products provide professional recognition to those who generate and publish the data and enable appropriate acknowledgement in further interpretive products[41].

Access to data generated by others is facilitated through data warehouses and repositories which provide services of different types in return for fees. Preservation, access and use are common characteristics[42]. However, as noted in the strategic plan developed for implementation of AB1755, making data accessible to the widest range of users for the widest range of purposes to the extent permitted by law, has to be balanced with issues of privacy, security, and other valid restrictions.

Peer review

Peer review is a commonly used practice to enhance the quality and credibility of scientific information. It involves the review of a draft product for quality by specialists in the field who were not involved in producing the draft. It is also widely recognized that different types of peer review are appropriate for different types of information[43]. The challenge is to efficiently and effectively ensure credibility. This section outlines how peer review can be utilized for proposals and work plans, as well as key scientific products. In addition, periodic peer review by an external panel could be used to assess the success of the coordinated approach to science described here.

One of the Delta Science Program's strategic objectives is to 'promote and provide independent, scientific peer review of processes, plans, programs and products'. Their expertise can be leveraged to support some of the approaches described here.

Proposals and Work Plans

Peer review is an important part of competitive solicitation processes and most competitions will have their own procedures. The IEP Governance Framework also outlines a proposal process that values independent scientific peer review, and their procedures for open Proposal Solicitation Processes include independent technical review. The collaborative approach to science proposed in this report needs to ensure that, in the absence of an established structured processes, scientific proposals and work plans are reviewed by appropriate experts. The goal is to ensure at a minimum[44]:

- Data collection and research activities proposed are objective and replicable, and justified in relation to the scientific context
- Methods are documented including the processes to be used and the quality -assurance procedures to be applied. When non-standard alternative or experimental methods are proposed they should be described and the rationale for their use clearly stated.

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[41] For example, https://www.nature.com/sdata/ is a peer-reviewed, open-access journal for descriptions of scientifically valuable datasets

[42] See, for example, https://www.dataone.org/what-dataone, https://environmentaldatainitiative.org/, https://data.gulfresearchinitiative.org/about-griidc

[43] For example, https://obamawhitehouse.archives.gov/sites/default/files/omb/assets/omb/memoranda/fy2005/m05-03.pdf

[44] This section builds on established USGS procedures https://www2.usgs.gov/usgs-manual/500/502-2.html

- Anticipated information products are described and timelines for delivery are reasonable.

Internal review by specialists within the agency or institution can often be accomplishded more rapidly than seeking outside reviewers. Later sections of this report describe how such reviews can be operationalized,

Scientific Products

Table 4 identifies an array of products that can be derived from scientific studies, and synthesis reports have also been identified above as important in developing and capturing holistic understanding. The need for timely delivery of information means that external peer review of products needs to be tailored. Several existing outlets for information recognize the need for rapid turn around. The IEP Newsletter, and IEP Technical Reports that present larger, more complex studies or data collection efforts, undergo internal review, e.g., by the Newsletter editor, Science Management Team members, to ensure timely turn around, and IEP notes that all primary research results in their Newsletters and Technical Reports should be interpreted with caution. Publications in peer reviewed journals, such as SFEWS, usually undergo review by anonymous experts selected by editors who make a final decision on whether papers proceed to publication and any necessary changes in content that arise during the review process.

For the written materials identified in Knowledge 'Updates' above the following approaches could be appropriate

- Monthly short presentations on progress to CAMT do not require review but should be refined based on comments received during the presentation prior to archiving
- Quarterly short written reports including available summary information should undergo internal review by CAMT[45]
- Annual summaries should be reviewed by several external experts (i.e., those who have not been involved in the development of the summary or the primary work underlying it), and comments which cannot be addressed or on which opinions differ should be captured in the document.

Synthesis reports as described here (see Analysis and Synthesis) are evaluations of a body of knowledge where some profesional judgement is exercised to bridge uncertaintieis in available information or develop overarching conclusions. Their periodic nature means that can become reference sources of information for several years. As such, it is more important that these undergo external peer review, preferably managed by an independent party. This could be through submission for publication in a journal, coordinated through the Delta Science Program, or an experienced independent individual selected by CAMT.

[45] Or a designated work group of CAMT

A Programmatic Approach

In order to understand how environmental conditions influence Delta Smelt and assess the effectiveness of flow-related management actions, scientific activities must identify mechanistic response to actions when they are taken. It is also important to provide context for those actions by examining the same mechanisms under non-actions conditions, i.e., ambient conditions.

Planning and executing scientific activities using a programmatic approach enables consideration of interactions among actions, and enables field surveys and monitoring, improvements in predictive modeling, and investigative research to proceed in parallel as part of a coordinated approach to building knowledge. This section discusses some of the key components of such a programmatic approach. The next section provides details on how such a program could be planned and executed on a three-year cycle.

Assumed Program Structure

The 2016 SEW found that a successful science enterprise needs 'clear organizational structure that identifies roles and responsibilities of decision makers, managers, scientists, and stakeholders'. Figure 1 identifies the main organizational elements for adaptive management. This report focuses on the 'learn' function and proposes a collaborative approach to predict, detect and understand the response of Delta Smelt to changing ambient conditions and flow-related management actions. The main structural elements are a Science Program Manager and a collaboratively developed Three-Year Science Plan, which are described in detail below. It is beyond the scope of this report to determine how 'decide' or 'implement' will be conducted but, in order to develop approaches for the development of timely and useable science in support of understanding Delta Smelt response to changing ambient conditions and flow-related management actions, some assumptions must be made.

CSAMP provides a venue for collaboration and coordination among state and federal resource agencies, public water agencies, and stakeholders. Throughout this report CSAMP is considered to include those who make relevant decisions including the allocation of water for flow actions and associated operational changes, regulatory decisions regarding take, and the availability of financial resources to support actions and scientific activities. The intersection between 'learn' and 'decide' functions in Figure 1 is assumed, for the purposes of this report, to be through CAMT who may delegate deliberation and development of recommendations to a working group.

For this report, with its focus on flow-related management actions, the functional link to 'implement' is also important. For annual water operations, the Federal and State water operations agencies Bureau of Reclamation and Department of Water Resources. the State and Federal fisheries agencies, and the State Water Resources Control Board make overarching decisions regarding the allocation of water and regulatory issues. Local water agencies may also be involved in implementing actions. For example, the 2018 North Delta Food Web action entailed cooperation from the Glenn- Colusa Irrigation District, Reclamation District 108, Reclamation 2035, Knaggs Ranch, Conaway Ranch, the Tehama Colusa Canal Authority among others. The water operations and fisheries agencies coordinate work with local entities and are the main channel for operational or regulatory decisions. This report assumes that each flow-related management action has an identified ‘action champion’ who coordinates permitting and other issues, and is a key point of contact for understanding how an action, in any year, is expected to be implemented (i.e., the nature, timing and magnitude of changes in flow management). As described previously, such information is crucial to the effective planning of management action specific sampling designs.

As implementation of the Delta Smelt Resiliency Strategy proceeds it is likely that several flow related management actions will occur within a year (Table 6), providing a further opportunity for both coordination and systemic learning. A ‘roundtable’ of action champions could be useful to consider potential interactions among project expected effects and would be a useful central body for discussion of planning potential opportunities for scientific activity (see Developing a Three-Year Science Plan).

Table 6. Flow-related management actions and year types in which the actions are expected to occur

Year Type	Suisun Gates	Yolo Bypass Flow Pulse	Flood and Drain Managed Wetlands	Roaring River	Outflow Augmentation (Spr/Summ)	Fall Outflow action	Ambient Conditions
Wet			X	X		X	X
Above Normal		X	X	X	X	X	X
Below Normal	X	X	X	X	X		X
Dry	X	X	X	X	X		X
Critical			X	X			X

Science Leadership

The ongoing execution of science in the context of adaptive management, including detailed science plans, communication to a variety of audiences, advocacy for constrained resources, motivating delivery of information, and championing learning, requires a leader. The 2016 SEW identified science leadership as being critical to success. The leader identified here, the Science Program Manager, is responsible for execution of the scientific activities and is supported and empowered by CSAMP Policy Group members and CAMT members to carry out these tasks. S/he does not conduct the scientific work but works with scientific groups, e.g., IEP including PWTs, IMSC, Delta Science Program, as well as individual investigators to identify and leverage opportunities. The Science Program Manager also has a key role in the interface between science and decision making and implementation shown in Figure 1.

The role described here (Box 6) has been developed for science needs in relation to changing ambient conditions and flow-related management actions. However, this is just a subset of scientific issues related to Delta Smelt. It is possible that the role of Science Program Manager proposed here may be less than a full-time position. However, the right individual could probably provide value added to other Delta Smelt related actions (e.g., DSRS, EcoRestore, etc.) and thus ensure improved coordination of developing knowledge and information.

Box 6. Dedicated Science Leadership – Science Program Manager

The Science Program Manager works at the interface between those who generate the science and those who use the science. Specific responsibilities include:

- Planning scientific activities in consideration of science needs, flow-related management actions, environmental conditions and resource availability
- Direct engagement with policy makers, managers and scientific leaders to effectively leverage resources, avoid duplication and identify outstanding needs
- Representing the science and progressive learning in scientific, management and policy settings
- Advocating for the advancement of research, studies, and technology development and application in support of Delta Smelt with a focus on response to flow-related management actions and changing ambient conditions
- Maintaining awareness of ongoing and emerging science regarding the Delta ecosystem and Delta Smelt
- Developing, disseminating and communicating key findings to a variety of audiences

The Science Program Manager needs scientific credentials (extensive research experience) and needs to be knowledgeable, but not an expert, across a range of relevant scientific issues. Experience working at the science-management interface is also important as the individual needs to have the respect of the scientific community and managers and be able to communicate complex issues in technical but accessible terms. It has been noted that the process of transferring and transforming the results of technical analyses into knowledge to support decisions requires skilled individuals who are inter-disciplinary 'polymaths'. The Science Program Manager needs to responsible for the overall execution and delivery of the science, recognizing that responsibility for specific tasks and activities will be with specialists. It is important that the Science Program Manager be able to speak authoritatively on behalf of the science plan, and such recognition maybe best enabled by direct association/employment with an action agency. Given the key role of both action and regulatory agencies in flow-related management actions, California Resources Agency may be an appropriate 'home'. An appointment as unclassified staff, under contract as staff augmentation or as an IPA from, for example, a university could be appropriate arrangements. If the Science Program Manager is a contractor, and some may be appropriately skilled, steps must be taken to ensure s/he is seen as empowered by CSAMP members to take on this role.

This position is similar in some respects to that of the previously proposed IICG Manager although that position has been described as having a more managerial than scientific focus, with a range of responsibilities beyond Delta Smelt. Depending on the status of the AMP, the Delta Smelt Science Program Manager could work closely with an IICG Manager or the person/group responsible for integration and coordination of Delta actions, and possibly with a parallel position for salmon and sturgeon.

Programmatic Planning for Science: Three-Year Cycle

Most flow-related management actions occur within a single water year, and the effects on Delta Smelt will be reflected within the annual life cycle. Thus, activities related to predicting and detecting change in the system for Delta Smelt (see Predicting Delta Smelt Response and Detecting the Response) will occur within an annual cycle. However, efforts to better understand the response, through laboratory research or synthesis studies, for example, are rarely accomplished within a single year. A three-year cycle is proposed here for planning and executing scientific activities, with annual supplements to tailor plans, particularly field surveys and opportunistic studies, around specific flow-related management actions or ambient conditions. Planning for three years enables coordination with other processes such as IEP Workplan development, and allows for completion and reporting of research studies.

The limited flexibility of agency contracting procedures further underscores the need to plan scientific activities for more than one year. Some potential sources of funding are more flexible in contracting than others, but one advantage of the programmatic approach proposed here is that needs, at least in general terms, can be anticipated and planned for. There are established mechanisms for transferring funds between federal agencies, e.g., Reclamation and USGS, and state entities, e.g., state agencies and state universities. However, the engagement of non-agency scientists, e.g., in NGOs and the private sector, may be needed to execute the needed array and intensity of activities. Agencies that have the ability to engage in master service agreements could identify potential contractors in advance, enabling early agreement on terms and conditions, rates, etc.

Developing a Three-Year Science Plan

This section outlines the steps needed to develop a three-year science plan (Figure 5) and discusses the information to be considered, and the roles and responsibilities of different persons and groups.

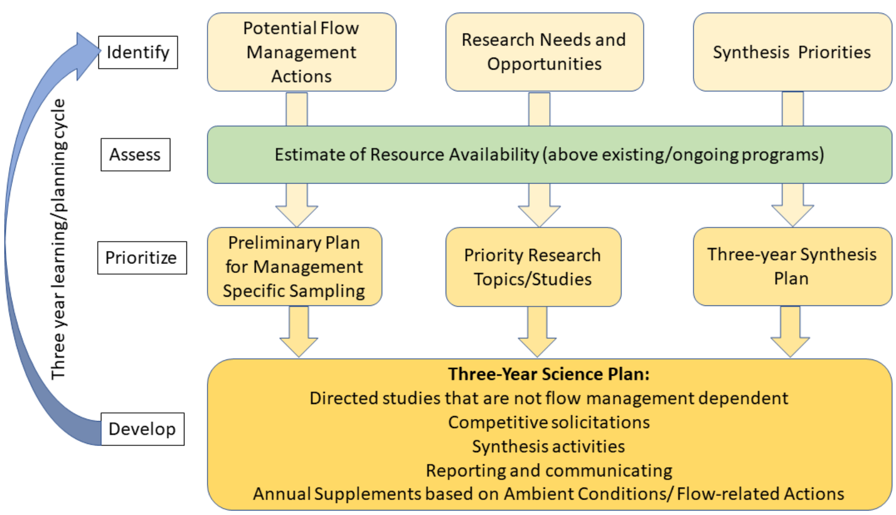

Figure 5. Outline of steps in the development of a Three-Year Science Plan

Identify Candidate Science Activities

A wide array of scientific activities could be undertaken in support of understanding Delta Smelt response to changing ambient conditions and flow-related management actions[46]. In the absence of any articulated priority science needs from managers[47], the initial development of candidate activities would be conducted by the Science Program Manager soliciting ideas from many sources including the DSST, IEP PWTs, and Delta Smelt researchers. Identifying the ideas, potential, utility, resource needs and timelines is a necessary prerequisite to prioritizing research in relation to potential funding sources. Using the expected effects of ambient conditions and flow related management actions on Delta Smelt (e.g., Table 1), and the ongoing development of understanding of the system as a whole, the Science Program Manager endeavors to ensure that activities are identified to provide insight on a breadth of topics.

For each candidate scientific activity, the following information would be tabulated:

- Nature of the activity including any seasonal/spatial specificity, and/or direct relationship to a flow-related management action (e.g., the effects listed in Table 1)
- Potential role in predicting, detecting, or understanding Delta Smelt response to changing ambient conditions or flow-related management actions
- Estimated resource needs, i.e., skilled personnel, financial, equipment
- Estimated timeline for delivery of results/findings

The tabulation should also include observations regarding the work that set it is a broader or programmatic context, e.g., specific gaps that it might fill, relation to previous work, potential utility beyond Delta Smelt and flow-related management actions. The candidate activities can be categorized as shown in Figure 5:

- Activities related to flow-related management actions or ambient conditions need to be thought through and articulated in advance but cannot be activated until specific water year types or plans for management actions are developed.
- Research that can be conducted independently of water year type or flow-related management actions, e.g., laboratory studies, model development, may be suitable for competitive funding opportunities, or discretionary funding of specific studies. A subset of this category may be opportunistic research that includes in depth exploration for conditions associated with flow-related management actions, within the context of a larger research study.
- Synthesis is expected to be an ongoing process. The identification of priority topics and issues (see Synthesis) for a three-year plan may be driven by system changes, the need for periodic synthesis of knowledge around key areas, etc.

[46] As previously mentioned, scientific activities include monitoring, field surveys, data collection laboratory analysis, field and laboratory experiments, statistical analysis, synthesis, meta analysis, investigative research, conceptual modeling, numerical modeling and other applied science pursuits

[47] Note that an early product of the proposed 2019 Compass SDM process is expected to be identifying priority science needs for Delta Smelt.

For use in subsequent development of three-year science plans, the Science Program Manager would continually update a list of potential science actions based on newly identified needs, the results of ongoing science activities and emerging management priorities.

Assess Resource Availability

The approximate level of financial resources available to support scientific activities is an important constraint that needs to be considered early during the planning stage. This report assumes that ongoing monitoring programs and field surveys conducted by IEP will not be sufficient to detect changes in detail and fully support understanding of Delta Smelt response to changing ambient conditions and flow-related management actions. Previous sections of this report (see Detecting the Response) have discussed the need to enhance or add on to existing efforts, and the Annual Supplements to the Three-Year Science Plan section below details how decisions about what to add could be made within a given year. However, planning on a three-year cycle is more effective if it is informed by potential available funding levels. It may not be possible to assure resource allocations several years in advance. However, knowing an estimate of resource availability enables planning for scientific activities to be more realistic than idealistic, with specific cases being needed to justify additional resources in any year. Having funding estimates for a multi-year program also better enables staffing to be planned and an available pool of scientifically skilled personnel to be available to support the effort.

While resources are a key constraint to any program implementation, assessment of resource availability is likely more of an iterative process. CSAMP participants including agencies, water contractors, IEP and Delta Science Program, will be better able to make decisions about resource allocation (assuming they have some discretion) if they can see the types of activities that could be funded. The list of candidate scientific activities begins that iteration. The Science Program Manager would be responsible for working with CSAMP, the CSAMP Program Manager and CSAMP members to crosswalk potential funding with candidate science activities.

Take is also a limited resource more likely to vary with population estimates or environmental conditions than actions to be taken and will need to be allocated in close coordination with IEP. Advance multi-year planning is therefore unlikely to be possible, but this is a key consideration for Annual Supplements to the Three-Year Science Plan.

Prioritize Scientific Activities

Prioritizing candidate scientific activities and matching them up with the potentially available resources with the various candidate scientific activities requires dialog between CAMT, the Science Program Manager, established science providers such as IEP and the Delta Science Program, and entities providing funding. CAMT[48] is an appropriate venue for these discussions because of its collaborative approach and broad-based participation. The selection of which activities to pursue in any three-year science plan will require additional detail from investigators, and the Science Program Manager is responsible for working with scientists to develop information and iterating with CAMT. This role in both understanding management

[48] Or a designated working group or CAMT

needs and the science process is a key role for the Science Program Manager (Box 6) and is shown in Figure 6.

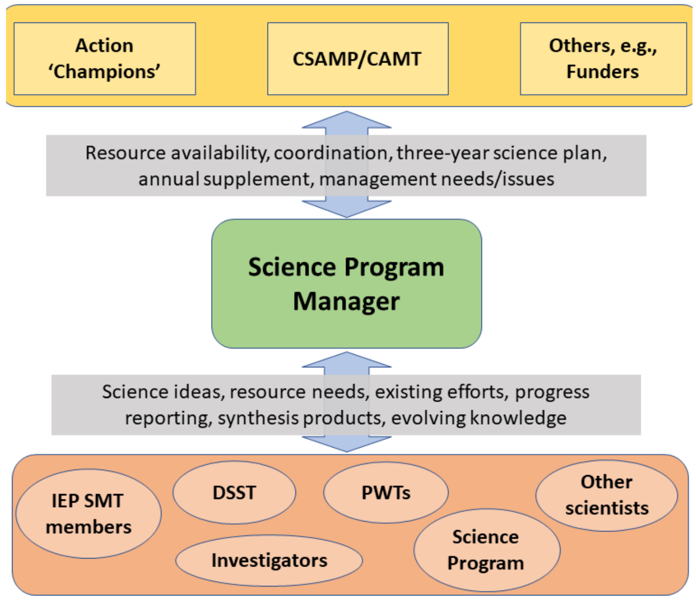

Figure 6. Diagrammatic representation of the Science Program Manager's role in dialog between managers and scientists

Prioritizing is one of the most important aspects of developing the three-year plan and includes several steps.

Relevance to Management Need

CAMT, supported by the Science Program Manager, sorts the candidate scientific activities according to their expected responsiveness to management needs. Note that in development of future three-year plans it is expected that management needs will be articulated in advance allowing such sorting to occur at the candidate stage. Given the limited amount of information available candidate activities would be ranked as Highly Relevant, Moderately Relevant, or Marginally Relevant. It is expected that all candidate activities would be in some way relevant but some may require considerable refinement in which case they would not be considered further and set aside for future development, e.g., Science Program Manager working with investigators to develop improved links to management needs.

Concept Proposals

For each scientific activity categorized as Highly Relevant a concept proposal template will be prepared, similar to concept proposals required by IEP for their Solicitation process. The Science Program Manager will develop a template and make requests of investigators for information. Depending on the potential availability of resources relative to the activities categorized, those considered Moderately or Less Relevant may also be asked to complete a workplan. If CAMT identifies any particular aspects of the work which are more important or could be refined, the Science Program Manager communicates this to the investigator. For some potential activities, such as synthesis around specific topics or issues, a synthesis lead may need to be identified. The

Science Program Managers will work with CAMT to identify potential leads and team members, and will solicit the development of a concept proposal from willing experts.

The concept proposals, ~ 2 pages in length, are not expected to be time consuming for investigators and are designed to ensure early common understanding of what a scientific activity can provide and on what timeline. They are not full proposals but include summary information on the scientific work, timing and needed resources, expected start/end dates, expected deliverables and timelines for those deliverables following execution of contracts. For scientific activities dependent on specific ambient conditions or flow-related management actions, workplan timelines will be contingent on future conditions and management actions. Concept proposals requiring permitting for take or incidental take should be identified to enable early assessment of feasibility.

Note that this is not an open solicitation. The Identify Candidate Science Activities step above is where the Science Program Manager is responsible for gathering ideas for scientific activities relevant to understanding the response of Delta Smelt to changing ambient conditions and flow-related management actions. In future iterations of this three-year process, it is expected that the gathering of these ideas is a continual process.

Preliminary Funding Alignment

In parallel with the development of concept proposals by investigators, CAMT can work to align the scientific activities considered most management relevant with the identified potential sources of funding (see Assess Resource Availability). The assumption is made here that existing surveys and monitoring programs (i.e., those listed in Table 3) are in place and providing data that can be used to understanding the response of Delta Smelt to changing ambient conditions and flow-related management actions. The focus of this step is on any discretionary funding identified and other programmatic sources. This 'alignment' can also include identification of which activities could be candidates for funding under Prop 1 solicitations, the IEP annual workplan process, etc. recognizing that those programs have their own decision-making processes for the allocation of resources.

Ranking Scientific Activities

CAMT may choose to seek feedback from technical experts, e.g., members of the DSST, on the relative merits of the concept proposals. The Science Program Manager can also support CAMT by identifying connectivity or overlap amongst the concept proposals, and ensuring concept proposals provide appropriate information.

The ranking step can assign scientific activities to four, separate 'buckets':

- Priority scientific activities for which funds are likely to be available and which are no dependent on specific ambient conditions or flow-related management action. These could include model development, laboratory studies, synthesis efforts, technology development and testing, and/or field studies. These studies proceed to incorporation into the three-year science plan, the development of full scopes of work, etc. (Figure 7)

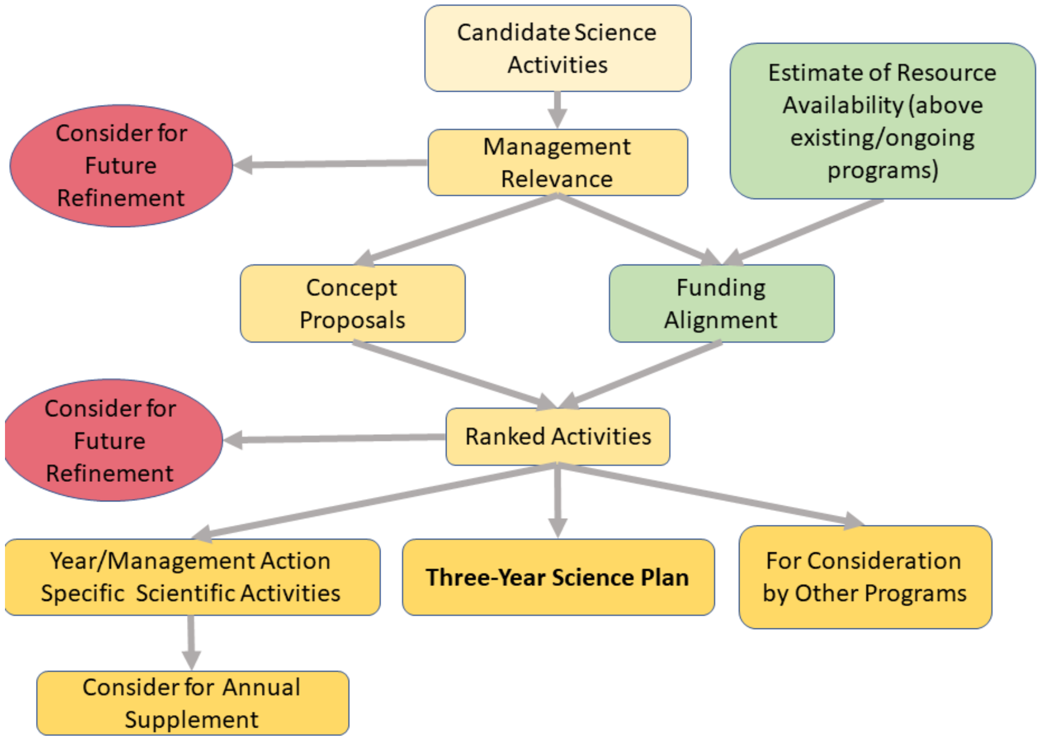

Figure 7. Process map for the prioritization of scientific activities and inclusion in the Three-Year Science Plan (see text for details of each step)

- Those that are management relevant and potentially fundable but which are dependent on specific ambient conditions in the system, or flow-related management actions, which cannot be predicted to occur within the three-year window. These activities will be considered during the development of annual supplements to the science plan depending on water year type and changing conditions (see Annual Supplements to the Three-Year Science Plan)
- Those with management relevance but for which funding cannot yet be identified and which may be eligible or appropriate for funding through other mechanisms, e.g., IEP Annual Workplan process, expected competitive solicitations.
- Activities which are potentially relevant but are not considered a priority for the three-year cycle. These can be considered for future refinement.

It is expected that the consideration of available funding will be iterative as promising activities are identified, and CAMT members seek additional resources to support specific work. Priority scientific activities requiring permitting for take or incidental take could be coordinated through IEP. The Science Program Manager will provide feedback to the investigators including requests where appropriate for more detailed scopes of work (see next section).

Three-Year Science Plan Finalization and Approval

Following the prioritization of scientific activities, the Science Program Manager develops a three-year plan of activities taking into consideration factors such as interdependencies among activities, the desired sequence for synthesis products, availability of funds, the expected duration of research studies, etc. This process includes:

- Development of detailed scopes of work by investigators (Priority Research Topics/Studies in Figure 5). The format for these may be tailored for specific identified funding sources but they will include details of the approach and methods, milestones for completion of the work, timing of those milestones, plans for QA/QC and data management/archiving, reporting including quarterly updates and annual summaries, and deliverables. Scopes of work should be externally reviewed to ensure methods are appropriate, expectations of scientific contribution are reasonable, and that budgets and timelines are suitable given the work proposed. The Science Program Manager will coordinate this review using the guidance provided in Appendices K and L of the Delta Science Plan regarding selection of reviewers. Should any concerns arising from the reviews, the Science Program Manager will develop a recommendation (e.g., adjustment of timelines, clarification of methods, etc.) for consideration by CAMT, and work with the investigator to ensure the final scope of work is appropriately responsive to the reviews.
- Organizing priority scientific activities which are dependent on specific ambient conditions or flow-related management actions (Preliminary Plan for Management Specific Sampling in Figure 5). This could include aligning activities with different year types or potential flow-related management actions, working with investigators to identify lead times necessary to activate the work, or other preparatory work for their consideration in the Annual Supplement process (see below) including potential sources of funding, available contracting mechanisms etc.
- Coordination of a three-year plan for synthesis products with IEP MAST efforts and Delta Science Program plans for SBDS (Three-Year Synthesis Plan in Figure 5).
- Structuring of research and study timelines for the three-year period to identify expected dates for quarterly reporting and annual progress reports. If annual or biennial workshops to discuss new findings for Delta Smelt are adopted, these would be incorporated into the timeline. The timeline would also include other relevant regular science events such as the Delta Science Conference, IEP workshop, etc.,

Due to the need to develop detailed information for inclusion in the plan, the review process, and extensive coordination required to align scopes of work with funding sources, the final completion of the plan could take 1-2 months following the previous steps. Table 7 shows a generalized timeline for the steps leading to the Three-year Science Plan. The plan would be discussed with CAMT, refined as appropriate and approval requested from CSAMP.

Table 7. General timeline for development of a Three-Year Science Plan

Step	Month 1	Month 2	Month 3	Month 4	Month 5-6
Identify Candidate Science Activities					
Estimate Resource Availability					
Categorize by Management Relevance					
Concept proposals					
Funding Alignment					
Ranking Activities					
Three Year Science Plan Finalization and Approval					

Annual Supplements to the Three-Year Science Plan

Decisions regarding the implementation of flow-related management actions will be taken in the light of expected water year conditions. Given that these cannot be anticipated more than a few months in advance, the incorporation of scientific activities designed to detect the effects of management actions or specific ambient conditions on Delta Smelt cannot be planned in detail as part of the Three-Year Science Plan. An Annual Supplement process using information developed during the development of the three-year plan, and additional information developed in the intervening period, allows a nimble response to changing conditions within an ongoing progressive learning process.

The status of the water resource available for flow-related management actions becomes clear in March and April as the wet season draws to an end and forecasts of the volume of seasonal runoff from the state's major watersheds become available[49]. This designation identifies the potential flow-related management actions to be taken that year (Table 6). However, the nature of precipitation in the preceding months suggests the potential availability of water for flow-related management actions. Decisions regarding which actions will actually be realized likely depends on additional considerations. The formal, or informal process used, will depend on the agencies and the context for the decision. The specification of the actions, especially those which have not been previously undertaken or which vary in nature from year to year, will need to be provided by agencies, via the action champions, in order for Annual Supplements to be planned.

Figure 8 outlines the process for developing an annual supplement based around the three components essential to SDM and adaptive management processes characterized previously in this report: prediction, detection and understanding.

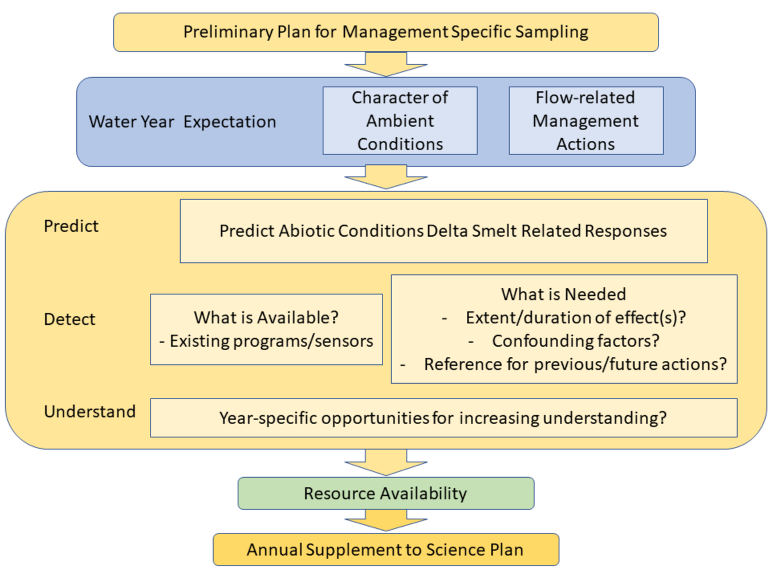

Figure 8. Process for development of Annual Supplement to Three-Year Science Plan

[49] https://cdec.water.ca.gov/snow/bulletin120/index2.html

Table 8 shows the series of key steps that need to be taken in December – April in order to identify and plan appropriate scientific activities for that water year and develop an Annual Supplement to the Three-Year Science Plan. Appendix 3 provides a hypothetical example of the types of information that would be developed, and how the annual supplement process uses information developed in the Three-Year Science Plan in addition to recognizing how other scientific activities could be leveraged. Any scientific activities planned requiring permitting for take or incidental take could be coordinated through IEP.

Table 8. Outline of process for development of Annual Supplements

	Process Step	**What Needs to be Accomplished?**	**Who is Involved?**
December - January	Step 1 - Prepare	a. Identify potential year specific low-related management actions and scientific activities related to those actions/ambient conditions identified in the Three-Year Science Plan. Include i. Science activities related to ambient conditions and previous year actions ii. Continuing science activities from annual actions or previous years actions iii. Other issues identified in Box 2	CAMT, Action Champions, Science Program Manager, other experts, e.g., FLOAT PWT members
		b. Determine level of resources available to support year-specific scientific activities	CSAMP/CAMT
		c. Prepare for annual supplement e.g., identify resources for predictive modeling, updates from investigators in relation to previously prepared concept proposals -	Science Program Manager working with investigators
February - March	Step 2 – Draft Annual Supplement	a. Specify flow-related management actions expected	Agencies/Action Champions
		b. Conduct modeling to determine temporal and spatial extent of effects c. Identify (see Detecting the Response for additional considerations) i. Interactions among flow-related management actions in space and time ii. Gradients in abiotic conditions within the influence area including hot spots of potentially desirable or undesirable conditions, and how changes in abiotic conditions might interact with structural habitat features iii. The magnitude and duration of change in abiotic conditions associated with flow-related management actions	Science Program Manager, CAMT, appropriate IEP science managers, investigators
		d. Select initial list of science activities based on those identified in Three-Year Science Plan	Science Program Manager
		e. Estimate resource needs based on initial list and identify shortcomings –	Science Program Manager

		f. Prioritize activities for available funding and document rationale. This is based on the scientific information that could be generated (identified in previous steps) and the management priority for that information	CAMT, Science Program Manager
		g. Develop draft timeline for actions and expected outputs i. Review contracting mechanisms, availability of personnel and equipment	Science Program Manager, funding entities
April	Step 3 – Finalize Annual Supplement	a. Develop plan i. Document suite of scientific activities to be undertaken including field sampling, laboratory analyses, with timeline for intermediate deliverables from each and final reporting ii. Describe expected scientific outcomes – hypotheses being tested, questions that will be informed/resolved iii. Detailed timeline 1. Activities 2. Delivery of information 3. Reporting	Science Program Manager, investigators
		b. Present to CAMT for comments, refine and finalize	Science Program Manager
		c. Present to CSAMP for approval	Science Program Manager
		d. Disseminate	Science Program Manager

The suggested timing of the annual cycle is driven by the assumption that flow-related management actions are taken according to water year type (e.g., as described in the Delta Smelt Resiliency Strategy and Table 6) and that preparations could be made over the late fall and early winter with some flow action decisions being dependent on predictions of expected runoff. Scientific activities in relation to flow-related management actions which occur every year could be planned as part of the Three-Year Science Plan but their interactions with year-specific actions needs to be considered as part of the Annual Supplement process. The timing proposed could be readily adjusted with the steps remaining the same. The quarterly and annual reporting within the three-year science plan approach allows new information from other sources, e.g., research studies, routine monitoring not related to flow actions, to be readily considered.

Executing the Three-Year Science Plan

Planning and Timing

Development and execution of the Three-Year Science Plan develop occurs in parallel with the development and execution of the Annual Supplements (Table 9). The initial development of a three-year plan will require assembling candidate scientific activities and concept proposals, it is expected that once the process is established and both managers and investigators are aware of the rhythm of planning and execution, ideas for scientific activities will be generated on an ongoing basis. The Science Program Manager is responsible for engagement with both scientists and mangers interested in Delta Smelt response to changing ambient conditions and flow-related management actions (Figure 6).

Reporting and communicating the findings of the work, as well as setting it in the context of other developing knowledge in Annual Progress Reports, is an important part of the execution process. Table 9 does not include presentations at venues such as the IEP workshop and the Delta Science Conference which, as discussed previously in this report, are important mechanisms for engaging scientists into the science plan processes. A State of Delta Smelt symposium on a regular basis, annual or biennial, could provide an excellent venue for open discussion of management needs and how they can best be met by the scientific community. Such an event would be broader in scope than the response of Delta Smelt to changing ambient conditions and would need to be more broadly coordinated. However, such an event could readily be incorporated into the three-year science plan process.

Table 9. Planning and execution time horizons for Three-Year Science Plan and Annual Supplements

	Year 0		Year 1				Year 2				Year 3				Year 4			
	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Three-Year Science Plan																		
Planning	xxx	xxx											xxx	xxx				
Execution			xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
Annual Supplement																		
Planning		x	xxx			x	xxx			x	xxx			x	xxx			
Execution – varies by action				xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
Reporting and Communicating																		
Project completion reports					Variable by scientific activity													
Quarterly Updates			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Annual Progress						x				x				x				x

Tracking and Coordination

Regularly and routinely tracking progress in execution of the science plan is important for responding to unexpected circumstances, e.g., gear problems, adverse field conditions, as well as for the timely delivery of findings (see Delivering Understanding for Management).

The development and execution of the Three-Year Science Plan, Annual Supplements and the multiple activities, deliverables and reports requires dedicated staff time to avoid confusion and ensure status is tracked and reported out as needed. The Science Program Manager could work with the CSAMP Program Manager, CAMT, and agency/funding entity contract managers to track work proposed, the progressive delivery of information and reports, and funding. Routine activities contributing information to understanding the response of Delta Smelt to changing ambient conditions and flow-related management actions, such as IEP programs (Table 3), have established procedures for tracking and monitoring which will not need adjustment. In many cases tracking simply requires wider communication of information already generated and should be structured to be efficient, effective and not onerous to those undertaking the scientific work. Information flows need to be ensured. Regular reports on execution progress should be available to all involved in the development and execution of the Three-Year Science Plan.

Next Steps

The framework provided here for identifying scientific activities to increase understanding of Delta Smelt response to changing ambient conditions and flow-related management actions is best operationalized as part of an overall adaptive management program where interactions amongst deciding, implementation and learning (Figure 1) are structured. Even without such a program in place, steps can be taken to make progress in planning and coordination of scientific activities, advancing knowledge, and improving the availability and collaborative utilization of results and findings. This section identifies some critical path steps that are foundational to the overall approach and could be taken in the near time while a structured approach to adaptive management is further developed.

Leadership

The need for leadership in science is widely recognized[50] and has been seen as crucial for flow-related management actions for some time[51]. A dedicated 'Science Program Manager', who works at the interface between those who generate the science and those who use the science is essential. The key role of this individual in mobilizing scientists in response to the needs of mangers, championing science but making it relevant, and ensuring the generation and delivery of useable information is essential. Lead Scientist positions already exist in the Delta Science Program, IEP and DWR and each play key roles within those very different contexts. However, the broad collaborative context within which this plan is set, consistent with the CSAMP mission, and the need to draw in science and scientists from wherever expertise is available is different. The Delta Science Program has an important independent role which needs to be maintained. DWR science engages on a diverse set of issues that include Delta Smelt but may be drawn to specific other issues as they arise. IEP science embodies many of applied science approaches included in this plan and with a mission that includes 'management of the Bay-Delta ecosystem and the water that flows through it' IEP is currently a key element of generating information on the effects of flow-related management actions. It also has a number of mandates related to compliance monitoring which, by its very nature, is less adjustable than might be needed. It is expected that the Science Program Manager role identified here will work collegially with these three Lead Scientists to effectively coordinate, leverage and learn.

This report describes the need for the Science Program Manager to have responsibility for the overall, planning, execution and delivery of science. While the details of how this position is established and empowered is beyond the scope of this report, ***the establishment of the position of Science Program Manager as described here is essential to collaborative, coordinated, and effective generation and delivery of scientific information around Delta Smelt response to changing ambient conditions and flow-related management action***.

[50] http://deltacouncil.ca.gov/events/implementation-committee-event/science-enterprise-workshop
[51] http://deltacouncil.ca.gov/docs/delta-science-program-review-science-program-science-program-product-seminar/fall-low-salinity

Science in a Collaborative Adaptive Management Framework

The Science Program Manager is essential to operationalizing the work but the 'collaborative' approach described here and the links and feedbacks to decision makers and managers is best operationalized through using a structured adaptive management approach. Building strong connections among those who decide, implement and learn (Figure 1) allows science to be responsive to management needs and provide information which can be directly used in implementation. This is especially true for understanding Delta Smelt response to changing ambient conditions and flow-related management actions, due to the annual life cycle of the species, and interannual variability in ambient conditions. Being able to build on data and information from previous years and actions allows flow-related management actions that target Delta Smelt to be adjusted as understanding about the interaction of dynamic and structural habitat within the system increases. Coordination, communication and leveraging are key elements of the scientific framework provided in this report. Moving this framework forward, even without all the details of adaptive management in place, can promote learning and demonstrate the benefits of a broad-based collaborative approach to science. ***Initiating the structured approach to planning, coordinating and communicating a range of scientific activities discussed is not dependent on any specific programmatic structure being in place. CSAMP should adopt the Three-Year Science Planning process, with provision for Annual Supplements, to increase understanding of Delta Smelt response to changing ambient conditions and flow-related management actions.***

Process-Based Predictive Modeling

This report has pointed to a number of studies which can provide value added to understanding Delta Smelt response to changing ambient conditions and flow-related management actions. None of them is more important than the recommendation on predictive modeling. Quantitative predictions of the mechanistic response to changing ambient conditions, including flow-related management actions, is a key missing link in management of this system. Several life cycle models for Delta Smelt have been developed by different groups of scientists during the past decade. But these models are not sufficiently spatially explicit. This report has demonstrated that a solid foundation exists for the development of a spatially explicit model that could allow for testing the potential effects of flow-related management actions, as well as others such as habitat restoration, food enhancement, etc., at various locations.

The Science Program Manager may or may not have the skills and interest to coordinate the proposed approach to full proposal development so a separate contractor may be needed to coordinate and track this effort even if the Science Program Manager was in place. ***Advancing an integrated process-based tool to predict the effects of annual flow-related management actions and changing ambient conditions on Delta Smelt will require several years and dedicated resources. The first step is a detailed approach and proposal to set appropriate expectations, timelines and resource needs.***

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