INTERAGENCY ECOLOGICAL PROGRAM SCIENCE STRATEGY 2020 – 2024:

INVESTMENT PRIORITIES FOR INTERAGENCY COLLABORATIVE SCIENCE

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Interagency
Ecological Program

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Table of Contents

INTRODUCING SCIENCE STRATEGY 2.0

What is this document?

The IEP Science Strategy is one of three organizing documents that together set the course for annual (IEP Annual Work Plan), 5-year (IEP Science Strategy), and 5+ year (IEP Strategic Plan) organization planning for the Program. The Science Strategy is where the Science Management and Coordinators Teams articulate what they understand as the most pressing suite of subjects requiring additional data collection for management-relevant purposes for the IEP 9-Agency collective. The Science Strategy serves the additional purpose of providing a 5-year focus of planning effort to even-out short-term (annual) imperatives that change depending on mutable Agency directives.

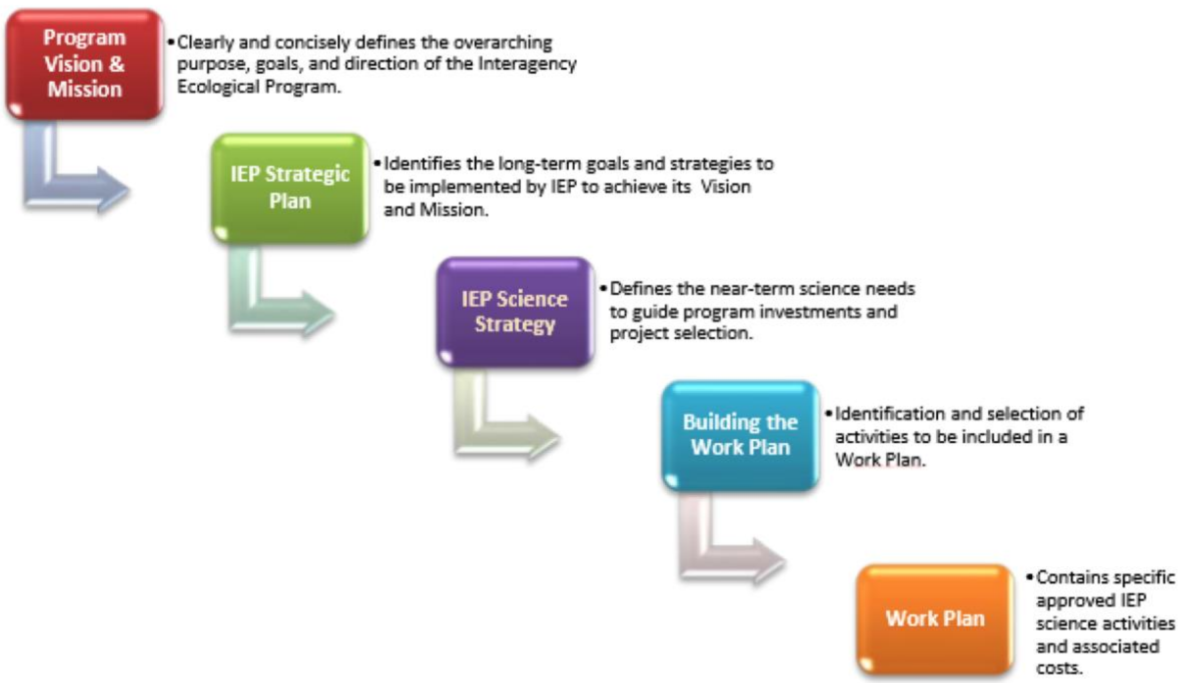

Figure 1 Relationship between various IEP elements and documents.

The IEP Science Strategy describes an approach, specific to the IEP, for enhancing both the communication and coordination of IEP science, and for implementing the science necessary for an enhanced and updated understanding of San Francisco Bay-Delta ecology. The Science Strategy is renewed every 5 years. The development process includes an evaluation of the current state of IEP science (e.g., what we have covered in recent work plans), identification of emerging knowledge gaps, articulation of emerging needs for IEP coordination with management Agencies, and includes description of the science infrastructure (staff and equipment resources) needed for successful implementation.

Other available science strategies and agendas are specific to their own program needs or are overarching, community-wide documents. The Delta Science Program's Science Action Agenda is the main overarching document for the Delta science community and is self-described as the "gaps and glue" between this (IEP) and other programmatic science agendas. The Delta Science Program Science Action Agenda highlights the knowledge gaps that other agendas do not cover, including the IEP Science Strategy. The IEP Science Strategy is focused on the monitoring science required for resource management associated with water extraction from the Sacramento-San Joaquin Delta (and the supporting watersheds).

How to use this document?

This Science Strategy supports on-going dialog between agencies regarding funding and staffing priorities in pursuit of collective IEP Agency needs for environmental information when evaluating management options and estuarine ecology. This document is also useful for Annual Work Planning by helping the Science Management Team and Coordinators Team understand what priority to give proposed projects in any one year while remaining mindful of longer-term objectives for creating collaborative monitoring and research programs useful for interagency management. At a minimum, the areas of emphasis described in the Science Strategy should be the high-priority subject areas Science Management Team members regard as needing mid-term investment and data collection. It is our hope that individual Agency Directors will also use this document to guide their internal priorities since considerable technical and programmatic expertise and experience has been brought to bear on these topics while preparing this 5-year Science Strategy. *This document represents 2020-2024 IEP priorities for membership Agency science investments.*

Figure 1 displays the relationship of the various planning documents IEP uses to step down from the IEP Program Vision and Mission to the Strategic Plan and to the Annual Work Plan. All individuals and groups proposing work for inclusion in the IEP Annual Work Plan are asked to identify how their work fits into the IEP Science Strategy. In this way, the Science Strategy acts as a "filter" of sorts that defines the range of elements included in the Annual Work Plan. When assessing an annual Work Plan for recommendation to the Directors, the Coordinators and Science Management Team will comment on how and where individual elements meet our desire for consistency and support for the IEP 5-year Science Strategy.

How to use the Science Strategy:

Example 1: IEP Agency Director or Program Manager. Use the Science Strategy to understand IEP program element priorities for addressing current knowledge gaps and help determine appropriate use of available science funds.

Example 2: Graduate or post-doctoral researcher at a university, applying for funding (e.g., Prop 1, CVPIA, etc.) to start a new research project in the Delta. Use the Science Strategy to tailor their research proposal such that it is coordinated with IEP work and priorities. Provides evidence in a research proposal that the subject matter is identified as a priority by IEP.

Example 3: New staff member at an IEP agency (from Environmental Scientists to new Directors). Read the Science Strategy to understand IEP preferences for near-term science activities.

PURPOSE OF THE SCIENCE STRATEGY

As part of our annual schedule, proposed IEP Work Plan Elements are evaluated by understanding how they will contribute to the implementation of high-priority science (the Science Strategy) on a 5-year time horizon and to the reduction of data and information gaps associated with that science. Additional evaluation steps include identifying financing, feasibility, and other resources needed for successful implementation. Articulating our Science Strategy here represents a core function of the organizational role IEP plays for Delta and Estuary aquatic monitoring science. We articulate these investment priorities based upon input from all levels of the IEP organization – from Project Work Teams, the Science Management Team, the Coordinators, and from input by Agency Directors – during the normal conduct of IEP business and through dedicated workshops and meetings held throughout the annual work schedule. Every 5 years we update the Science Strategy to reflect evolving needs, technology improvements, and availability of interagency resources to support the core IEP Mission.

IEP Mission Statement

The mission of the IEP is to provide and integrate relevant and timely ecological information for management of the Bay-Delta ecosystem and the water that flows through it. This is accomplished through collaborative and scientifically sound monitoring, research, modeling, and synthesis efforts for various aspects of the aquatic ecosystem. The IEP addresses high priority management and policy science needs to meet the purposes and fulfill responsibilities under State and Federal regulatory requirements. The IEP relies upon multidisciplinary teams of agency, academic, non-governmental agencies (NGO), and other scientists to accomplish its mission.

This document represents a guidepost for IEP science investments against which potential project elements are considered for inclusion in subsequent Annual Work Plans. It is recommended that Work Plan element proposals describe consistency with or coordination with the general science investments promoted as Agency priorities herein. These descriptions will be evaluated as part of the regular review process established by the Coordinators and outlined in Program management documentation.

What does the Work Plan represent?

The IEP Annual Work Plan reflects the annually planned work by IEP agencies to be conducted as part of the IEP consortium within the Bay-Delta ecosystem during the following calendar year. The authorities, responsibilities, and management needs for implementing (and funding) projects and programs included in this plan are generally guided by regulatory requirements such as biological opinions, incidental take permits, and water rights decisions that cover the operations of the State Water Project (SWP) and the Central Valley Project (CVP). It is intended that the Annual Work Plan reflect a finer-scale focus for planning encompassed within a higher level of strategic vision (3-5 years and beyond) outlined by the IEP Science Strategy.

COORDINATION OF THE IEP SCIENCE STRATEGY WITH MANAGEMENT DIRECTIVES

Recent Work Plan element additions (since 2013 or so) have been limited to those elements that come to the IEP Coordinator and Science Management Teams as pre-selected and pre-funded initiatives from one or more IEP MOU-signatory Agencies. Ideally, elements that are not consistent with IEP Science Strategy priorities would receive lesser support from IEP Directors and Coordinators, while those that fit into our overall Science Strategy discussions would receive stronger support. At a minimum, the Directors, Coordinators, and Science Management Teams should regard their support for individual elements in light of the stated priorities articulated and adopted into the 5-year IEP Science Strategy.

In an ideal situation where the IEP Coordinators and Science Management Teams are selecting priorities to fund using competitive solicitations (a.k.a. “PSPs”), candidate element proposals would be required to satisfy IEP consistency determinations upon submission to be considered for possible funding – this would be incorporated using existing mechanisms for review at the Administrative, Science Integrity, Science Relevancy, and Agency Consistency proposal evaluation stages.

What is compliance science?

Compliance science is monitoring (data collection) and contextual analysis that allows technical experts and program managers to understand what the monitoring data is telling them about the system under scrutiny. It involves dialog among data users and regulators, scientific review, and learning over time. Simply collecting data does not ensure we glean from the system what we need to manage it more effectively. We also seek to adapt and evolve the compliance science over time to remain relevant to changing management and scientific concerns.

As a general approach the IEP science program aims to be responsive to management needs as articulated to the Lead Scientist and the IEP Program Manager at the Director and Coordinator Team levels. Our characterization of appropriate scope is one of an inclusive “compliance science.” This is more than mere monitoring because “being responsive to management” can mean many things, for example:

1. Monitoring to comply with endangered species and water quality regulations (e.g., EMP monitoring for implementing SWRCB Water Rights Decision D-1641)
2. Special studies to supplement existing monitoring (e.g., gear efficiency testing) and investigate the potential for new technologies that would improve the efficiency and defensibility of current monitoring approaches
3. Understanding the ecosystem context of the Delta and broader Estuary since water and resource management actions in the Estuary depend, fundamentally and always, on that broader context
4. Synthesizing available information to enhance scientific understanding of a management relevant topic (entrainment, for example), to evaluate current management actions and inform adaptive management of the Delta (e.g., Delta Smelt Resiliency Strategy actions) and to inform future management actions and science (e.g., Delta Smelt MAST report)

The list of major management directives that drive IEP science is long: (e.g., NMFS and USFWS BiOps, Incidental Take Permit for SWP and CVP, Salmon and Delta Smelt Resiliency Strategies, SWRCB Water Rights Decision 1641, etc.), but revolve around the impact of water project operations on water quality, species, and habitats within the San Francisco Bay Delta and Estuary. These impacts necessarily include ecological inputs upstream and downstream but cannot practicably include every important issue or management objective. IEP financial and personnel resources are limited, and we remain committed to satisfying articulated management agency needs for information as a first priority. Through partnerships with University researchers, private consulting firms, and Pubic Water Agencies we can extend IEP-associated monitoring science beyond water management in the Bay-Estuary, but mandated compliance science is our underlying focus.

Exploring the correct application of science to policy needs also includes occasional investment in new or updated techniques and technologies, as well as consistently refreshed support for data archival, storage, and retrieval. Long-term datasets should be supported to the extent they underpin our ability to document mid- and longer-term changes in the Estuary, particularly under inconsistent climate, hydrologic, and agency management regimes. The IEP resource management environment (both physical/biological and social) is constantly evolving. The specific role of IEP may change throughout the development and implementation of this 5-year Science Strategy. To guide IEP science in the midst of a dynamic regulatory environment, we aim to follow these basic science guidelines:

- *We are responsive to major management initiatives;*
- *We direct science to enhance our understanding of the estuary's ecology;*
- *We support agency compliance science;*
- *We aim to be nimble, collaborative, and transparent in responding to new and emerging science needs;*
- *We strive to maintain longevity and integrity in ecological datasets and surveys for understanding trends that are critical to management options into the future.*

An emerging common theme among many major management directives is that management actions and restoration must operate adhering to an adaptive management framework (e.g., 5 Agency Adaptive Management Framework for the California Water Fix and Current Biological Opinions on the coordinated operations of the Central Valley and State Water Projects). IEP monitoring science plays an essential role in the adaptive management process and will provide critical information to managers implementing the new Adaptive Management Framework brought forward by the 5 agencies (e.g., the Interagency Implementation and Coordination Group (IICG)). While IEP cannot and does not implement the entirety of the adaptive management cycle (Weins et al. 2017), IEP science can play a key role in several of the steps of adaptive management, especially those that involve assessing and understanding effects of management actions (Figure 2).

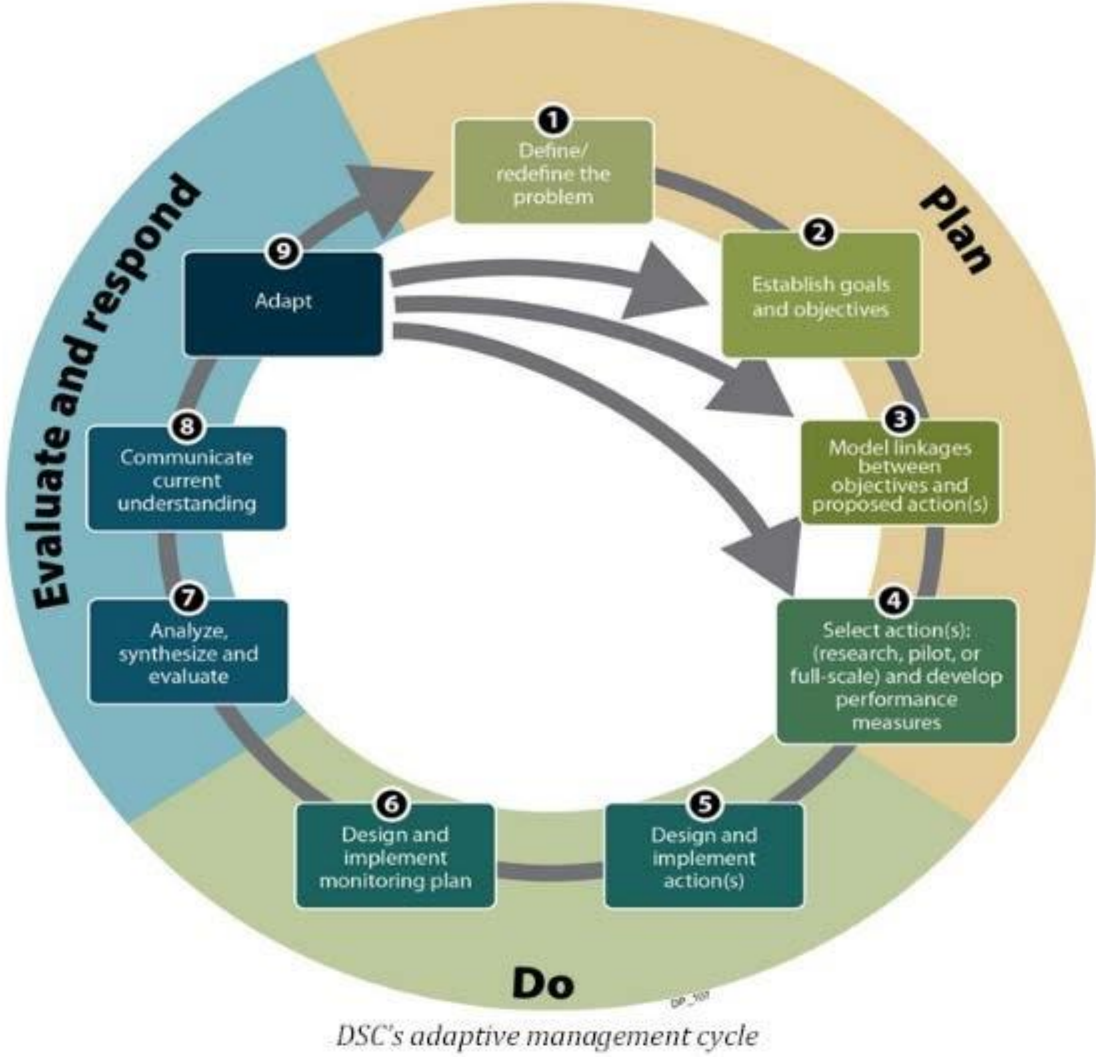

Figure 2. Delta Stewardship Council's Adaptive Management Conceptual Process.

HOW WE APPROACH SCIENCE IN IEP

The IEP Annual Work Plan exists as one element of an Estuary-wide architecture of science infrastructure and investment. Figure 3 includes descriptions of some complementary science efforts in the Estuary and how we achieve coordination of science within the Bay-Delta science community. Several precepts are important to how the IEP Science Management Team and Lead Scientist view organizing and implementing management-relevant compliance science:

1. Science prioritization proceeds in top-down and bottom-up directions, but science excellence is largely driven by the interactions between the scientists themselves rather than via institutional arrangements
2. Difficult science questions and management problems require a multi-pronged approach to decrease existing uncertainty; open communications and repeated exchange of views between scientists and managers are crucial to maintain relevant conversations and meaningful approaches to providing information of value
3. Single-minded or isolated investigations are quickly losing relevance in our complex ecological and multi-faceted interagency world. To this end, IEP often uses different categories and combinations of approaches. These include:
    a. Long-term monitoring surveys subject to periodic review and revision to ensure integrity and relevance
    b. Modeling (both quantitative and conceptual)
    c. Special studies focused on multidisciplinary observational and experimental science
    d. Interdisciplinary and interagency synthesis of status, trends, climate impacts, and emerging issues of concern

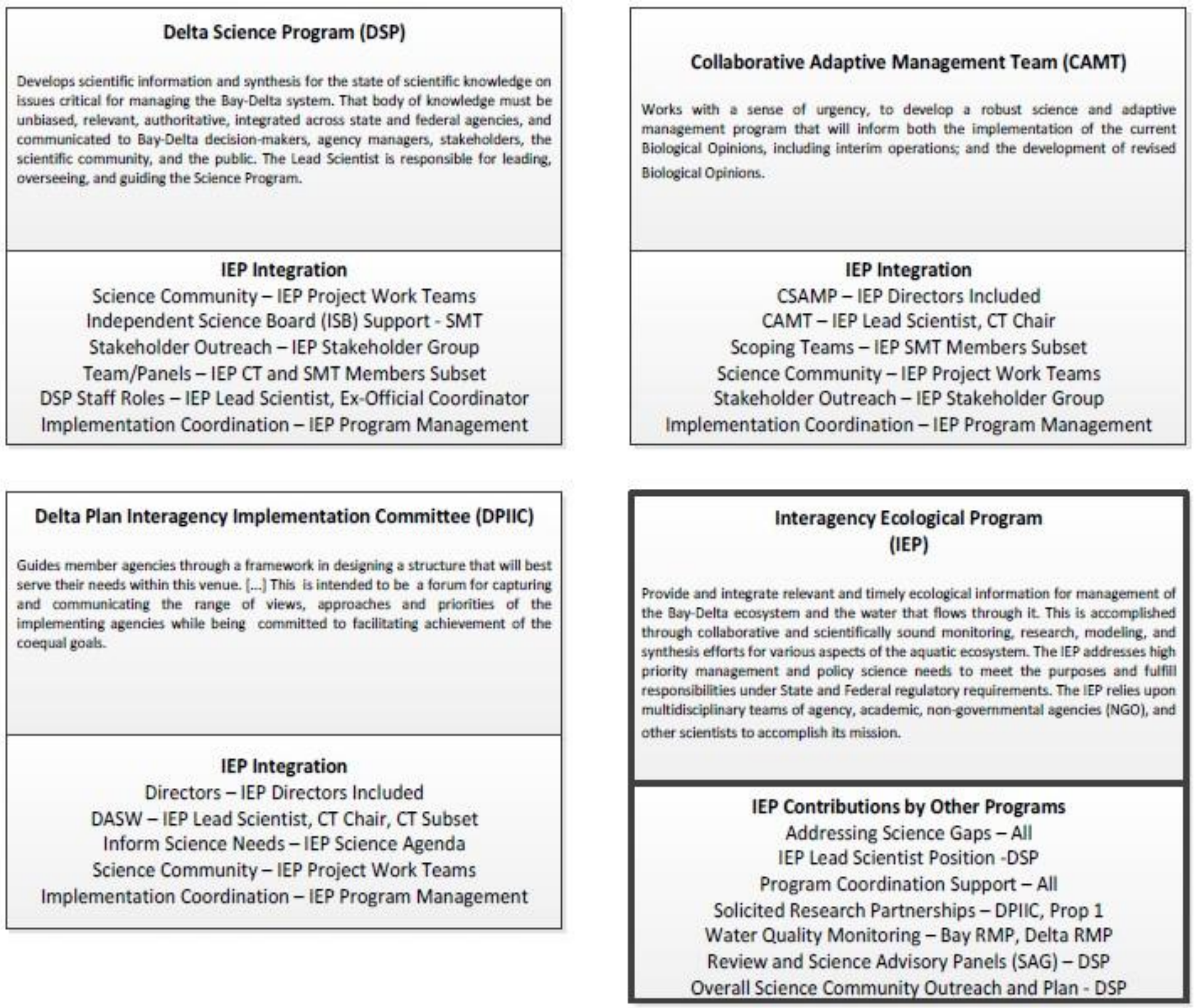

Figure 3. Select Interagency Ecological Program Collaborative Science Program Partnerships.

We view mandated monitoring as the core of our efforts, but relevant related science provides proper context for IEP Program Element data collection and evaluation. We have taken an eclectic and “it takes a village” approach to Bay-Delta Estuary collaborations. While we (the authors) feel considerable responsibility to organize and direct Agency coordinated Bay-Delta monitoring science within the IEP, we have to admit our inability to do it all. We cannot provide an effective monitoring enterprise without substantial additional investment and participation from our academic, NGO, and water agency partners. At current levels of fiscal and personnel support the IEP cannot achieve all requests made to us for data collection, analysis, and information synthesis when supporting management decision making. We welcome participation of all scientists who want to contribute understanding, relevance, and resources to the Bay-Delta Estuary science enterprise.

BUILDING OUR SCIENCE INFRASTRUCTURE

The list of potential important topics to include in the Interagency Ecological Program Science Strategy is long and pursuit of just our priority list of six focus topics is ambitious. With existing resources at IEP agencies, the entirety of work outlined in this document is not feasible (and certainly beyond our ability to fund in any given year). To implement studies that realize our Science Strategy over 5-years, the existing IEP infrastructure needs expansion to meet the growing demands on the program. We have identified both staff and program needs that require immediate additional resources from participating agencies. These needs exist in four areas:

1. *Science Communication*
    a. Enhancing IEP's coordination, collaboration, and communication with stakeholders is a major priority for IEP. We need dedicated communication staff for enhancing outreach activities and communicating the findings of IEP compliance science with the scientific and managerial communities. We will support the update and maintenance of the IEP websites, writing science communication documents for targeted audiences (e.g., IEP Directors, general public), and increasing methods for engaging the community at large (e.g., blogs, on-line videos, briefing one-pagers, etc.).
2. *Sample Curation and Archiving*
    a. In our growing science and sampling programs, we rely on an increasingly large collection of valuable biological samples (fish, phytoplankton, and zooplankton). Dedicated staff time is required to curate and maintain this library of samples, to track chain of custody as samples move from investigator to investigator, and to ensure proper storage, retrieval, and archival conditions.
3. *Synthesis*
    a. As management and scientific efforts within the Bay-Delta increase and involve more complex interactions, it is imperative that IEP bolster its resources for using increasingly diverse data to produce summary information of use to scientists and managers. Simply put, synthesis is the distillation of multiple lines of data into a condensed information set of narrative take-home points and follow-up questions. In particular, the IEP Synthesis Team needs to bolster its capacity for quantitative, predictive modeling work and for development of cohesive, synthetic narratives on relevant topics (similar to the past FLaSH and Delta Smelt MAST narratives).
4. *Data Stewardship*
    a. Having established a new, data-centric and data management-oriented technical team (the Data Utilization Working Group, or DUWG), the IEP is working on improving its data stewardship, data availability, and supporting the emerging "Open Science" movement. In plain terms, the

> IEP seeks to carry out the vision articulated by the DUWG: “improve practices of data documentation, data sharing, and generally pursue a more open science within the Bay-Delta.”

In the end, our Science Strategy includes the notion that IEP member Agencies, and in particular, individual IEP Agency scientists, can be powerful agents for the cultivation of a thriving scientific and management-oriented compliance science enterprise. We forward the notion as a community that we desire at least the following imperatives for the duration of our Science Strategy 2.0 (2020-2024):

1. Promote clear science communication and useful narratives
2. Provide meaningful data documentation and availability
3. Foster *Open Science* via Annual Work Plan implementation

Principles of Open Science:

1) Open Data
2) Open, Versioned Code & Documents
3) Open Publishing
4) Open Minds
5) Open Process
6) Open Community

IEP SCIENCE PRIORITIES 2020-2024

BAY-DELTA ECOSYSTEM RESILIENCE TO CLIMATE CHANGE

Why this major topic for the IEP Science Strategy from 2020-2024?

While drought has long been of concern to IEP agencies because of its effects on water management and species of concern (e.g., Chinook Salmon), interest in climate change emerged more recently. Much of the recent interest has evolved around expected changes in flow regime and how they will affect water allocation and flow management in the Delta and upstream watersheds (see Dettinger et al. 2016 for a review). Several studies have also documented likely biological effects of climate change on native fish populations residing in the Delta, such as Delta Smelt (Feyrer et al. 2010, Cloern et al. 2011, Brown et al. 2013, 2016), and species that move through the Delta on their way to and from upstream areas, such as Chinook Salmon (Thompson et al 2012, Katz et al 2013). Thus, consideration of climate change is an important topic for IEP and understanding the resilience of the ecosystem to changes expected with climate change will be important in understanding effects on aquatic resources of concern.

The "problem" with climate change is that it does not *seem* urgent, given that the most radical changes are not expected for decades. However, if we can identify developing problems early, we can develop a suite of potential responses in advance, greatly improving our chances of developing effective adaptation strategies that can be implemented with minimal effects on all Delta beneficial uses. The previous IEP Science Strategy identified climate change and extreme events as an important issue (IEP 2016) but we have not made much progress on suggested activities. This topic is included in the 20202024 Science Strategy with the intent of making real and substantive progress.

We are also aware that changing climate likely means that habitats will move and species will respond through behavioral changes or through adjustments in movement patterns and timing, and we need to implement monitoring surveys that will dependably track and monitor these changes.

Climate change has, and will, fundamentally affect a multitude of resources in California (Staudinger et al. 2013). The Delta Stewardship Council (2018) identified several aspects of climate change that models have identified with high certainty:

1. Air temperatures will increase by about 2C by mid-century and by 4C by 2100, if greenhouse gas emissions continue on their accelerating trajectory.

2. Precipitation will arrive as more intense storms with more dry days separating storms. More intense storms combined with warmer air temperatures will lead to less snow, and projections indicate increased risks of extreme flood and drought.
3. Sea-level rise (SLR) was approximately 22 cm during the previous century and is estimated to range from 30 to 100 cm over the current century, resulting in increased risk of inundation and saltwater intrusion.

However, climate change models do not agree on predictions for total amount of future annual precipitation; available credible projections include both wetter and drier futures.

The combination of SLR, reduced snowpack, earlier snowmelt, more intense storms, and warmer summer water temperatures will challenge both water operations infrastructure and management of aquatic resources. Climate change-induced changes in sea level rise and air temperature will have profound changes on Bay-Delta habitats and fishes of concern (Cloern et al. 2011, Feyrer et al. 2010, Brown et al. 2013, 2016). The extent and location of abiotic habitat (salinity, turbidity, and water temperature) suitable for Delta Smelt will likely change (Feyrer et al. 2010, Brown et al. 2013, Feyrer et al. 2015). Changes in seasonal air temperatures may affect important life stages for a species (e.g., maturation; Brown et al. 2016). Increasing water temperatures and less snowmelt runoff may limit floodplain inundation, which will favor reproduction of exotic species over native species (Sommer et al. 2003; Moyle et al. 2007). SLR could alter the function of tidal wetland restoration sites or carbon sequestration projects (Swanson et al. 2014). Changes in inundation patterns and water temperatures could affect sources and sinks of contaminants (Brooks et al. 2012, Fong et al. 2016). Increasing water temperatures could limit migration opportunities for anadromous fishes moving through the Delta and changes in operations to control water temperatures below dams and limit salinity intrusion into the Delta may result in the need to balance impacts among different species and water quality. Increasing water temperatures could also lead to an increase in non-native predators adapted to warmer water. Complex problems like these are difficult to resolve and require the best scientific information available (Luoma et al. 2015).

Evaluation of climate adaptation has been identified by the Secretary of Interior as a high priority to provide context for and to assess vulnerability of Bay-Delta resources (USBR 2014). Similarly, the State of California has adopted a statewide Climate Adaptation Strategy that includes the sectors of Water and Biodiversity and Habitat, among others (http://www.climatechange.ca.gov/adaptation/strategy/index.html). Understanding the effects of climate change and developing management actions for adaptation are high priorities for federal and State agencies.

The IEP *Science Strategy* prioritizes assessing the impact of climate change on the Bay-Delta and its natural resources. Furthermore, it will be important to identify potential adaptation responses in coordination with existing California and Department of the Interior (DOI) programs, such as the USFWS Landscape Conservation Cooperative activities (http://lccnetwork.org/lcc/california) and the USGS CASCADE effort (http://cascade.wr.usgs.gov/). Studies of habitat vulnerability to climate change have immediate application to the activities outlined within the Restoring Bay-Delta Native Fishes and Community Interactions section of this *Science Strategy* (see below). Programs for monitoring adaptation strategies will also rely on IEP resources to provide ecological context and analytical support.

What are the primary issues for direct management concern?

Because the global processes driving climate change are not within the control of local entities, IEP must necessarily concentrate on adaptation strategies. Effective adaptation strategies must be based on reasonable predictions of future environmental conditions and an understanding of current and future infrastructure available to Estuary resource managers. Further, this effort will require close collaboration of ecologists, water managers, and modelers in several fields (e.g., hydrodynamics, water temperature, future water demand). In this regard, it will be useful to take into account progress towards San Francisco Estuary Integrated Modeling -- currently an area of emphasis for the Delta Science Program [Draft Delta Science Plan].

1) The San Francisco Estuary depends upon snowpack storage of water during winter and the subsequent prolonged period of meltwater runoff – changes in precipitation, shifts in timing of runoff, and increasing regional temperatures will change the character of the resulting estuarine water quality

2) Mandates for monitoring water project impacts to Bay-Delta natural resources will continue regardless of climate change, and understanding what Project impacts are can only be correctly understood if we track and appropriately sample the Bay-Delta ecosystem as climate change-related shifts occur

3) Deploying newer sensor technologies and re-designing sample programs as habitats shift can help adapt existing monitoring surveys as the Bay-Delta landscape changes in response to regional climate changes – this will keep long-term data relevant as we adjust to present and future changes

The first issue is to describe for managers likely changes in abiotic habitat available to species of concern. This effort will likely focus on current fish species of concern but should be as broad as possible. The main variables of interest are salinity, water temperature, and turbidity. We should catalog existing models and their outputs for these variables with the goal of describing our existing tools and current state of prediction. Analysis and synthesis of this information will help identify the ecosystem relationships of most concern and the species most likely to suffer negative effects given input climate changes. This exercise will also highlight gaps in monitoring programs that will need to support into the future. For example, more water temperature data might be needed to validate model results for habitats that have not been of concern until recently, e.g., tidal wetlands and terminal sloughs.

The second issue is the need for new integrated modeling tools. Developing effective adaptation strategies will require combining climate change models with short- and long-term operations models to construct a range of management scenarios for gaming and simulation. In addition, we require improved methods for turning model outputs into quantification of habitat needed for species of concern. Linking such outputs to life cycle models of species of concern is also critical for evaluating effectiveness.

Beyond the considerable challenges of developing and validating Estuary-relevant integrated models, such an integrated effort requires experienced modelers and considerable investment in computing power and data storage; such investments are beyond the capacity of IEP and will require participation of other entities to realize. The

Delta Stewardship Council and others are exploring avenues for supporting an Integrated Modeling science initiative, and the Delta Science Plan calls for just such action within the broader Delta community (see link to Delta Science Plan, above).

What are the key opportunities an investment in this topic will support?

An Integrated Modeling Steering Committee has been organized under the auspices of the Delta Stewardship Council (DSC). The DSC recognizes that addressing large problems in the Estuary like climate change will require development of complex integrated monitoring infrastructure or frameworks. By making complimentary Programmatic investments in a framework for addressing climate change IEP will be in a position to play a leadership role in developing integrated models to address its associated priority questions (regarding endangered species populations, for example) into the future as climate change consequences appear.

In 2019, IEP should make an initial investment by establishing a Climate Change Project Work Team (PWT) and a Climate Change Management Analysis and Synthesis Team (MAST). The PWT will have broad membership from the IEP member agencies, other groups with an interest in modeling including the California Water Quality Monitoring Council (CWQMC), the California Water and Environmental Monitoring Forum (CWEMF), and the wider stakeholder community. The MAST would spend a year organizing, conducting meta-analysis of existing literature (quantitative or otherwise), and identifying existing data sources and modeling tools of relevance to managing Estuary at-risk species. The MAST will also be responsible for identifying logistical limitations to making progress. If additional new tools are needed, the PWT and MAST would assess feasibility of developing them and could logically find IEP data with which to perform testing and prototyping.

In 2020 and beyond, if viable tools are available to predict changes in abiotic habitat and translate those results to ecological outcomes (endangered species protection especially), then the MAST would oversee analyses of existing climate change data and publish relevant results. If available tools are considered inadequate, then the MAST will identify what is needed to develop better tools and publish the results of the proposed meta-analysis. The MAST will disseminate any publicly-developed tools to the wider community for use. The MAST may or may not extend into the future. The PWT might be a long-term entity depending on participant interest.

References:

Brooks, M.L., and 14 others. 2012. Life histories, salinity zones, and sublethal contributions of contaminants to pelagic fish declines illustrated with a case study of San Francisco Estuary, California, USA. Estuary and Coasts, 35(2):603-621. https://link.springer.com/article/10.1007/s12237-011-9459-6

Brown, L.R., Bennett, W.A., Wagner, R.W., Morgan-King, T., Knowles, N., Feyrer, F., Schoellhamer, H.H., Stacey, M.T., and Dettinger, M. 2013. Implications for future survival of delta smelt from four climate change scenarios for the Sacramento-San Joaquin Delta, California. Estuaries and Coasts, 36:754-774. doi: http://dx.doi.org/10.1007/s12237-013-9585-4

Brown, L.R., Komoroske, L.M., Wagner, R.W., Morgan-King, T., May, J.T., Connon, R.E., and Fangue, N.A. 2016. Coupled downscaled climate models and ecophysiological metrics forecast habitat compression for an endangered estuarine fish. PLoS One, 11:e0146724. doi: http://dx.doi.org/10.1371/journal.pone.0146724

Cloern, J.E., Knowles, N., Brown, L.R., Cayan, D., Dettinger, M.D., Morgan, T.L., Schoellhamer, D.H.,

Stacey, M.T., van der Wegen, M., Wagner, R.W., and Jassby, A.D. 2011. Projected evolution of California's San Francisco Bay-Delta river system in a century of climate change. PLoS One, 6(9):e24465. doi: http://dx.doi.org/10.1371/journal.pone.0024465

Delta Stewardship Council. 2018. Climate change and the Delta: a synthesis (Public Review Draft). Accessed 1/23/2019 at: http://deltacouncil.ca.gov/sites/default/files/2018/04/Climate_Change_%26_The_Delta_Public_Draft_0 3232018.pdf

Dettinger, M., Anderson, J., Anderson, M., Brown, L.R., Cayan, D., and Maurer, E. 2016. Climate Change and the Delta. San Francisco Estuary and Watershed Science, 14(3):article 5. https://doi.org/10.15447/sfews.2016v14iss3art5

Feyrer, F., Newman, K., Nobriga, M., and Sommer, T. 2010. Modeling the effects of future freshwater flow on the abiotic habitat of an imperiled estuarine fish. Estuaries and Coasts, 34:120-128. http://dx.doi.org/10.1007/s12237-010-9343-9

Feyrer, F., Cloern, J.E., Brown, L.R., Fish, M.A., Hieb, K.A., and Baxter, R.D. 2015. Estuarine fish communities respond to climate variability over both river and ocean basins. Global Change Biology. http://dx.doi.org/10.1111/gcb.12969

Fong, S., Louie, S., Werner, I., Davis, J., and Connon, R.E. 2016. Contaminant effects on California BayDelta species and human health. San Francisco Estuary and Watershed Science, 14(4): article 5. https://doi.org/10.15447/sfews.2016v14iss4art5

Katz, J., Moyle, P.B., Quinones, R.M., Israel, J., and Purdy, S. 2013. Impending extinction of salmon, steelhead, and trout (Salmonidae) in California. Environmental Biology of Fishes, (96);1169-1186. https://doi.org/10.1007/s10641-012-9974-8

Luoma SN, Dahm CN, Healey M, Moore JN. 2015. Challenges facing the Sacramento–San Joaquin Delta: complex, chaotic, or simply cantankerous? San Francisco Estuary and Watershed Science. 2015; 13(3).

Moyle PB, Crain PK, Whitener K. 2007. Patterns in the use of a restored California floodplain by native and alien fishes. San Francisco Estuary and Watershed Science. 2007; 5(3).

Sommer TR, Harrell WC, Kurth R, Feyrer F, Zeug SC, O Leary GA. 2003. Ecological patterns of early life stages of fishes in a large river-floodplain of the San Francisco estuary. In: American Fisheries society symposium 2003 (pp. 111-123). American Fisheries Society.

Staudinger, M.D., and 14 others. 2013. Biodiversity in a changing climate: a synthesis of current and projected trends in the US. Frontiers in Ecology and the Environment, 11(9):465-473. doi: 10.1890/120272

Swanson KM, Drexler JZ, Schoellhamer DH, Thorne KM, Casazza ML, Overton CT, Callaway JC, Takekawa JY. 2014. Wetland accretion rate model of ecosystem resilience (WARMER) and its application to habitat sustainability for endangered species in the San Francisco Estuary. Estuaries and Coasts. 2014 Mar 1; 37(2):476-92.

Thompson, L.C., Escobar, M.I., Mosser, C.M., Purkey, D.R., Yates, D., and Moyle, P.B. 2012. Water management adaptations to prevent loss of spring-run Chinook Salmon in California under climate change. Journal of Water Resources Planning and Management, 138(5):465-478.

USBR. Climate Change Adaptation Strategy. 2014. https://www.hsdl.org/?view&did=760006

RESTORING BAY-DELTA NATIVE FISHES AND COMMUNITY INTERACTIONS

Why this major topic for the IEP Science Strategy from 2020-2024?

Native fishes have exhibited a multi-decade abundance decline in the Bay-Delta. As a result, several species have been listed as threatened or endangered under California or federal endangered species acts (ESA), including Delta Smelt, Longfin Smelt, Winter- and Spring-run Chinook Salmon, Steelhead, and Green Sturgeon. These listings prompted additional efforts to track and protect individuals, to understand and improve current habitats and to restore other habitats, and to understand, if possible, how to ameliorate stressors. Efforts aimed toward population recovery suffered setbacks during the recent multi-year drought (2013-2016), which resulted in further declines to near-record or record low abundance for several species, and increased risk of extinction. ESA-related regulations have been perceived as an impediment to achievement of the coequal goals of endangered species recovery and protection of native fishes while continuing to achieve water supply reliability for human beneficial use in California.

Exceptionally-low abundance levels create added management and research challenges: as monitoring-survey species detections become less frequent, recognition of species distributions, movements or migrations, and abundance levels become less certain, reducing confidence in decisions made from such data. In other words, as samples from the wild become less numerous, conclusions reached after processing and analysis become less authoritative. Survey and detection challenges emphasize the need for continued innovation and a thoughtful, broad-based approach to monitoring science and Estuary research.

Our approaches for several species are guided by recent (e.g., Delta Smelt, Winter-run Chinook and Sturgeon), ongoing (Longfin Smelt), and nascent (minnows and suckers) analysis and synthesis efforts, which developed species conceptual models and used them to identify gaps in knowledge of species life history, ecology, and other information necessary for effective management. These gaps, in-turn, have been used to identify high-priority science and monitoring needs for inclusion in the *Science Strategy 2.0*.

In our previous *Science Agenda (2016)*, we focused on listed fishes and only acknowledged the need for similar efforts on other native species. Here we formally discuss research and management needs for a larger suite of native species in effort to develop effective management knowledge before extreme intervention is needed to maintain them. As indicated previously, adequate knowledge is based on successfully monitoring species distribution and abundance trends, investigating specific questions through targeted laboratory and field experiments, and once knowledgeable, using quantitative modelling to further improve understanding and prediction.

We organize our discussion of native fishes into the following sections: 1) salmonids; 2) green and white sturgeon; 3) Cyprinids, Catostomids and other native fishes, and; 4) the smelts. In each section, we recognize that fishes do not survive independently from the rest of the environment, so some of our strategies and approaches address habitat, community, and/or ecological interactions as well.

SALMONIDS

Why this major topic for the IEP Science Strategy from 2020-2024?

The Sacramento River winter-run Chinook salmon Evolutionarily Significant Unit (ESU) and Central Valley spring-run Chinook salmon ESU are endangered and threatened, respectively, while the California Central Valley steelhead Distinct Population Segment (DPS) is threatened. Central Valley Chinook salmon (Oncorhynchus tshawytscha) and steelhead (Oncorhynchus mykiss) are anadromous species, which complete their life cycles through a variety of alternate pathways across the landscape. Given this range of habitat use, coordination of Chinook Salmon research and management across the various rivers, estuary, bays, and coastal ocean in California is critical. Central Valley salmonids have been in decline since the mid-1800s, due to overfishing, destruction of habitat by hydraulic and dredge mining, construction of dams, water-diversion projects and railroads, and logging (Yoshiyama et al. 1998). Because of the complexity of their habitat use and multiple factors of their decline, salmonid regulation alters the operation and delivery structure of human water use throughout the Central Valley and the San Francisco Estuary (SFE). The NMFS 2009 Reasonable and Prudent Alternative (RPA) Actions affecting the Operations Criteria and Plan (OCAP) for State/Federal Water Operations regulates: (1) reservoir and river flows, and temperature, (2) the operation, screening and passage at gates, diversions, dams, and pumping facilities, and (3) the genetic management goals of hatcheries, in an effort to recover Central Valley salmonids. The NMFS recovery plan for Central Valley Chinook salmon and steelhead recommends conservation efforts that concentrate on two principles: (1) the necessity of functional, diverse, and interconnected habitat across the Central Valley, SFE, and Pacific Ocean ecosystems, and (2) that species viability is jointly dependent upon spatial structure, diversity, productivity, and abundance (NMFS 2014). The California Natural Resources Agency has outlined specific objectives for reaching the Central Valley Project Improvement Act (CVPIA) salmonid doubling goals in the Sacramento Valley salmon resiliency strategy: (1) increased productivity by improving spawning and incubation conditions, and juvenile survival, (2) maintaining life history diversity by supporting the full range of juvenile and adult migration conditions, and (3) preserving genetic integrity of distinct runs by limiting interactions with hatchery-produced fish.

Due to the breadth of these conservation goals, and the commercial and regulatory importance of salmonids, there are many organizations involved in salmonid conservation and research. In addition to many programs within state (e.g., CDFW's Fisheries Restoration Grant Program) and federal agencies (e.g., NMFS's Central Valley winter-run life-cycle model) there are also a number of collaborative groups concerned with Central Valley salmonids, including: (1) IEP and its various project work teams (PWTs) and synthesis efforts (winter-run PWT, spring-run PWT, steelhead PWT, Salmon Analysis and Indicators by Life-stage), (2) the Collaborative Science and Adaptive Management Program (CSAMP) with the Collaborative Adaptive Management Team (CAMT) and Salmon Scoping Team (SST), and (3) the CVPIA and its Science Integration Team (SIT). Salmon occupy an expansive range, providing cumulative contributions to individual success and species viability (Figure 5). For example, adult escapement and in-river conditions impact the number of juveniles produced, and flow, temperature, ocean productivity, and pumping mortality impact their survival in the first year(s). 2002 to 2009 (Figure 5 -- purple and pink vertical lines) was a period of precipitous decline for Central Valley Chinook, without an individual definitive cause. The above-mentioned collaborative groups and coordination among resource users and regulators across the salmonid landscape are critical for effective conservation policy implementation given their varied life-histories and extensive ranges.

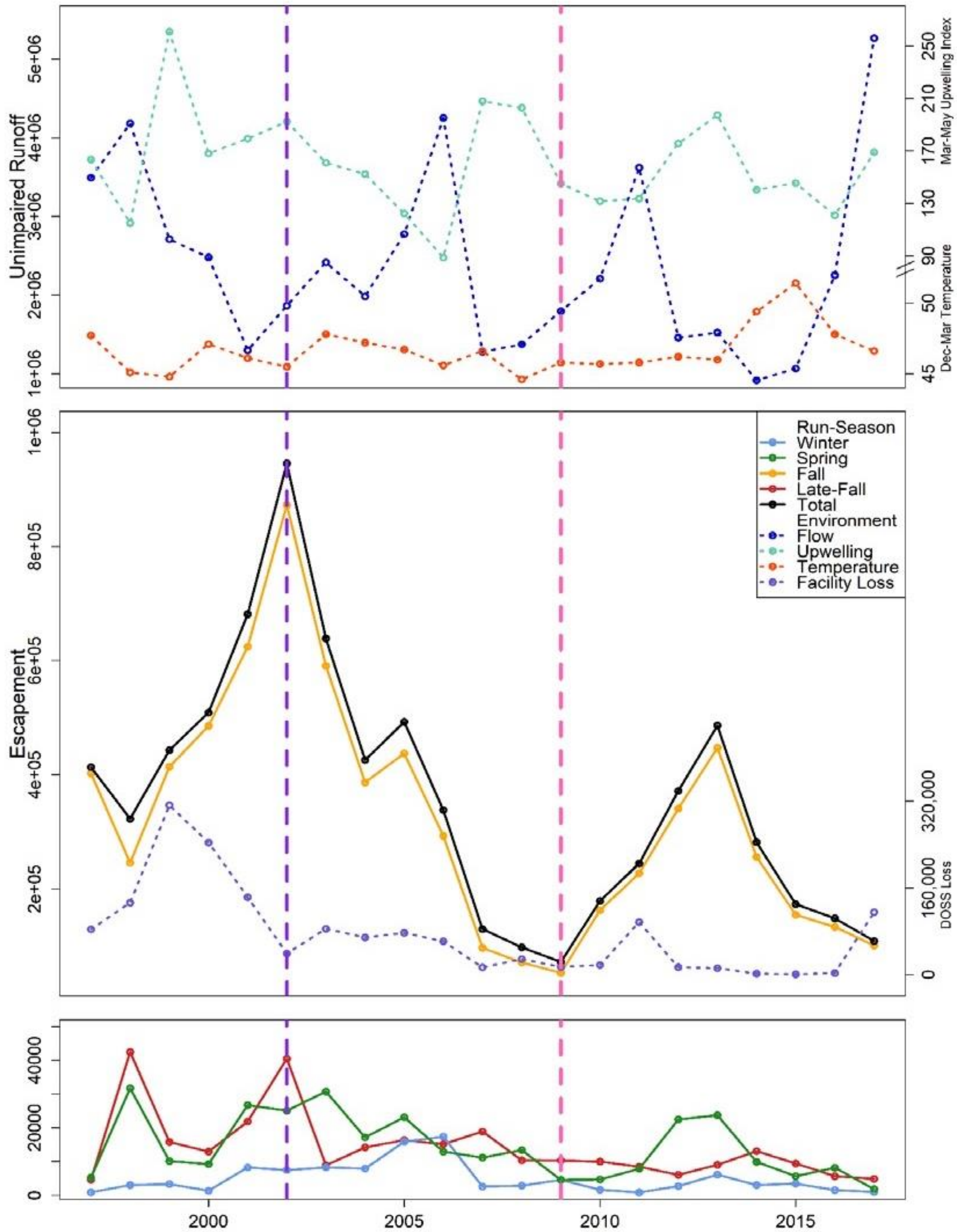

Figure 5. Time series plot of four Central Valley Salmon runs with several environmental variables and salvage losses that potentially co-vary or co-relate with fish abundance within the San Francisco Estuary. This figure is an illustration of the complex and sometimes contrasting environmental cues both salmon managers and the juveniles must navigate. For example, the period between 2002 and 2009 (purple and pink vertical lines) was a period of precipitous decline for Central Valley Chinook, without an individual definitive cause.

What are the primary issues of direct management concern?

Coordination between the monitoring network and focused, mechanistic, ecological studies. Many of the key monitoring locations within the freshwater fluvial and tidal system are sampling salmonids, but are limited to estimating presence and timing (Johnson et al. 2017). The salmonid monitoring network is missing reliable run-specific abundance estimates, and landscape-scale assessments of life history diversity and fish condition. Johnson et al. 2017, a substantial synthesis of the monitoring network for winter-run Chinook salmon, clarified this with six recommendations, all of which require coordination between the traditional monitoring system and hypothesis-based focused studies and/or incorporating newer technology. Several other synthesis efforts, such as the SIT (in collaboration with the winter-run PWT) and NMFS's winter-run life-cycle model have also highlighted priorities for focused, mechanistic, ecological salmonid studies. There is also considerably less effort spent on understanding salmon and steelhead use of the brackish and saline environment within the SFE and coastal ocean. These habitats are considerably less constrained and complex making them difficult to sample, however disentangling human impacts and management actions on population dynamics requires a mechanistic understanding of the entire salmon landscape. For example, Woodson et al. 2013 found that larger sized juveniles with higher freshwater-estuarine growth rates were more likely to survive their first months at sea in a poor recruitment year, but during years of improved ocean productivity there was no evidence for size and growth-rate selective mortality. In this study a broader range of growth rates and sizes (e.g., including small and slow-growing individuals) was an indicator for improved ocean conditions. Similarly counterintuitive, Losee et al. 2014 demonstrated that early ocean growth and condition were positively related to parasite species richness, which was suggested as an indicator for diverse diets during migration and ocean entry. These studies reiterate the need for focused fish condition research (Advancement 5 in Johnson et al. 2017) in order to better understand the mechanisms that enhance population viability and the range of habitat types experienced by salmon across the landscape.

Flow modification tradeoffs. The Central Valley has been substantially altered by water control structures (levees, temporary rock dams, weirs, dams, agricultural siphons, and floodgate diversions) to minimize flooding and facilitate out-of-basin water exports (Nichols et al. 1986; Kimmerer 2004). Numerous studies have demonstrated that large scale water operations can greatly alter the flow regime (e.g., Delta outflow) and water quality (e.g., salinity) at both regional and local scales (Jassby et al. 2002; Kimmerer 2002, 2004). Flows can have a very important and highly variable impact on juvenile and adult salmon habitat availability, productivity and risk. These water control structures are regulated to minimize negative impacts on salmonids, but there are also opportunities to use this infrastructure to benefit fish. The Yolo Bypass is a well-studied example of a flood control structure used to increase productivity and available habitat for salmonids (Sommer et al. 2001), while managing entrainment risk (Sommer et al. 2005). However, these opportunities require creative and adaptive water management, which in turn necessitates in-season, real-time data and modeling to make informed decisions, including tradeoffs for fish habitat extent and quality. For example, in the Feather River the Hatchery Operation Team and Feather River Technical Team (collaborations between DWR, CDFW and NMFS) used experimental pulse flows to protect juvenile spring-run outmigrants from parasitism by *Ceratonova shasta* during the recent drought and improve survival in a low hatchery production year (2018). These pulse flows are both an example of the opportunities available through collaborative flow action and the challenge of evaluating flow modifications for fish benefits. Currently, the assessment of these pulse flow actions through adult returns is not yet available for, but the addition of focused survival and parasitism studies could provide better insights to the tradeoffs of pulse flows for springrun salmon and inform modeling efforts for future actions.

Habitat limitations and restoration targets. Rehabilitating native fish habitat requires compromise with human resource users and can be difficult to evaluate for transient species such as salmon, which temporarily occupy any one location.

Simenstad and Cordell (2000) recommend assessing the functions (e.g., habitat capacity and opportunity) of recently restored habitat, and the IEP Tidal Wetlands project work team has provided a series of conceptual models emphasizing the best available science and key knowledge gaps specific to the SFE (Sherman et al. 2017). Although the realities of implementation are an inevitable constraint, restoration projects must be designed at the appropriate scale and include sufficient planning to address their management goals (Simenstad et al. 2006).

The reintroduction of spring-run to the San Joaquin River illustrates the challenges of reestablishing salmonids within degraded habitats. In addition to the direct habitat restoration, which consists of channel improvements (including rehabilitating floodplain and riparian habitat), fish screening, restorative flow scheduling and water temperature management, this program also includes genetic management, in-river monitoring of juvenile migration timing, survival and size, and adult trapping. However, the San Joaquin River Restoration Program’s spring-run population will need to migrate to, and return from, the ocean. Disentangling the impact of time spent in the SFE from that of time in the ocean will complicate evaluations of restoration success for the San Joaquin spring-run reintroduction. Additional collaborations will be necessary to provide this population with the rehabilitation of the full range of habitats used throughout their life-cycle.

Artificial propagation contributing to diversity goals. Major declines in Pacific salmon have given rise to artificial spawning and rearing of juveniles in hatcheries to improve growth and survival in the first year of life. To counteract harvest declines and ameliorate rearing habitat loss, hatcheries target fast growth and large-sized juveniles. Particularly in the Central Valley, hatcheries have increased the size of juvenile Chinook at release since the 1980s and decreased the life history diversity within releases (Huber and Carlson 2015). However, there is no one optimum phenotype, and it has been found that spatial variation in juvenile Chinook habitat use decreases interannual variation in juvenile production (Thorson et al. 2014). Further, in certain years the smallest juveniles at outmigration can be a larger contributor to the returning adult population than the largest juveniles (Sturrock et al. 2015).

During the recent drought, a higher percentage of hatchery juveniles were trucked past the Delta to the San Francisco Bay in an effort to further reduce risk to juvenile survival (Huber and Carlson 2015; Satterthwaite and Carlson 2015). This practice has caused an unintended increase in adult straying rates (for trucked fish) and weakened portfolio effect (synchrony in production) (Satterthwaite and Carlson 2015). Three of the fourteen major issues identified in the California Hatchery Review Report (2012) and much of the salmonid regulatory language supports life history diversity, but there is deficient direction for hatchery participation. Therefore, there is a need to test practical alternative actions for hatcheries and identify best practices that would enhance age/size and timing variation with Central Valley salmonid runs.

What are the key opportunities an investment in this topic will support?

Coordination between the monitoring network and focused, mechanistic, ecological studies. There is incredible potential for improvements to the salmon monitoring network with the addition of focused, mechanistic, ecological studies. For example, in response to a study recommendation from Johnson et al. 2017 to improve estimates of juvenile abundance, a five-year collaborative evaluation of the existing Sacramento and Chipps Island trawls was conducted. Preliminary efforts suggest that coordinated enhancement of the existing monitoring could estimate abundance in the Sacramento River and SFE, which, in turn, could improve evaluations of ocean harvest and project take targets. This same effort could potentially be repeated for steelhead or for the Mossdale trawl on the San Joaquin River. We support the close coordination of modeling and monitoring efforts in just this way into the future.

Flow modification and potential tradeoffs between strategies for managing different runs and run timing. There are a number of synthesis efforts and decision support tools already invested in this topic, some of which have identified innovative approaches and research needs. Resources should continue to be allocated to expanding these efforts, such as accurate salmon run identification (Johnson et al.

2017, Advancement 1). Genetic identification of juvenile salmon is being conducted at the Central Valley Project and State Water Project salvage facilities, the San Joaquin River Restoration Project, and CVPIA and IEP fish monitoring stations (including alternate corridors like the Yolo Bypass). Without accurate salmon run identification, it will continue to be difficult to distinguish between juveniles from different runs of Central Valley Chinook salmon, manage ESA-listed ESUs, and measure run diversity and between- or across-run resilience.

Habitat limitations and restoration targets. Targeted habitat restoration requires a multidimensional approach. Currently, habitat targets focus on areas of greatest loss, but identifying bottlenecks to habitat rehabilitation and prioritization based on species/run-specific limitations is needed. IEP's Tidal Wetland PWT is a model for coordination and communication among restoration practitioners and researchers, which is necessary when managing anadromous species. Aggregation across the landscape is critical for recovery and evaluating restoration success. For example, Phillis et al. (2018) found that 44-65% of winter-run reared in non-natal habitats. Further, Central California coastal steelhead have been observed entering the ocean and then swimming up neighboring creeks as juveniles during winter, suggesting rearing occurs across a complex of watersheds, rather than simply the watershed of origin. It is possible that smaller watersheds that enter into the San Pablo and Suisun Bays and fall-run dominated tributaries may be important rearing habitats for ESA-listed salmonids. There are numerous opportunities for regulatory-focused restoration efforts with monitoring already in place to pair with experimental research studies to address the knowledge gaps discussed here.

Opportunities for research investments to improve understanding of ESA-listed salmonids:

1) Where/what are the most limited/limiting habitats in the Central Valley?

2) How do trajectories and rates of habitat restoration and evolution affect Central Valley runs and species?

3) How does landscape integration occur among and between species (Simenstad and Cordell 2000)?

Acritical propagation contributing to diversity goals. Irreversible damage to Central Valley steelhead population structure may have already occurred, in part due to hatchery introgression (Pearse and Garzo 2015). It is important to consider how gene flow from hatchery fish may be influencing fitness and resilience in natural populations. Further, there may be a tradeoff between managing year-to-year variability in abundance with maintaining natural-origin fish. Willmes et al. (2018) found that hatchery contribution to natural spawners on the Feather River dramatically increased after the 2007-2009 drought (and stock collapse). Hatcheries could attempt to reflect the diversity of outmigration behaviors and sizes in the wild population. Hatcheries are meant to ameliorate the lack of upstream spawning and rearing habitat for salmonids and this extirpation impacted production and life history diversity (Miller et al. 2011), and hatchery targets should include enhancing diversity. Additional examination of the genetic variability incorporated into hatchery management and release plans could suggest improvements to genetic management for the long-term, especially as genetic information becomes more commonly available system-wide.

References:

[California HSRG] California Hatchery Scientific Review Group. 2012. California Hatchery Review Report. Prepared for the US Fish and Wildlife Service and Pacific States Marine Fisheries Commission. Available from: http://cahatcheryreview.com/wpcontent/uploads/2012/08/CA%20Hatchery%20Review%20Report%20Final%207-31-12.pdf

Huber, E., and S. Carlson. 2015. Temporal trends in hatchery releases of Fall-Run California Salmon in California's Central Valley. San Francisco Estuary and Watershed Science 12:1-23.

Jassby, A. D., J. E. Cloern, and B. E. Cole. 2002. Annual primary production: patterns and mechanisms of change in a nutrient-rich tidal ecosystem. American Society of Limnology and Oceanography 47:698–712.

Kimmerer, W. J. 2002. Physical, biological, and management responses to variable freshwater flow into the San Francisco Estuary. Estuaries 25:1275-1290.

Kimmerer, W. J. 2004. Open water processes of the San Francisco Estuary: from physical forcing to biological responses. San Francisco Estuary and Watershed Science 2: 1–140.

Johnson, R.C., S. Windell, P. L. Brandes, J. L. Conrad, J. Ferguson, P. A. L. Goertler, B. N. Harvey, J.

Heublein, J. A. Israel, D. W. Kratville, J. E. Kirsch, R. W. Perry, J. Pisciotto, W. R. Poytress, K. Reece, and B. G. Swart. 2017. Increasing the management value of life stage monitoring networks for three imperiled fishes in California's regulated rivers: case study Sacramento Winter-run Chinook salmon. San Francisco Estuary and Watershed Science 15: 1-41.

Losee, J.P., J. Fisher, D.J. Teel, R.E. Baldwin, D.J. Marcogliese, and K.C. Jacobson. 2014. Growth and condition of juvenile coho salmon Oncorhynchus kisutch relate positively to species richness of trophically transmitted parasites

Miller, J.A., V.L. Butler, C.A. Simenstad, D.H. Backus, and A.J.R. Kent. 2011. Life history variation in upper Columbia River Chinook salmon (*Oncorhynchus tshawytscha*): a comparison using modern and ~500-year-old archaeological otoliths. Canadian Journal of Fisheries and Aquatic Sciences 68: 603–617.

Nichols, F. H., J. E. Cloern, S. N. Luoma, and D. H. Peterson. 1986. The modification of an estuary. Science 23:567-573.

[NMFS] National Marine Fisheries Service. 2009. Biological opinion and conference opinion on the longterm operations of the Central Valley Project and State Water Project. National Marine Fisheries Service, Southwest Region. Available from: https://calisphere.org/ item/14a15905-9981-4e5a803bcb2e363b063 e/

[NMFS] National Marine Fisheries Service. 2014. Recovery plan for the evolutionarily significant units of Sacramento River winter-run Chinook Salmon and Central Valley spring-run Chinook Salmon and the distinct population segment of California Central Valley Steelhead. Available from: http://www.westcoast.fisheries.noaa.gov/protected_species/salmon_steelhead/recovery_planning_and_implementation/california_central_valley/california_central_valley_recovery_plan_documents.html

Pearse, D.E. and J.C. Garza. 2015. You Can't Unscramble an Egg: Population Genetic Structure of Oncorhynchus mykiss in the California Central Valley Inferred from Combined Microsatellite and Single Nucleotide Polymorphism Data. San Francisco Estuary and Watershed Science 13: 1-17.

Phillis, C.C., A.M. Sturrock, R.C. Johnson, P.K. Weber. 2018. Endangered winter-run Chinook salmon rely on diverse rearing habitats in a highly altered landscape. Biological Conservation 217: 358-362.

Satterthwaite, W. H., and S. M. Carlson. 2015. Weakening portfolio effect strength in a hatchery supplemented Chinook salmon population complex. Canadian Journal of Fisheries and Aquatic Sciences 72(12):1860-1875.

Sherman, S., R. Hartman, and D. Contreras. 2017. Effects of tidal wetland restoration on fish: a suite of conceptual models. IEP Technical Report 91. Department of Water Resources, Sacramento, California.

Simenstad, C. A., and J. R. Cordell. 2000. Ecological assessment criteria for restoring anadromous salmonid habitat in Pacific Northwest estuaries. Ecological Engineering 15:283-302.

Simenstad, C., D. Reed, and M. Ford. 2006. When is restoration not? Incorporating landscape-scale processes to restore self-sustaining ecosystems in coastal wetland restoration. Ecological Engineering 26:27-39.

Sommer, T. R., M. L. Nobriga, W. C. Harrell, W. Batham, and W. J. Kimmerer. 2001. Floodplain rearing of juvenile chinook salmon: evidence of enhanced growth and survival. Canadian Journal of Fisheries and Aquatic Sciences 58: 325-333.

Sommer, T. R., W. C. Harrell, and M. L. Nobriga. 2005. Habitat use and stranding risk of juvenile Chinook Salmon on a seasonal floodplain. North American Journal of Fisheries Management 25:1493– 1504.

Spence, B. 2016. Effects of Staggered Release Timing of Hatchery Coho Salmon Smolts on Subsequent Adult Returns to Scott Creek, California: Spreading Risk to Cope with Variable Ocean Conditions. Oral presentation at the 34th Annual Salmonid Restoration Conference, Fortuna, CA. April 6-9.

Sturrock, A. M., J. D Wikert, T. Heyne, C. Mesick, A. E. Hubbard, T. M. Hinkelman, P. K. Weber, G. E. Whitman, J. J. Glessner, and R. C. Johnson. 2015. Reconstructing the migratory behavior and long-term survivorship of juvenile Chinook salmon under contrasting hydrologic regimes. PLOS One 00:00-00.

Thorson, J. T., M. D. Scheuerell, E. R. Buhle, and T. Copeland. 2014. Spatial variation buffers temporal fluctuations in early juvenile survival for and endangered Pacific salmon. Journal of Animal Ecology 83:157-167.

Willmes, M., J.A. Hobbs, A.M. Sturrock, Z. Bess, L.S. Lewis, , J.G. Glessner, R.C. Johnson, R. Kurth, and J. Kindopp. 2018. Fishery collapse, recovery, and the cryptic decline of wild salmon on a major California river. Canadian Journal of Fisheries and Aquatic Sciences 00: 1-13.

Woodson, L. E., B. K. Wells, P. K. Weber, R. B. MacFarlane, G. E. Whitman, and R. C. Johnson. 2013. Size, growth, and origin-dependent mortality of juvenile Chinook salmon *Oncorhynchus tshawytscha* during early ocean residence. Marine Ecology Progress Series 487:163-175.

Yoshiyama, R. M., F. W. Fisher, and P. B. Moyle. 1998. Historical abundance and decline of chinook salmon in the Central Valley region of California. North American Journal of Fisheries Management 18:487-521.

GREEN AND WHITE STURGEON

Why this major topic for the IEP Science Strategy from 2020-2024?

Sturgeon populations are in decline and preliminary analysis indicates that demographic trends of harvested species (White Sturgeon) will be negative for the foreseeable future. Managing sturgeon is particularly challenging compared with other target native species for the following reasons:

1. sturgeon populations are relatively small;
2. sturgeon are iteroparous and broadcast spawn in deep, swiftly flowing river reaches, so adult populations cannot be monitored using techniques that work well for salmonids (e.g., carcass surveys, redd counts, visual observations);
3. young individuals (e.g., age-0 through age-5) are difficult to capture and monitor;
4. sturgeon are late maturing (e.g., 15+ years) and long-lived (50+ years);
5. sturgeon from the San Francisco Estuary may spend substantial time in estuarine areas outside the state of California and;

6. sturgeon achieve large size and support popular legal (White Sturgeon only) and lucrative illegal fisheries.

Understanding sturgeon in the Bay-Delta and tributaries is critical to the operation of reservoirs and large-scale water diversion and export facilities, ESA-listed species recovery tracking, and regulation of state and federally managed commercial and sport fisheries.

Problem Statement: Current surveys are not designed for evaluating population responses to management manipulation or useful for providing management alternatives to current practices.

Management Priority: What effect do water operation, environmental stress, and fisheries regulation have on White and Green Sturgeon abundance and recruitment? What data collection programs do we have to inform on mechanism of these effects?

Data Priority: Basic demographic information and population estimates. Basic life history ecology.

Current Monitoring and Research in IEP: There are currently only two long-term monitoring studies used in estimating and forecasting abundance in sturgeon (primarily White Sturgeon): the IEP estuarine and marine fish abundance and distribution study (Bay Study) and the IEP White Sturgeon population study (adult sturgeon population estimates). No demographic measures (i.e., abundance, recruitment, and survival) are currently available for Green Sturgeon. As a consequence, information necessary to evaluate the relationship between water operations and fisheries regulations and Green Sturgeon abundance and recruitment does not exist, and it is uncertain if the population is following general patterns observed during major environmental stress (e.g., the recent drought). Green Sturgeon adult abundance (escapement) has been estimated in the last few years (Mora et al. 2018), but population models necessary to accurately generate overall abundance from these estimates require further development (Beamesderfer et al. 2007). Synthesis of existing long-term data sets (including from IEP Work Plan Elements) is underway but requires further support and development. These investments are not currently programmed.

What additional science tools are needed?

Improved Demographic Monitoring and Programmatic Surveys. The long-term IEP surveys have provided key information on status and trends of sturgeon; however, additional tools are needed to expand and improve these estimates. Of note, while current IEP-funded projects have increased our understanding of the activities of adult sturgeon, the general ecologies of the early life stages of both species of sturgeon are poorly understood and under-studied to date. We recommend monitoring all life stages of sturgeon at some level by way of long-term IEP surveys to improve our understanding of the effects of water management on the different stages. For example, current sampling does not include a Year Class Index (YCI) survey for Green Sturgeon. We recommend implementing an annual long-term monitoring effort targeted at eggs and larvae utilizing proven methods, such as egg mats and benthic D-nets, in known and suspected spawning reaches of the Sacramento (Poytress 2015), Feather (Seesholtz et al. 2014), Yuba, and San Joaquin (Jackson et al. 2016) rivers. Further, IEP surveys associated with both the White Sturgeon YCI (Bay Study) and the adult sturgeon population study should be reviewed and expanded to better address the paucity of Green Sturgeon data and to improve confidence surrounding population estimates of both species.

The long-term fish surveys remain the core of IEP's work but expanding and refining these surveys is necessary. For example, age and genetic data collection should be added to existing surveys where appropriate. We recommend routine PIT tagging of both species captured in IEP studies to enhance long-term mark-recapture analyses and encourage the application of long-life (10+ yr) telemetric tags to Green Sturgeon. We recommend increased reliance on newer technologies, such as side-scan sonar and DIDSON imaging, in routine adult population surveys in known spawning reaches of both the Sacramento and San Joaquin rivers and tributaries. These techniques have been used successfully in 2010-2015, leading to the first estimate of Sacramento River Green Sturgeon adult run size (Mora et al. 2018) and should be considered as the basis of long-term monitoring in the future.

Key Monitoring Question: *What is the annual distribution and relative abundance of early life-stages of White and Green Sturgeon?*

Priority Data Collections: *a) Egg and larval collection to verify spawning and estimate spawning distribution; b) identification of spawning habitats, and; c) long-life tag technologies to inform basic demography and life cycle understanding*.

Focused Landscape Change and Restoration Studies. Establishing mechanisms for recruitment in sturgeon will improve our ability to predict the potential effects to sturgeon populations of large-scale changes to the Delta landscape and hydrology, such as the proposed California Water Fix and restoration of flood plain areas in the Yolo Bypass. Our current understanding of habitat preferences and how different life stages use those habitats is poor for both species. Recent studies (e.g., Mora et al. 2018; Wyman et al. 2018; Poytress et al. 2015; Seesholtz et al. 2014) have started to clarify where and when adult Green Sturgeon spawn; while, our understanding of White Sturgeon spawning is based primarily on one paper (Kohlhorst 1976), though a recent publication (Jackson et al. 2016) also documented some level of spawning in the San Joaquin River. From the start of exogenous feeding through the period of residence in the Delta, the habits of both species of sturgeon remain mysterious. Studies devoted to further identifying and describing spawning sites, microhabitat preferences of each life stage in the river and Delta, movements within and between habitats, and migration timing and routes to the Delta will inform decisions of managers with regard to both restoration efforts and water use.

Synthesis and Modeling. Monitoring and focused studies are critical in collecting data on life history, distribution, and diversity. Quantitative models are also necessary to synthesize these data into more pertinent metrics for management, such as status trends of sturgeon, while conceptual models provide the framework from which to understand the processes and conditions that influence sturgeon survival and recovery. We recommend an integrated approach using both conceptual and quantitative modeling. Several such tools are underway, for instance the SAIL model (Heublein et al. 2017), CDFW White Sturgeon brood-year modelling, and NFMS Green Sturgeon adult abundance model (Mora et al. 2018). Further development and refinement of these and related tools will support integrated analyses that inform management.

Comparative Studies and Technical Review. Assessment of sturgeon populations is generally challenging because of their broad distribution and life history diversity, and associated difficulty in sampling and development of quantitative population models. Given these limitations, technical review of existing quantitative models and comparison with other regions involved in similar sturgeon monitoring and management (e.g., Columbia River basin White Sturgeon) can be informative.

Many of the recommendations above have been identified as high priority by IEP Agency Directors, IEP PWTs, IEP MTs, IEP SAG, CSAMP/CAMT SST, Delta Smelt MAST, California Hatchery Scientific Review Group and/or Salmon and Sturgeon SAIL. Focused studies and synthesis on this topic would benefit from coordination with additional community members with parallel interests including DSP, SFCWA, SFEI, Universities, FRPA as well as the multiple IEP PWT’s focused on these species.

References:

Anderson JT, Schumer G, Anders PJ, Horvath K, Merz JE. 2018. Confirmed observation: a North American Green Sturgeon *Acipenser medirostris* recorded in the Stanislaus River, California. Journal of Fish and Wildlife Management 9(2):624–630; e1944-687X. doi:https://doi.org/10.3996/012018-JFWM006

Beamesderfer, R.C.P., Simpson, M.L., and Kopp, G.J. 2007. Use of life history information in a population model for Sacramento green sturgeon. Environmental Biology of Fishes, 79:315-337.

Heublein, J., R. Bellmer, R.D. Chase, P. Doukakis, M. Gingras, D. Hampton, J.A. Israel, Z.J. Jackson, R.C.

Johnson, O.P. Langness, S. Luis, E. Mora, M.L. Moser, L. Rohrbach, A.M. Seesholtz, and T. Sommer. 2017. Improved Fisheries Management Through Life Stage Monitoring: the Case for the Southern

Distinct Population Segment of North American Green Sturgeon and the Sacramento-San Joaquin River White Sturgeon. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-SWFSC588

Jackson Z.J., Gruber J.J., and J.P. Van Eenennaam. 2016. White sturgeon spawning in the San Joaquin river, California, and effects of water management. Journal of Fish and Wildlife Management, 7:171–178

Kohlhorst, D.W. 1976. Sturgeon spawning in the Sacramento River in 1973, as determined by distribution of larvae. California Fish and Game, 62(1):32-40

Mora, E.A., Battleson, R.D., Lindley, S.T., Thomas, M.J., Bellmer, R. , Zarri, L.J., and A.P. Klimley. 2018. Estimating the Annual Spawning Run Size and Population Size of the Southern Distinct Population Segment of Green Sturgeon. Transactions of the American Fisheries Society, 147:195-203

Poytress, W.R., Gruber, J.J., Van Eenennaam, J.P., and M. Gard. 2015. Spatial and Temporal Distribution of Spawning Events and Habitat Characteristics of Sacramento River Green Sturgeon, Transactions of the American Fisheries Society, 144(6):1129-1142

Seesholtz, A.M., Manuel, M.J., and J.P. Van Eenennaam. 2015. First documented spawning and associated habitat conditions for green sturgeon in the Feather River, California. Environmental Biology of Fishes. 98:905-912

Wyman, M.T., Thomas, M.J., McDonald, R.R., Hearn, A.R., Battleson, R.D., Chapman, E.D., Kinzel, P., Minear, J.T., Mora, E.A., Nelson, J.M., Pagel, M.D., and A.P. Klimley. 2018. Fine-scale habitat selection of green sturgeon (*Acipenser medirostris*) within three spawning locations in the Sacramento River, California. Canadian Journal of Fisheries and Aquatic Sciences 75:779-791

CYPRINIDS, CATOSTOMIDS AND OTHER NATIVE FISHES

The previous version of the IEP Science Strategy simply states, "*Beyond the listed species emphasized here, other native fishes (e.g., Sacramento Blackfish, Hitch, Tule Perch, Lamprey) deserve consideration in our research and monitoring portfolios.*" This section expands on this notion and provides discussion and justification for further investigation into less studied native fishes. Our goal is not to detract from the important monitoring regarding more high-profile species (e.g., Smelts, Salmonids and

Sturgeon), but rather to elevate our understanding of less-studied species in order to inform restoration and management, elucidate community dynamics and interactions, and prevent additional fish from requiring ESA listing or other special protections.

What are the primary issues for direct management concern?

The majority of IEP synthesis and research on native fishes focuses on a few species considered important due to management or commercial interest. However, the population dynamics, ecological function, and potential community importance of many native species remain understudied. This may mean we are not effectively managing for the long-term persistence of these species, and they may become candidates for ESA listing in the future. Many native species that use brackish, low-salinity, and freshwater portions of the Estuary for all or part of their life cycle fall into the broad category that is the focus of this section.

Three species of Lampreys (Petromyzontidae) occur in the Estuary: Pacific Lamprey (*Entosphenus tridentatus*), River Lamprey (*Lampetra ayresi*), and the less common Western Brook Lamprey (*L. richardsoni*) (Moyle 2002). However, only Pacific Lamprey have a targeted conservation plan in the form of the U.S. Fish and Wildlife Pacific Lamprey Conservation Initiative (PLCI). A statewide assessment produced as part of the PLCI identified numerous knowledge gaps including the following: adult populations levels, current range, and the impacts of habitat loss, predation, disease, entrainment and altered flow regimes (Goodman 2012). It is assumed that, like many other native fishes, Pacific Lamprey populations are a fraction of their historic levels (Moyle 2002). This is not surprising given the extent to which their range has been restricted and altered by impassable barriers and highly managed river flows. However, the extent of their decline has proven difficult to quantify given the lack of targeted studies and long-term monitoring data (Goodman 2012). Even less is known about Western Brook and River Lamprey.

Minnows (Cyprinidae) are one of the most diverse groups of native fishes that occur in the Estuary with at least seven extant species recognized in addition to the extinct Thicktail Chub (*Gila crassicauda*) (Moyle 2002). The majority of literature regarding minnows in the Estuary focus on the semianadromous Splittail (*Pogonichthys macrolepidotus*). Investigations into Splittail genetics, population dynamics and physiology are presented in peer-reviewed literature (Baerwald et al. 2007, Feyrer et al. 2015, Verhille et al. 2016) for example, as well as a fair amount of grey literature regarding their distribution, spawning and catch trends (Baxter 1994, Baxter 1996). However, similar investigations have yet to be conducted for most other native minnows making it difficult to assess population trends or to predict or evaluate their response to restoration projects, altered flow regimes, climate change or other actions.

What are the key opportunities an investment in this topic will support?

While there are numerous native species that present a wide variety of opportunities for discovery, three concepts in particular align with the program goals of the IEP and the greater research community: *1) preventing further loss of biodiversity; 2) improving understanding of native community interactions to better inform management decisions and restoration efforts, and; 3) addressing known knowledge gaps.*

The historic ranges of many native species, including some cyprinids and lampreys, stretched across a variety of habitats or biogeographic regions (Moyle 2002). Researchers have recently begun applying newer genetic approaches to describing species. As a result, several genera are in the process of being reclassified as multiple species. For example, recent investigations into California Roach (*Hesperoleucus symmetricus*) and isolated populations of Sculpins (*Cottus spp.*) suggest that these groups are made up of multiple cryptic species within their respective genera (Baumsteiger et al. 2012, Baumsteiger et al. 2017). Other native species have been grouped into finer classifications, such as evolutionarily significant units (ESU) or distinct population segments (DPS), for management or conservation purposes (e.g., Splittail, Green Sturgeon Southern DPS, Central Valley Steelhead). Identifying smaller units within species for targeted studies or management and conservation efforts may prove useful for species whose range extends beyond the geography typically examined by IEP (e.g., lamprey). These distinctions have consequences for conservation and recovery of species and communities that share habitat requirements within the San Francisco Estuary. Management of water use and delivery will need to confront these nuances within the aquatic resource community, and what these distinctions will mean for biodiversity and its conservation.

The interactions between less-studied native species and species of interest for management or conservation purposes is another category that warrants further investigation. For example, larval life stages of Pacific Herring (*Clupea pallasii*) and Prickly Sculpin (*Cottus asper*) occur in adult Delta Smelt diets (Hammock et al. 2019) and have overlapping diets with larval Longfin Smelt (Burris, unpublished). However, the relative importance of these two species as prey or competitors for Delta and Longfin Smelt have not been evaluated in detail. Understanding how these and other species interact and impact each other will inform restoration planning by identifying benefits or costs of restoration projects. Monitoring that informs these complex community interactions will help the Estuary community implement a more integrated conservation and recovery strategy. Taking an ecosystem approach rather than focusing on single species may improve our restoration success (Ostfeld 1997).

A holistic and integrated approach to species conservation and recovery requires identifying and addressing knowledge gaps at multiple levels (i.e., physiological, species, ecosystem/watershed, etc.). Some of these gaps in life history, systematics, and abundance, have already been identified as is the case with Hitch (*Lavinia exicauda*) and the aforementioned Pacific Lamprey (Moyle 2002, Goodman 2012). Knowledge gaps regarding more complex interactions at the community or ecosystem level have yet to be commonly described. The IEP supports collaborative efforts where researchers can use existing studies or datasets to investigate native species other than Smelts, Salmonids, and Sturgeon. More in-depth analysis regarding community interactions and targeted studies examining less-studied species will benefit from dedicated funding and specifically directed synthesis efforts.

References:

Baerwald, M., et al. (2007). "Genetic analysis reveals two distinct Sacramento splittail (*Pogonichthys macrolepidotus*) populations." Conservation Genetics 8(1): 159-167.

Baumsteiger, J., et al. (2012). "Life history and biogeographic diversification of an endemic western North American freshwater fish clade using a comparative species tree approach." Molecular Phylogenetics and Evolution 65(3): 940-952.

Baumsteiger, J., et al. (2017). "Genomics clarifies taxonomic boundaries in a difficult species complex." PLOS ONE 12(12): e0189417.

Baxter, R. D. (1994). "Preliminary results of a summer gill-net survey for Sacramento splittial." Interagency Ecological Program Newsletter 7(5): 2.

Baxter, R. D. (1996). "1995 Splittial Spawning Investigations." Interagency Ecological Program Newsletter 9(4): 3.

Burris, Z. (Unpublished) Dietary overlap in larval Longfin Smelt, Prickly Sculpin and Pacific Herring in the San Francisco Estuary.

Feyrer, F., et al. (2015). "Metapopulation structure of a semi-anadromous fish in a dynamic environment." Canadian Journal of Fisheries and Aquatic Sciences 72(5): 709-721.

Goodman, D. H. a. S. B. R. (2012). Pacific Lamprey (Entosphenus tridentatus) Assessment and Template for Conservation Measures in California. Arcata, CA, U.S. Fish and Wildlife Service: 117.

Hammock, B. G., R. Hartman, S. B. Slater, A. Hennessy, and S. J. Teh. 2019. Tidal wetlands associated with foraging success of Delta Smelt. Estuaries and Coasts 42.

Moyle, P. B. (2002). Inland Fishes of California: Revised and Expanded, University of California Press.

Ostfeld, R. S., S.T.A. Pickett, M. Shachak, and G.E. Likens (1997). Defining the Scientific Issues. The Ecological Basis of Conservation Biology. S. T. A. Pickett, R.S. Ostfeld, M. Shachak, G.E. Likens.

Verhille, C. E., et al. (2016). "Inter-population differences in salinity tolerance and osmoregulation of juvenile wild and hatchery-born Sacramento splittail." Conservation Physiology 4(1): cov063-cov063

SMELTS

Currently, Delta Smelt and Longfin Smelt are among the most influential species we monitor (along with several Central Valley salmon runs) relevant to water management and operations within the Sacramento-San Joaquin Delta. The Delta Smelt Biological Opinion and the Longfin Smelt Incidental Take Permit for the Operation of the State Water Project both contain biological triggers, which if activated, can impose limits to water exports. Concern for the population status of Delta Smelt and Longfin Smelt led to both listings (USFWS 1993, CA F&G Comm 2009). Yet, even with protections provided by listing status, both species continued to decline, reaching historical low abundance levels at the end of the recent drought and raising concern about each population's persistence without considerable human intervention (Hobbs et al. 2017). Further, the links between each species' abundance and hydrology – Delta Smelt with low salinity spring through fall habitat (Sommer and Meija 2013, IEP MAST 2015), and Longfin Smelt with winter-spring outflow (Dege and Brown 2004, Baxter et al. 2010, Merz et al. 2013) – has kept both species front and center in discussions about the effects of the California Water Fix.

The fate of the smelts is curious and difficult for a variety of reasons, not the least of which is that recovery is likely to be achieved only by addressing a variety of issues currently diminishing smelt vital rates and population size (see, for example, Merz et al. 2016, Moyle et al. 2016). Figure 4 depicts potential relationships between abundance of pelagic organism decline (POD) fish – including smelts – and environmental co-variates that illustrate just a few of the multiple factors influencing smelt recovery and management.

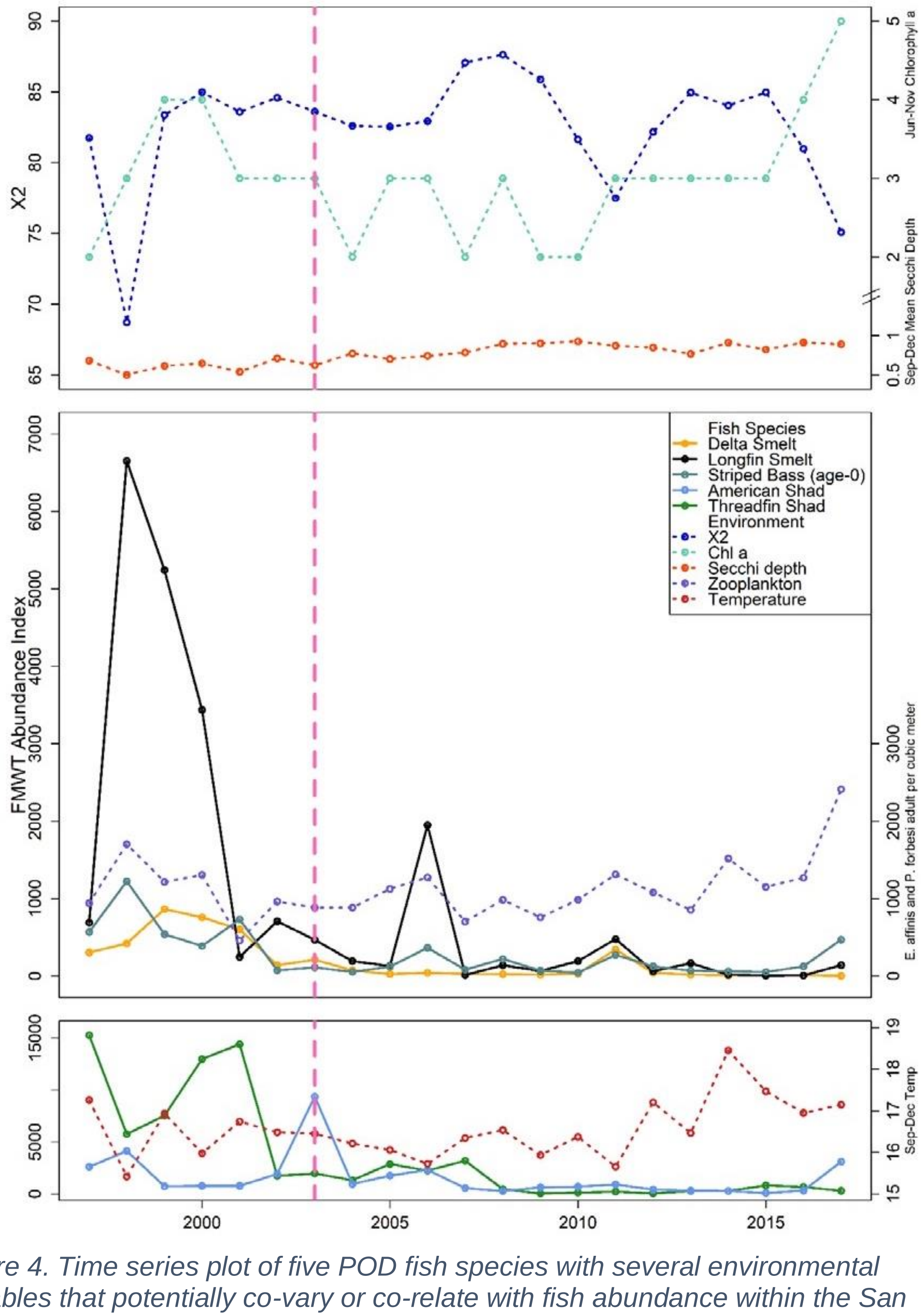

Figure 4. Time series plot of five POD fish species with several environmental variables that potentially co-vary or co-relate with fish abundance within the San Francisco Estuary. Vertical dashed line indicates approximate start of post-pelagic organism decline (Post-POD) era. These relationships are multidimensional and complex, and likely change over time.

Through the period of recent decline, several efforts have been made to improve circumstances for, and to better manage, both smelts: 1) the Smelt Working Group and the Water Operations Management Team work to reduce the risk of entrainment in south Delta water export facilities; 2) IEP agencies continue investing in research on stressors and stressor interactions (e.g., Drought Funding, Delta Science Fellows, Proposition 1 project funding) for smelts and for synthesis of this information (e.g., Delta Smelt Synthesis; Longfin Smelt Synthesis), and; 3) restoration of important shallow water habitat and research into potential benefits of this habitat to smelts (Fish Restoration Program Agreement).

What are the primary issues for direct management concern?

Improvements to existing monitoring surveys.

1. Surveys designed to assess entrainment of early life stages of Longfin Smelt (Smelt Larva Survey, or SLS), and surveys used for young Delta Smelt distribution (20-mm Survey) could be expanded in time (i.e., mid-December through early April for SLS, and February through mid-July for 20-mm) and geography (expand both to include San Pablo Bay). Such expansions will encompass most larval habitat and allow calculation of abundance indices for newly hatched larvae and small juveniles – these, in turn, can be used to investigate recruitment dynamics under varying outflow conditions within or across years.
2. For Delta Smelt, limited detections during species-specific surveys (i.e., Enhanced Delta Smelt Monitoring, USFWS) underscores the need for new approaches to improve effectiveness. The “SmeltCam” has been used with some success (Feyrer et al. 2013, 2017). Environmental DNA (eDNA) represents another non-lethal possibility for monitoring rare and endangered species; hydro-acoustics and multi-scan sonar are others with potential utility. Among these methods, only eDNA is species-specific without secondary sampling. eDNA appeared to be effectively implemented during early 2018 to detect Delta Smelt at risk of entrainment in the south Delta, but more work is needed to understand the ramifications of positive and negative detections.
3. Expanding monitoring of zooplankton during fish trawls – available food is quickly becoming an important management-related habitat attribute of interest. Performance of within-year life stage cohorts has been shown to depend on available food resources – for many native species, including smelts, these food resources contain zooplankton species with complex lifecycle dynamics of their own that respond to management inputs.

1. Both smelts are in severe decline and Delta Smelt appears less resilient to declines recently.
2. We cannot manage what we cannot detect. Improved, non-lethal monitoring methods are needed to supplement traditional and recently enhanced (EDSM) fish monitoring.
3. Recognition of key habitats will likely involve targeted field sampling and various types of modeling; these will require additional investment.

Flow modifications and benefits. For both smelt species, flow-related effects have been recognized for decades, but their underlying mechanisms are only now beginning to be demonstrated. Understanding the benefits of flow-related processes as mediated by life-stage throughout the year remain as important as ever when trying to maintain and recover smelt. Both targeted field studies associated with Smelt Resilience Strategy actions (e.g., Directed Outflow Project; Summer/Fall re-operation of Suisun Marsh Salinity Control Gates), and fish behavioral/hydrodynamic simulation modeling efforts are necessary to understand flow-related changes (and perhaps benefits) that will occur with increased spring, summer, or fall flows, and/or with the proposed change in the point of diversion for Delta water exports as outlined in California Water Fix.

Habitat identification and benefit assessments.

1. For both species, specific spawning habitats and locations remain unknown. Such habitats cannot be assessed, protected, or improved without knowledge of their whereabouts or conditions and processes leading to their creation and maintenance. Investigation should focus on locating and characterizing spawning habitats. This may involve increased sampling effort in certain areas or at certain times of year.
2. For both species, buoyancy and behavior of newly hatched larvae, hatch location, and hydrodynamics at the time affect dispersal and fate of the larvae. 3-dimensional modeling is needed to explore mechanisms behind how early stage larvae are retained in the Estuary and where. Such studies might also determine if larval retention and food retention locations are the same, potentially creating important recruitment “hot spots” that should be recognized, protected, or enhanced.
3. Restoration of shallow water habitat is mandated for both smelts, but the benefits of such habitats are only now starting to be documented in the San Francisco Estuary. Restoration is costly, and benefits, though assumed, need to be verified. The Fish Restoration Program was established for monitoring and

assessing the benefits of shallow water habitat and restoration. This work should be supported and expanded if necessary.

Captive Culture. The successful culture of Delta Smelt supports research improving our understanding of Smelt life history, biology and ecology, and can improve management. A similar effort is needed for Longfin Smelt. Initial funding to improve Longfin Smelt captive culture methods has been provided by small grants from the USFWS and more substantial funding from Proposition 1.

What are the key opportunities an investment in this topic will support?

Monitoring. Funding, personnel, and a discussion forum will identify, field test, and evaluate innovative fish monitoring methods for their ability to answer management questions. Expanding current fish monitoring surveys (SLS, 20-mm) to cover Longfin Smelt larval and early juvenile distributions will involve substantial additional investment of personnel (at least one biological and two lab personnel), field time (two added field days per survey) and boat operations costs. The benefits could include improved understanding of the early life ecology of Longfin Smelt and accurate abundance indices for larvae and small juveniles. These information streams will allow evaluation of factors affecting early survival, a critical piece to understanding the species' outflow/abundance relationship.

Habitat recognition and assessment. For both Smelts, managers have tacitly bet that habitat restoration will be sufficient to stop current smelt abundance declines and possibly start recovery. Current (e.g., Fish Restoration Program) and future investments in researching the benefits of restoring shallow water habitat and any other important limited habitat (e.g., spawning habitat?) will be critical to effective species management. Managers need to know if restoration provides incrementally tangible benefits and if restored habitats will provide sufficient cumulative benefit to at least stem existing population declines. There is value in quantifying benefits as early as possible in the restoration timeframe, both to provide support for continued investment and to support restoration as an appropriate management strategy.

Captive Culture. Initial funding has been identified to develop Longfin Smelt culture methods; hopefully this investment will be sufficient to complete implementation. Similar to Delta Smelt, there are both research (i.e., improved biological and ecological understanding of the species) and management (i.e., genetic conservation) rationales to support development of Longfin Smelt culture methods and to consider long-term funding for their on-going culture. The IEP can help support these efforts through coordinated field collection, field performance assessments, and by including IEP Principal Investigators in proposal development, program implementation, and evaluation.

References:

Baxter, R., and 12 others. 2010. Interagency Ecological Program 2010 Pelagic Organism Decline Work Plan and Synthesis of Results. IEP Report. 259 pp.

California Fish and Game Commission. 2009. Notice of Findings Longfin Smelt (*Spirinchus thaleichthys*), Woodland, California.

Dege, M., and Brown, L.R. 2004. Effect of outflow on spring and summertime distribution and abundance of larval and juvenile fishes in the upper San Francisco Estuary. In Feyrer, Brown, Brown, and Orsi (eds.): Early life history of fishes in the San Francisco Estuary and watershed, American Fisheries Society, Symposium 39. Pages 49-65.

Feyrer, F., D. Portz, D. Odum, K. B. Newman, T. Sommer, D. Contreras, R. Baxter, S. B. Slater, D. Sereno, and E. Van Nieuwenhuyse. 2013. SmeltCam: underwater video codend for trawled nets with an application to the distribution of the imperiled Delta Smelt. Plos ONE 8(7):e67829. doi:10.1371/journal.pone.0067829.

Feyrer, F., S. B. Slater, D. E. Portz, D. Odom, T. Morgan-King, and L. R. Brown. 2017. Pelagic nekton abundance and distribution in the northern Sacramento-San Joaquin Delta, California. Transactions American Fisheries Society 146(1):128-135.

Hobbs, J., P. B. Moyle, N. Fangue, and R. E. Connon. 2017. Is extinction inevitable for Delta Smelt and Longfin Smelt? An opinion and recommendations for recovery. San Francisco Estuary and Watershed Science 15(2): 21 pages.

IEP MAST [Interagency Ecological Program Management Analysis and Synthesis Team]. 2015. An updated conceptual model of Delta Smelt biology: our evolving understanding of an estuarine fish. Technical Report 90. Interagency Ecological Report. 224 pp.

Merz, J.E., Bergman, P.S., Melgo, J.F., and Hamilton, S. 2013. Longfin smelt: spatial dynamics and ontogeny in the San Francisco Estuary, California. California Fish and Game, 99(3)122-148.

Merz, J.E., Brgman, P.S., Simonis, J.L., Delaney, D., Pierson, J., and Anders, P. 2016. Long-term seasonal trends in the prey community of Delta Smelt (Hypomesus transpacificus) within the Sacramento-San Joaquin Delta, California. Estuaries and Coasts, 39(5):1526-1536. https://link.springer.com/article/10.1007/s12237-016-0097-x

Moyle, P.B., Brown, L.R., Durand, J.R., and Hobbs, J.A. 2016. Delta Smelt: Life history and decline of a once-abundant species in the San Francisco Estuary. San Francisco Estuary and Watershed Science, (14)2): http://escholarship.org/ojs/index.php/jmie_sfews/editor/viewMetadata/doi:%20http:/dx.doi.org/10.154 47/sfews.2016v14iss2art6

Sommer, T., and Meija, F. 2013. A place to call home: a synthesis of Delta Smelt habitat in the upper San Francisco Estuary. San Francisco Estuary and Watershed Science, 11(2): https://escholarship.org/uc/item/32c8t244

United States Fish and Wildlife Service (USFWS). 1993. Final Rule: Endangered and threatened wildlife and plants; determination of threatened status for the Delta smelt. Federal Register 58:12854-12864.

ASSESSING EFFECTS OF FLOW ALTERATION ON BAY-DELTA AQUATIC RESOURCES

Why this a major topic for the IEP Science Strategy from 2020-2024?

The specific mechanisms accounting for the Delta Outflow/X2 relationship with abundance of estuarine organisms have not been consistently demonstrated through time, though correlation exists. We have therefore defaulted to management of complex organism-habitat processes by making small changes to outflow in an otherwise overwhelmingly complex physiochemical environment. The assumption is that Delta Outflow/X2 drives habitat area or quality in some way that affects the success of species across life stages and years. Scientific studies have improved knowledge of Delta Smelt biology in the San Francisco Estuary (SFE) and have shown how habitat quality might or can (or has) affect(ed) Delta Smelt. Changes to flow can alter the quality, quantity, and location of aquatic habitat, turbidity, water temperature, location of the low-salinity zone, concentrations and sources of contaminants, and abundance, quality, and transport of food resources (Moyle et al. 2016, Brown et al. 2016).

Delta Outflow is an important regulatory focus. Riverine flows in the Delta have become a critical Estuary management tool and Delta outflow is highly regulated during certain times of the year. Several studies highlight the importance of outflow and the position of the low salinity zone (LSZ) during certain times of the year (PPIC 2017, Delta Science Program, 2014, Kimmerer et al. 2013). The position of the LSZ is indexed by ‘X2’, which is the distance in kilometers (km) from the Golden Gate Bridge to the tidally averaged 2-psu near-bottom isohaline (Jassby 1995, EPA 2017). When freshwater inputs are high the area of the LSZ is larger because it is pushed downstream of the confluence of the Sacramento and San Joaquin Rivers where it can expand into Suisun Bay and other areas within Suisun Marsh (X2 < 75 km). When freshwater inputs are low the LSZ is more upstream where wetted areas are constrained within leveed river channels and surface area is smaller.

An association between the position of the low salinity zone (X2) and the abundance of organisms in the San Francisco Estuary (SFE) has been described for the spring period (Jassby et al. 1995). The understanding of this relationship has changed and become more nuanced over time, including the effects of changes in food webs associated with species invasions (Kimmerer 2002, 2004). The location of X2 during the fall has also been suggested as being an important factor for the habitat quality for Delta Smelt ahead of the spawning season (Feyrer et al. 2010, Brown et al. 2014, IEP-MAST 2015). These associations are not simple, not consistent, and may not be responsive to management manipulation in ways envisioned when viewed from a regulatory context. We contend that our understanding of flow-habitat-abundance relationships is changing and evolving, but is still amenable to monitoring science and management input (see, for example: Brown et al. 2014, IEP-MAST 2015).

Delta Smelt (*Hypomesus transpacificus*) are currently at historically low abundance, and the mechanisms driving the decline are complex and interactive (IEP-MAST 2015, Moyle et al. 2016). Given the hypothesized importance of Delta outflow and the associated position of the low-salinity zone to the life history of Delta Smelt, this issue remains one of the central questions for management of the Bay-Delta system. The Delta Smelt Biological Opinion contains requirements for a fall flow action (Fall X2 action) that is adaptively managed to the benefit of Delta Smelt habitat (USFWS 2008). Since the adoption of the Biological Opinion, such conditions have only been seen in the fall of 2011 and 2017. Because of the great interest in understanding the response of the Delta Smelt population and its habitat to the Fall X2 action, several studies and synthesis efforts have been conducted to understand these responses, including the 2011 fall low-salinity habitat investigation (Brown et al, 2014), the current Directed Outflow Project (DOP) and the associated 2017-18 Flow Alteration Team Management Analysis and Synthesis (FLoAT MAST) project. While these studies have improved our understanding of how flows link to food production, fish survival, and changes in organism abundance, they also continue to point out that the problems and causes of population declines are multivariate and result from multiple interactions and sources of influence in the environment. Furthermore, these changes are not stationary, but reform and recombine in different ways in successive years.

The Delta Smelt Resiliency Strategy is a key Natural Resources Agency implementation program. The Delta Smelt Resiliency Strategy (DSRS -- CNRA 2016) contains additional flow alteration actions that have been, or are planned to be, implemented. The North Delta Food Web Action, developed after studying the response of phytoplankton in the Delta to agricultural drainage flows coming out of the Yolo Bypass in 2011 and 2012, was implemented in the summer of 2016 with positive lower trophic level responses (Frantzich et al. 2018).

Suisun Marsh Salinity Control Structure Experiment. Adjustments to the operation of the Suisun Marsh Salinity Control Structure aims to tidally pump freshwater into Suisun Marsh during the summer to reduce salinity and expand habitat suitable for Delta Smelt in the summer/fall. This pilot action and associated monitoring science are planned for 2018 and 2019 (reports in preparation). The DSRS also envisions future outflow augmentation actions that would complement the Fall X2 RPA by testing the impact of altering outflow more generally in the Delta during spring and/or summer.

Using barriers to alter salinity field behavior in the Delta. Barriers are installed annually in the south Delta to change the flow dynamics in such a way as to maintain fresher water for agricultural use and export. During the severe drought in 2015 an additional emergency drought barrier was installed to prevent salinity intrusion into State and Federal Water Project export facilities – with mixed results (ICF 2016). In the future management of flows will continue to be an important tool for resource management for water quality and ecosystem benefits. The California State Water Resources Control Board's proposed changes to the Bay-Delta Plan includes updates to tributary inflow, interior Delta flow, and Delta outflow requirements (see: SWRCB 2018).

Flow Alteration Actions requiring monitoring and evaluation:

1) Delta Outflow Augmentations Actions
    a) Fall X2 Action (USFWS Biological Opinion)
    b) Spring Outflow Standards (D-1641)
2) Estuary Alteration Actions
    a) North Delta Food Web Action (DSRS)
    b) Suisun Marsh Salinity Control Gate Summer Operation (DSRS)
    c) Drought Barriers (D-1641)

What are the primary issues for direct management concern?

Understanding technical merits of policy and management alternatives. Extensive water management infrastructure in California creates a conundrum whereby flows to and within the Delta remain one of the only controllable factors affecting the Delta ecosystem. As such, flow alteration is often highlighted as a management tool. It is important that IEP continue to inform management-related policy making in the Delta, and although the regional atmospheric and climatic context may yet prove more determining, flow management will continue to play a role in aquatic resource performance. Altering flows can realistically take two forms, either adding additional water to the system (e.g., outflow augmentation) or by routing water in different ways to change local conditions (e.g., Suisun Marsh Salinity Control Gate reoperation). Due to the presence of large upstream reservoirs, in-Delta water control structures, and the water export facilities in the south Delta, flows in the Delta can be altered in magnitude, routing, and in some cases direction, very rapidly and in a variety of ways. These changes can provide a quick and adaptive response that many other approaches to resource conservation (e.g., habitat restoration) cannot match.

However, flow alteration necessarily requires the utilization of water stored or conveyed within the system, in-turn posing potential conflicts between interests in Delta water management. While some options for flow alteration exist that have minimal water supply impacts, understanding and balancing the multitude of human interests when using flow alteration as a tool for ecosystem benefits is, and will continue to be, an issue of primary concern when deciding whether and how to augment or alter flows in the Delta. And no matter the magnitude of the augmentation or alteration, the larger Estuary ecosystem will absorb and respond to a management action in ways that are complex, hard to predict, and potentially in opposition to our desired outcome.

Quantifying and qualifying differences between choices. On one hand, flow alteration actions are predictable, have a well-defined temporal extent, and a known water volume, making assessments of their effect potentially easier to detect and quantify relative to other management actions. Experiments evaluating the effects of additional flow in the Delta benefit from observing changes in the system before, during, and after the period of flow alteration. These studies also capitalize on the extensive monitoring network already in place in the Delta and can likely proceed with relatively minor supplemental sampling. On the other hand, one important limiting factor when assessing flow alteration has been the lack of a full suite of measurements from appropriate alternate flow conditions, at least to this point in our outflow management experience. Studies examining the effectiveness of the fall X2 RPA thus far have sampled only in years where the fall X2 RPA is in effect, so there are fewer relevant inter-annual datasets to compare when evaluating the effect of outflow differences. Studies of flow alteration would greatly benefit from having the resources and support necessary to examine their respective metrics not only in association with flow alteration actions but also during years where there is no flow alteration. This additional data would provide crucial context for interpreting ecosystem responses in years where there is flow alteration.

What are the key opportunities an investment in this topic will support?

Understanding the relationship between flow, habitat, and endangered species performance. Due to our expanding knowledge of the importance of freshwater flow to the ecological functions of the SFE, and the relative ease, from a technical and operational perspective, with which flow alteration can occur, flow alteration actions are likely to play an increasing role in how resource managers seek to address precipitous declines in listed species abundance. Flow alteration will be critical in bridging the gap between the immediate need for improved habitat for these species and the long-term, less-flow related habitat solutions like increasing the amount of restored tidal wetland habitat or food supplies in the Delta.

Specific, directed, interagency scientific discourse and exchange. IEP's Flow Alteration Project Work Team (FLOAT PWT) was created in early 2017 to provide an open, technical forum for discussing and reviewing studies related to the evaluation of flow alteration and its effects. The primary nexus for the creation of the FLOAT PWT was the 2017 Fall X2 RPA, with the goal of providing technical review of the Dedicated Outflow Project to evaluate the effectiveness of the 2017 Fall X2 action. To aid in that effort, the FLOAT Management Analysis and Synthesis Team (MAST) was created to synthesize data from Fall 2017 and characterize the action it in the context of previous low-flow or high-flow years, similar to the FLASH effort in 2011 (Brown et al, 2014). Sustained support of these efforts over multi-year timescales is important to enable evaluation of additional future flow actions.

Accumulation of experience understanding and analyzing natural flow experiments. Smaller scale flow related projects provide excellent opportunities for investment as well. The North Delta Food Web Action and the Suisun Marsh Salinity Control Structure Reoperation projects both require support and resources to be able to implement their respective flow actions, conduct the necessary monitoring and modelling, and synthesize the results for evaluation and improvement. These particular actions are attractive because they have low or zero water cost associated with them, instead altering flow by using existing water infrastructure to influence flow direction. If these actions have their desired outcomes of increasing food supply and suitable habitat for Delta Smelt during an important growth period, these actions expand the current toolset for enhancing habitat. To be properly evaluated and adaptively managed, these types of actions need to be supported, monitored, and evaluated over long enough timeframes and water year types, regardless of whether flow any actions are taken, to provide critical context and comparisons to determine the effects of any future flow alteration.

Opportunities for investment:

1) Support flow related synthesis efforts such as FLOAT MAST
2) Support continued DOP efforts across many different water year types
3) Studies evaluating the North Delta Food Web Action
4) Studies evaluating the Suisun Marsh Salinity Control Gate Reoperation

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References:

Bever, A. J., M. L. MacWilliams, B. Herbold, L. R. Brown, and F. V. Feyrer. 2016. Linking hydrodynamic complexity to Delta Smelt (Hypomesus transpacificus) distribution in the San Francisco Estuary, USA. San Francisco Estuary and Watershed Science 14.

Brown, L. R., R. Baxter, G. Castillo, J. L. Conrad, S. Culberson, G. Erickson, F. Feyrer, S. Fong, K. Gehrts,

L. Grimaldo, B. Herbold, J. Kirsch, A. Mueller-Solger, S. B. Slater, T. Sommer, K. Souza, and E. Van Nieuwenhuyse. 2014. Synthesis of studies in the fall low-salinity zone of the San Francisco Estuary, September-December 2011. U.S. Geological Survey Scientific Investigations Report 2014-5041.

California Natural Resources Agency. 2016. Delta Smelt Resiliency Strategy. http://resources.ca.gov/docs/Delta-Smelt-Resiliency-Strategy-FINAL070816.pdf

Delta Science Program. 2014. Workshop on Delta Outflows and Related Stressors: Panel Summary Report. Accessed 2/4/2019 at: http://deltacouncil.ca.gov/sites/default/files/documents/files/DeltaOutflows-Report-Final-2014-05-05.pdf

Environmental Protection Agency. 2017. Advancement of salinity and flow monitoring in the San Francisco Bay Delta. Final Report contract number EP099BOA001. Accessed 2/4/2019 at: https://www.epa.gov/sites/production/files/2017-02/documents/epa_bay_action_plan_salinity_and_flow_monitoring_020117.pdf

Feyrer, F., K. Newman, M. Nobriga, and T. Sommer. 2010. Modeling the effects of future outflow on the abiotic habitat of an imperiled estuarine fish. Estuaries and Coasts 34:120-128.

Frantzich, J., B. Schreier, and T. Sommer. 2018. Physical and Biological Responses to Flow in a Tidal Slough Complex. San Francisco Estuary and Watershed Science, 16(1): https://doi.org/10.15447/sfews.2018v16iss1/art3

ICF. 2016. Evaluation of Salinity Patterns and Effects of Tidal Flows and Temporary Barriers in South Delta Channels. Report prepared for the California Department of Water Resources. 191 pp.

IEP MAST. 2015. An updated conceptual model of delta smelt biology: our evolving understanding of an estuarine fish. Interagency Ecological Program for the San Francisco Estuary. https://www.water.ca.gov/LegacyFiles/iep/docs/Delta_Smelt_MAST_Synthesis_Report_January%2020 15.pdf

Jassby, A. D., W. J. Kimmerer, S. G. Monismith, C. Armor, J. E. Cloern, T. M. Powell, J. R. Schubel, and T. J. Vendlinski. 1995. Isohaline position as a habitat indicator for estuarine populations. Ecological Applications 5:272-289.

Kimmerer, W. J. 2002. Effects of freshwater flow on abundance of estuarine organisms: physical effects or trophic linkages? Marine Ecology Progress Series 243:39-55.

Kimmerer, W. J. 2004. Open water processes of the San Francisco Estuary: from physical forcing to biological responses. San Francisco Estuary and Watershed Science 2.

Kimmerer, W.J., MacWilliams, M.L., and Gross, E.S. 2013. Variation of Fish Habitat and Extent of LowSalinity Zone with Freshwater Flow in the San Francisco Estuary. San Francisco Estuary and Watershed Science, 11(4): https://doi.org/10.15447/sfews.2013v11iss4art1

Moyle, P. B., L. R. Brown, J. R. Durand, and J. A. Hobbs. 2016. Delta Smelt: life history and decline of a once abundant species in the San Francisco Estuary. San Francisco Estuary and Watershed Science 14.

Public Policy Institute of California. 2017. A New Approach to Accounting for Environmental Water: insights from the Sacramento-San Joaquin Delta. Accessed 2/4/2019 at: https://www.ppic.org/wpcontent/uploads/r_1117ggr.pdf

U.S. Fish and Wildlife Service, 2008, Formal Endangered Species Act consultation on the proposed coordinated operations of the Central Valley Project and State Water Project: Sacramento, Calif., U.S. Fish and Wildlife Service, 410 p., http://www.fws.gov/sfbaydelta/documents/swp-cvp_ops_bo_1215_final_ocr.pdf

BAY-DELTA FOOD WEBS AND HABITATS FOR SPECIES OF CONCERN

Why is this a major topic for the IEP Science Strategy from 2020-2024?

The large shift in the abundance, biomass and species composition that occurred at multiple trophic levels within the estuarine food web after about 2000, known as the Pelagic Organism Decline, has persisted, and may lead to the extinction of native estuarine fish and fish species of concern (Sommer et al. 2007). Decreased production at the base of the food web and habitat loss are considered to be potential drivers of the fishery decline, because they control fish recruitment through impacts on larval and juvenile fish health and survival.

Shifts in species composition, size structure, periodicity and abundance in zooplankton, amphipods and mysids, which are important invertebrate food for larval and juvenile fish, coincided with the long-term decline in fish abundance, and are thought to be key direct and indirect factors that contributed to the fishery decline (Winder and Jassby 2011, Kimmerer 2004). Because zooplankton abundance is dependent on other organisms in the lower aquatic food web, the structure and function of the entire lower food web is also important for fish production. Concern over long-term changes in the biomass and species composition of phytoplankton, the primary food of invertebrates, is high (Glibert et al. 2010, Jassby 2008, Lehman et al. 2004). Importantly, the quality of phytoplankton food has declined with the increase of toxic cyanobacteria (bluegreen algae) blooms since 1999, coincident with the Pelagic Organism Decline (Lehman et al. 2017).

Decreased production at the base of the food web controls fish recruitment via impacts on larval juvenile fish health and survival.

Changes in the food availability in the lower food web have been attributed to a number of physical or chemical factors, including removal of phytoplankton by clam grazing (Lucas et al. 2016), ammonium discharged from wastewater treatment plants (Parker et al. 2012), allelopathic responses to toxic algae (Lehman et al. 2017), nutrient ratios (Glibert et al. 2010), water temperature (Lehman 2000, 2004), streamflow (Lehman 1992, Lehman 2004), and light (Jassby 2008). Our ability to determine the impact of environmental conditions on the lower food web is hampered by environmental complexity caused by the simultaneous interaction of multiple environmental conditions. In addition, baseline environmental conditions are changing due to increases in water temperature, increased biomass of aquatic vegetation, long-term sediment reduction, and increased frequency and intensity of flood and drought cycles.

What are the primary issues for direct management concern?

Food web: How can we increase the abundance of large copepods and mysids in the winter, spring, summer and/or fall months at locations relevant to larval and juvenile fish growth and survival? How can the quality and quantity of primary producers (algae, cyanobacteria and bacteria) be managed to benefit the production of large zooplankton and mysids? How do changes in the species or biomass of lower food web organisms or the timing of their development affect the biomass, abundance or species composition throughout the food web?

Primary issues of management concern:

1) How to enhance the quality and quantity of primary producers needed to support zooplankton growth?
2) How to increase the abundance of large copepods and mysids at times and locations relevant to larval and juvenile fish growth and survival?
3) How to manage water quality and streamflow to support environmental conditions needed by food web organisms?

Habitat: What is the contribution of different habitat types (open water, floodplain, tidal marsh, benthic, floating and submerged aquatic vegetation, etc.) to food web production (e.g., phytoplankton, invertebrates, mysids and zooplankton) and water quality (e.g., suspended sediments, salt, water temperature, and nutrients) in each region of the estuary? How can we use hydrodynamics (State and Federal Water Project operations) to manage water quality conditions (e.g., nutrient concentration, salinity, suspended sediment, pesticides, wastewater contaminants, cyanotoxins) within and between habitats (e.g., open channel, wetland, near-shore and tidal marsh) to enhance lower food web production? How can we manage water quality and hydrodynamics to minimize adverse impacts of biological (e.g., clams, aquatic vegetation, cyanobacteria blooms, and exotic species) and water quality factors (e.g., water temperature, turbidity, and nutrients) on food web production?

What are the key opportunities an investment in this topic will support?

> Sustainable food web structure and functions allow resiliency of Delta Fish populations

Identifying the links between food web structure and function and habitat are important pieces of information needed to develop management strategies that achieve ecological resiliency of the Delta fishery and water quality specified in legal agreements including Biological Opinions, the State Water Resources Control Board Basin Control Plan, NEPA/CEQA documents, and SWRCB decision 1641. This information will also provide information needed for wetland restoration and rehabilitation programs associated with California EcoRestore.

Effort spent understanding the food web and habitat impacts on fishery production in the Delta will also allow us to improve the state of knowledge needed to support strategic planning, enhance communication among on-going research and monitoring efforts, and allow preparation for and utilization of unexpected events, like floods or toxic spills.

What are the specific tools we can use to achieve these goals?

- Increase spatial and temporal information for analysis by enhancing continuous and discrete monitoring networks in critical habitats
- Use high speed mapping to gain information at high frequency spatial scales
- Increase collaboration and data sharing among agencies
- Develop a suite of models to evaluate the impact of flow on water quality and ecosystem production
- Use synthesis of data in historical databases to gain insight into mechanisms, patterns and data needs
- Conduct directed research to address data gaps and test hypotheses
- Conduct adaptive management studies to develop long-term management resiliency strategies

References:

Glibert, P. M. 2010. Long-term Changes in Nutrient Loading and Stoichiometry and their Relationships with Changes in the Food Web and Dominant Pelagic Fish Species in the San Francisco Estuary, California. Reviews in Fisheries Science 18:211-232.

Jassby A D. 2008. Phytoplankton in the Upper San Francisco Estuary, Recent biomass trends, their causes and their trophic significance. San Francisco Estuary and Watershed Science 6(1), Article 2.

Kimmerer, W., 2004. Open water processes of the San Francisco Estuary, From physical forcing to biological responses. San Francisco Estuary and Watershed Science 2, issue 1, article 1.

Lehman, P. W. 2000. The influence of climate on phytoplankton community carbon in San Francisco Bay Estuary. Limnology and Oceanography 45:580-590.

Lehman, P. W. 2004. The influence of climate on mechanisms that affect lower food web production in estuaries. Estuaries 27:312-325.

Lehman, P. W. 2000. Phytoplankton, carbon, cell diameter and species composition in the low salinity zone of northern San Francisco Bay Estuary. Estuaries 23:216-230.

Lehman, P. W. 1992. Environmental factors associated with long-term changes in chlorophyll *a* concentrations in the Sacramento-San Joaquin Delta and Suisun Bay, California. Estuaries 15:335-348.

Lehman, P. W., Kurobe, T., Lesmeister, S., Baxa, D, Tung, A.., Teh, S. J. 2017. Impacts of the 2014 severe drought on the Microcystis bloom in San Francisco Estuary. Harmful Algae 63:94-108.

Lucas, L. V., J. E. Cloern, J. K. Thompson, M. T. Stacey and J. R. Koseff. 2016. Bivalve grazing can shape phytoplankton communities. Frontiers in Marine Science (3), Article14.

Parker, A. E., R. C. Dugdale and F. P. Wilkerson. 2012. Elevated ammonium concentrations from wastewater discharge depress primary productivity in the Sacramento River and the Northern San Francisco Estuary. Marine Pollution 64:574-586.

Sommer, T. R., Armor, C., Baxter, R., Breuer, R., Brown., L,, Chotkowski, M., Culberson S., Feyrer, F., Gingras, M., Herbold, B., Kimmerer, W., Mueller-solger, A., Nobriga, M., Souza, K . 2007. The collapse of pelagic fishes in the upper San Francisco Estuary. Fisheries 32: 270-277.

Winder, M. and A. Jassby. 2011. Shifts in Zooplankton Community Structure: Implications for Food Web Processes in the Upper San Francisco Estuary. Estuaries and Coasts 34:675-690

IMPORTANT UNMET SCIENCE NEEDS

In this final section of our updated Science Strategy for 2020 – 2024 we address resource allocation choices facing the Interagency Ecological Program in an era of increasingly tight budgets and intensifying competition for community science. Two subjects of keen interest to IEP managers and scientists (and deemed important by the core Science Strategy writing team, the IEP Coordinators Chair, and the IEP Lead Scientist) are struggling to receive adequate Agency support: a) contaminants monitoring and research, and; b) aquatic vegetation monitoring and research. We treat these topics briefly here, and welcome efforts that will increase the IEP's ability to participate in, guide, and evaluate issues relevant to contaminants and aquatic vegetation control over the next 5 years.

The reader is hereby reminded that IEP monitoring programs have emerged and evolved over time as the result of changing concerns on the part of Water Project operators and according to environmental compliance requirements associated with permission to operate the State and Federal Water Projects. For the IEP this has meant focusing on biological responses of listed species to export-related manipulation of the aquatic environment. Water quality monitoring investments have been associated with salinity management and temperature regulation throughout the watershed, and, to a certain degree, nutrient management from identified permit holders near to and within the Bay-Delta.

We also note that mandates to monitor and research myriad aspects of contaminant-related problems within the Estuary, including direct toxicity to listed ESA-species and other species of concern (see Connon et al. 2011, for example), have not been linked to IEP programmatic funding or explicit mandates for limits on exposure, or loading, or body burden for compounds of particular concern. While we agree that an Estuary monitoring program should include monitoring for pesticides and contaminants there has been no nexus for a mandate or funding within the Delta that allows clear articulation of annual plan elements the IEP might implement as part of its compliance science or regulatory requirements.

In a parallel way with contaminants, invasive aquatic vegetation (and its control) likely has pervasive direct and indirect effects on species and habitats of direct relevance to mandates governing IEP activities. However, the IEP is not responsible for invasive plant control. Instead, the State Parks and Recreation Division of Boating and Waterways is designated by the California legislature as the lead for control efforts. In the interest of providing timely ecological information to managers, the IEP has taken on, and included in previous Annual Work Plans, several efforts investigating aquatic vegetation. However, (like contaminants) given a lack of a clear funding source for major investment in invasive plant dynamics, and the current lack of a cohesive and consistent monitoring program, we cannot sufficiently pursue aquatic vegetation science as a key topic area for the 2020-2024 Science Strategy. The subjects of contaminants and aquatic vegetation comprise **critical unmet needs** for IEP- and Estuary-related science over the next five years.

In recognition of the critical importance of these issues to Estuary resource management and a comprehensive understanding of Estuary ecosystem function, we include herein our view of the management concerns and the science priorities for each of these topic areas. It is our hope that other leaders within the larger science enterprise of the Bay-Delta will take initiative to address these topics, and in so doing will use IEP and its scientists as resources for consultation on project direction to make strides in advancing our knowledge base in these areas.

THE DELTA'S CONTAMINANTS PROBLEM

Why should this be a major topic for the IEP Science Strategy from 2020-2024?

The Delta is a contaminated ecosystem (Healy et al. 2016). The presence of, and impacts from, contaminants are well documented (see Fong et al. 2016) and are cited in governing policies (see, for example Water Quality Control Policy for developing California's Clean Water Act Section 303(d) Listing Policy and Basin Planning for the Sacramento and San Joaquin River Basins), yet there are information gaps that necessitate research to prioritize management actions.

Several decades of research on contaminant impacts to endangered fish species show how contaminants are stressors for fish. For example, a 4-year study evaluating the health of wild Delta Smelt identified contaminants as a key factor – manifesting as hepatotoxicity, necrosis, low nutritional status, and low reproductive status (Acuna et al. 2018). Similarly, Hammock et al. (2015) found that internal lesions were more prevalent in Delta Smelt found in water bodies containing high levels of contaminants. Other investigations have traced toxicity of field water and sediment to current-use insecticides and to specific tributaries within the Cache Slough Complex (Amweg et al. 2006, Weston et al. 2010) and Suisun Marsh (Weston et al. 2015). Historic monitoring data collected within the Delta indicate that complex mixtures are the norm, and insecticide levels in major water bodies frequently exceed aquatic-life benchmarks (Orlando et al. 2014, Jabusch et al. 2018).

What are the primary issues for direct management concern?

There is a foundational need to quantify the relative impacts of contaminants on Delta fish. Fong et al. (2016) demonstrated that pyrethroid pesticide use around the Delta could be as important a factor contributing to the Pelagic Organism Decline as was the change in flow. The authors emphasized the importance of evaluating effect of multiple contaminant mixtures while considering other factors impacting Delta fishes and the quality of their habitats. The Delta Regional Monitoring Program (RMP) is evaluating the toxicity of pesticides and other contaminants on aquatic species using field sample toxicity and contaminant concentration data collected throughout California. Results from this synthesis will identify which pesticides pose the greatest risk to Delta fish via direct and indirect toxic action. However, more realistic complex ecological and risk assessment models that can account for a range of environmental factors and stressors and identify their relative impacts on Delta fish species and habitats do not yet exist.

The Delta aquatic environment is constantly changing, and our monitoring science should account for future altered conditions and additional stressors. This need is highlighted in the Delta Independent Science Board's review of chemical contaminants and nutrients (Delta ISB 2018). For example, in the next 10 years we expect to see an addition of over 8,000 acres of tidal habitat (USFWS 2008, NMFS 2009), and new water regulations may change flow regimes (SWRCB 2017). Climate change may result in more saline conditions, warming water temperatures, and may contribute to enhanced growth of invasive aquatic species. Studies evaluating the cumulative effects of temperature and contaminant stressors (for example, DeCourten et al. 2017, Russo et al. 2018) indicate this is both a global and regional concern. An important study within the Yolo Bypass assessed the effects of contaminants on copepods under varying hydrologic conditions (Orlando et al. 2018). Similarly, investigations of contaminant fate and transport, sediment fractionation and bioavailability, and degradation rates over time in will provide insight to inform the IEP Tidal Wetland Monitoring plan conceptual model for contaminants (Sherman et al. 2017). As a result this conceptual model will need periodic updates as we learn and improve from upgraded contaminants monitoring.

There has been little investment on sediment-associated contaminants. Monitoring programs within the Delta include little sediment toxicity testing or sediment chemical analyses. Studies in Delta waterways have found that sediments are contaminated with an array of pesticides at high concentrations (Amweg et al. 2006, Weston et al. 2013) and up to three orders of magnitude greater than in the overlying water column (Lesmeister and Hoffmann et al., *unpublished data*). Among the toxicity evaluations that have occurred in Delta sediments, most sediment samples are toxic to standard invertebrate test species (Amweg et al. 2006, Weston et al. 2013, Kemble et al., *unpublished*). Sediment-associated contaminants will be impacted by tidal restoration, and these restoration-associated contaminants may have impacts on the food web within tidal wetlands. Other actions to increase sediment loading (and thereby increasing turbidity) in the Delta will also need to consider potential sediment-associated contaminant impacts.

There is a need for greater focus on source control and mitigation for known contaminants. Several current-use insecticides and other contaminants (e.g., mercury, cyanotoxins), are known “bad actors” in the Delta, and the Delta RMP synthesis of monitoring data will further inform which pesticides are of greatest concern. Controlling for certain known problem contaminants may also control for many unknown ones (e.g., as with pesticides due to similar properties like K_{oc} for similar functionalities). There are surface water protection programs under several State agencies focused on research addressing the impacts of best management practices to reduce runoff of pesticides and other contaminants, including the California Department of Pesticide Regulation, the Central Valley Regional Water Quality Control Board, and the California Environmental Protection Agency. The science of wastewater treatment using constructed wetlands is also well established. How these technologies can be applied or optimized in natural waterways to control or mitigate Delta contaminants needs further evaluation. Additionally, models to help quantify the sources and beneficial impacts of contaminant reduction in our system will be crucial for determining targets of local and regional management actions.

What are the key opportunities an investment in this topic will support?

It is clear that Delta fish are suffering from contaminants in their environment from both direct and indirect effects on their health and habitat, respectively. Important to the protection of State- and Federally-listed fish species are actions to mitigate the impacts of contaminants. Key opportunities that will benefit resource management include:

1. Characterize the relative impacts of contaminants on Delta and San Francisco Estuary resident and migratory fishes
2. Prioritize actions, taking into consideration the context of changing Delta conditions (e.g., climate change, impacts/benefits/timelines of tidal wetland restoration)
3. Evaluate the effects of contaminants accumulating in Delta sediments. In particular, discover how existing contaminants jeopardize habitat restoration and species recovery through direct and indirect effects.
4. Prioritize management actions to reduce contaminant loading and mitigate potential impacts

Use quantitative models to evaluate impacts of contaminants on Delta Fish. Monitoring and targeted studies in the Delta provide data regarding environmental water toxicity and contaminant concentrations to inform models. Applying adverse outcome pathways analysis will identify mechanisms of contaminant impacts, and bioenergetic and population models will improve our understanding of impacts to species and communities. Environmental risk models are useful for quantifying the relative impacts of contaminants. For example, Landis et al. (2017) uses a Bayesian Network Relative

Risk Model to quantify the impacts of contaminants relative to other environmental stressors (like temperature) to aquatic species. Modeling exercises will help to prioritize management actions like flow, temperature, habitat restoration, contaminant control, etc. There are efforts that analyze the impacts of contaminants on ecosystems in other parts of California (e.g., Surface Water Ambient Monitoring Program: Stream Pollution Trends) and freshwater streams throughout the U.S. (e.g., USGS's National Water Quality Assessment Project), but there is no such concerted effort within the Delta.

Collect more sediment data. Contaminants are frequently concentrated in sediments, and often at concentrations several orders of magnitude greater than in the overlying water column. Sediment monitoring studies to date show Delta and California stream sediments are toxic to standard invertebrate test species (Amweg et al. 2006, Weston et al. 2013, Kemble et al., *unpublished*). Certain life stages of fish (eggs and early larvae) reside in sediments. Though eggs and larvae have protective tissues and mechanisms that reduce their levels of contaminant uptake, early life stages are especially vulnerable to toxicity via subsequent and cumulative effects on development and viability (Brander et al. 2013). Pyrethroid pesticides, which have been found to be correlated with the pelagic organism decline, or POD (Fong et al. 2016), are tightly bound to sediments. Moran et al. (2017) found sediment contaminant mixtures and bifenthrin (a pyrethroid) were significant predictors of lowered macroinvertebrate community health. Surprisingly, no study has yet evaluated the toxicity of contaminated Delta sediments to Delta Smelt (or other listed species) eggs or larvae.

Wetland restoration offers an opportunity to test hypotheses about how tidal wetlands interact with contaminants. An evaluation of contaminant loads and cycling within newly restored wetlands would fill critical information gaps, which in turn will help evaluate the overall benefits of tidal restoration to the aquatic community. It is likely that an increase in wetland habitat will reduce the bioavailability of many contaminants to aquatic species, though methylmercury may be an exception (Sherman et al. 2017).

Greater focus on reducing contaminant loads and mitigating effects. Recent studies give evidence that contaminants are a key stressor contributing to the endangerment of native Delta fish species. Our understanding of the contaminants problem is growing, and our science programs should place more emphasis on developing and implementing solutions. Identifying source control and mitigation strategies (e.g., environmental conditions that facilitate contaminant detoxification/biodegradation) is critical for sound management of Delta water quality to support aquatic species of concern.

References:

Acuna, S., Hammock, B., Hobbs, J., Slater, S., Baxter, R., Teh, S. Multiple stressor impacts from the San Francisco Estuary on the reproductive health of the threatened Delta smelt, *Hypomesus transpacificus*.

Platform Presentation, Society for Environmental Toxicology and Chemistry 39th Annual Meeting, November 8, 2018

Amweg EL, Weston DP, Jing Y, Lydy MJ. 2006. Pyrethroid Insecticides and Sediment Toxicity in Urban Creeks from California and Tennessee. Environmental Science and Technology 40: 1700-1706.

Brander SM, Connon RE, He G, Hobbs JA, Smalling KL, Teh SJ, et al. 2013. From 'omics to otoliths: responses of an estuarine fish to endocrine disrupting compounds across biological scales. PLOS One 8:e74251

Connon, R.E., Deanovic, L.A., Fritsch, E.B., D'Abronzo. L.S., and Werner, I. 2011. Subleathal responses to ammonia exposure in the endangered smelt *Hypomesus tanspacificus* (Fam. Osmeridae). Aquatic Toxicology, 105:369-377.

DeCourten, B.M. and S.M Brander. 2017. Combined effects of increased temperature and endocrine disrupting pollutants on sex determination, survival, and development across generations. Scientific Reports. 7:9310.

Delta Independent Science Board. 2018. Water Quality Science in the Sacramento-San Joaquin Delta. Chemical Contaminants and Nutrients. Sacramento, CA

Fong, S., Louie, S., Werner, I., Davis, J., & Connon, R. E. 2016. Contaminant Effects on California Bay– Delta Species and Human Health. *San Francisco Estuary and Watershed Science*, 14(4)

Hammock BG, Hobbs JA, Slater SB, Acuña S, Teh SJ. 2015. Contaminant and food limitation stress in an endangered estuarine fish. Sci Tot Environ 532:316–326

Healey, M., Dettinger, M., & Norgaard, R. 2016. Perspectives on Bay–Delta Science and Policy. San Francisco Estuary and Watershed Science, 14(4)

Hoffmann, K, Lesmeister, S, Stillway, M, Rasmussen, N, Caudill, J, Gilbert, P, Teh, S, Conrad, L. Testing the waters: Fluridone Fate and Toxic Effects After Application to Submerged Aquatic Vegetation. Bay Delta Science Conference Platform Presentation. September 12, 2018

Jabusch, T., Trowbridge, P., Heberger, M., Orlando, J., De Parsia, M., & Stillway, M. 2018. Delta Regional Monitoring Program Annual Monitoring Report for Fiscal Year 2015–16: Pesticides and Toxicity

Kemble, N., Steevens, J., Moran, P., Van Metre, P., Nowell, L. Evaluating the toxicity of California stream sediments with the amphipod *Hyalella azteca*, the midge *Chironomus dilutus*, Poster Presentation, Society for Environmental Toxicology and Chemistry 39th Annual Meeting, November 6, 2018

Landis, W. G., Ayre, K. K., Johns, A. F., Summers, H. M., Stinson, J. , Harris, M. J., Herring, C. E. and

Markiewicz, A. J. (2017), The multiple stressor ecological risk assessment for the mercury-contaminated South River and upper Shenandoah River using the Bayesian network-relative risk model. Integr Environ Assess Manag, 13: 85-99

Moran, P.W., Nowell, N.H., Kemble, N.E., Mahler, B.J., Waite, I.R., Van Metre, P.C. 2017. Influence of sediment chemistry and sediment toxicity on macroinvertebrate communities across 99 wadable streams of the Midwestern USA, Science of The Total Environment, v599–600 p. 1469-1478

NMFS (National Marine Fisheries Service). 2009. Biological Opinion on the Long-Term Central Valley

Project and State Water Project Operations Criteria and Plan. National Marine Fisheries Service, Southwest Region, Long Beach, California. June 2009

Orlando JL, McWayne M, Sanders C, Hladik ML. 2014. Dissolved pesticide concentrations entering the Sacramento–San Joaquin Delta from the Sacramento and San Joaquin rivers, California, 2012–13. U.S. Geological Survey Data Series 28

Orlando, J., Frantzich, J., Wright, H., McWayne, M., Sanders, C., DeParsia, M., Hladik, M. Understanding Inputs of Current-Use Pesticides to Cache Slough, Liberty Island, and the Yolo Bypass. Platform Presentation. Bay Delta Science Conference. September 12, 2018.

Russo, R., Becker, J.M., Liess, M. 2018. Sequential exposure to low levels of pesticides and temperature stress increase toxicological sensitivity of crustaceans. Science of the Total Environment, v610-611 p.563-569

Sherman, S., R. Hartman, and D. Contreras, editors. 2017. Effects of Tidal Wetland Restoration on Fish: A Suite of Conceptual Models. IEP Technical Report 91. Department of Water Resources, Sacramento, California.

SWRCB. 2017. Scientific Basis Report in Support of New and Modified Requirements for Inflows from the Sacramento River and its Tributaries and Eastside Tributaries to the Delta, Delta Outflows, Cold Water habitat, and Interior Delta Flows. State Water Resources Control Board. Staff Report.

USFWS (U.S. Fish and Wildlife Service). 2008. Formal Endangered Species Act Consultation on the Proposed Coordinated Operations of the Central Valley Project (CVP) and State Water Project (SWP). Reference No. 81420-2008-F-1481-5. January 2008.

Weston, DP, Lydy MJ. 2010. Urban and Agricultural Sources of Pyrethroid Insecticides to the Sacramento-San Joaquin Delta of California. Environmental Science & Technology 44:1833-1840.

Weston DP, Ding Y, Zhang M, Lydy MJ. 2013. Identifying the cause of sediment toxicity in agricultural sediments: The role of pyrethroids and nine seldom-measured hydrophobic pesticides.

Weston DP, Chen D, Lydy MJ. 2015a. Stormwater related transport of the insecticides bifenthrin, fipronil, imidacloprid, and chlorpyrifos into a tidal wetland, San Francisco Bay, California. Sci Tot Environ 527–528:18-25.

AQUATIC VEGETATION DYNAMICS

Why should this be major topic for the IEP Science Strategy from 2020-2024?

Of all the invasive species issues of the Delta, the spread of invasive aquatic vegetation has been one of the most dramatic trends in recent years. During the 2012 – 2016 drought, both submerged and floating invasive aquatic vegetation (SAV, FAV) reached substantial and unprecedented levels of coverage, including areas such as Liberty Island where presence has previously been unremarkable (Figure 6., Center for Spatial Technologies and Remote Sensing University of California Davis Department of Land Air and Water Resources 2018). As many of the invasive aquatic plants in the Delta are ecosystem engineers (Jones et al. 1994, Yarrow et al. 2009), the continued spread of invasive plants in the Delta has the potential for multiple adverse effects. These ecosystem effects include reduction of open-water habitat; negative effects on water quality (Hestir et al. 2016); fouling of water supply infrastructure; promotion of other alien species (Grimaldo et al. 2009, Conrad et al. 2016); hazards for boating and fishing, and the need for expensive treatment methods (Boyer and Sutula 2015). These effects have implications for major management actions, particularly the restoration of shallow-water habitat.

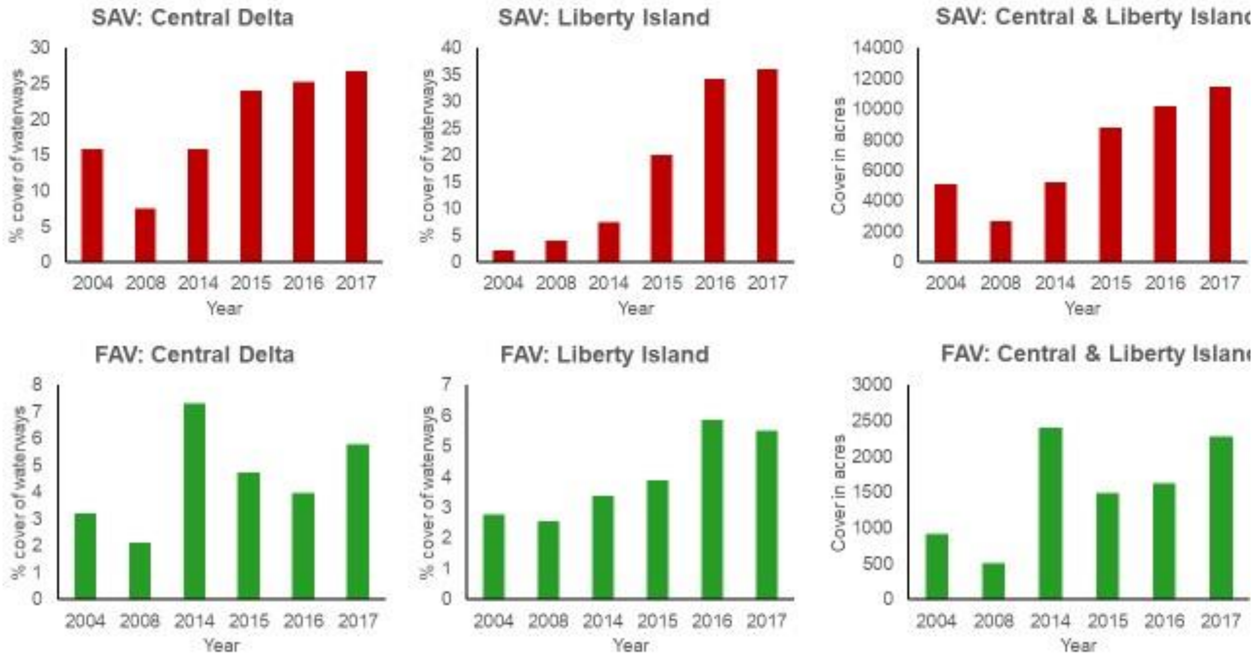

Figure 6. Percent waterway coverage of SAV and FAV in the Central Delta, Liberty Island, and coverage in acres for the two regions combined for 2004, 2008, and 2014 – 2017. Coverage is calculated from aerial, hyperspectral resolution images that are classified for the presence of each vegetation community. Figure from Center for Spatial Technologies and Remote Sensing, University of California, Davis 2018.

There is a major control program for floating and submerged aquatic plants that has been operated by the California State Parks Division of Boating and Waterways (DBW) for nearly 40 years. DBW has used chemical methods for control of Water Hyacinth (*Eichhornia cassipes*) since 1982 and for Brazilian Waterweed (*Egeria densa*) since 2001. Despite these efforts, there has been a system-wide expansion of aquatic vegetation. Commensurate with this spread, the acreage treated by DBW has also increased, particularly in the last decade: the FAV control program increased from approximately 1000 acres/year to 3000-4000 acres every year since 2015 (Caudill 2018). The SAV control program has covered 2500 – 4000 acres since 2011, while previous years generally covered less than 1000 acres (Caudill 2018). The ecosystem effects of treatment - resulting from the potential reduction in aquatic vegetation in targeted areas or the exposure of planktonic and other organisms to ambient herbicide concentrations in Delta waters – have not been evaluated, though some initial projects in these areas are underway.

In 2016, IEP initiated an Aquatic Vegetation Project Work Team to provide a venue for researchers and managers to discuss ongoing science investigations on aquatic vegetation ecology, monitoring, and its management. IEP has also included various elements for aquatic vegetation research in its annual work plan over the last decade. This work, and the Project Work Team, have helped bring aquatic vegetation science and management issues to the surface. IEP will continue to support this research as funding and resources allow. Given the potential impact of the spread of aquatic vegetation, however, existing efforts to track and manage this problem are likely to require substantial increased investment to be effective into the future.

What are the primary issues for direct management concern?

Several, major management-relevant topics are primed for investigation now. Some of these projects will involve new field activities that may include investment in emerging technologies (e.g., unpiloted autonomous vehicles, or drones). Other investigations may involve synthesis of available datasets to address high-level management questions. IEP is already supporting some of this synthetic work, as the appropriate scientific staff are available. Major topics that need increased science attention include the following:

Implications of current invasion trends for restoration of tidal and other shallow-water habitats. As tidal wetland restoration projects have recently broken ground, with additional projects planned in coming years, available habitat for aquatic vegetation could expand substantially. Recent trends in Water Primrose (*Ludwigia* spp.) are alarming, with rapid increases over approximately the last 15 years and specific encroachment in existing tidal wetland areas. (Khanna et al. 2018b). Given these trends, it is vital that succession patterns in newly restored shallow-water habitat be documented, along with other planned biological monitoring.

Evaluation of current control methods and exploration of alternative control measures. Preliminary findings from ongoing studies raise questions regarding the potential of current control methods to achieve significant control (Conrad et al. 2018). Investment in comprehensive analyses of these recent datasets, as well as synthesis of DBW treatment records with landscape-scale coverage maps will bring more clarity to the efficacy question. DBW is diligently pursuing permission for alternative treatment measures (e.g., new chemical treatment methods, benthic mats, containment booms, etc.). Agency partners should provide science support to DBW to evaluate these alternative treatments and their ecosystem effects, as much as possible.

What are the key opportunities an investment in this topic will support?

The Delta science enterprise currently lacks a monitoring framework for aquatic vegetation. While there is no explicit mandate for a monitoring program dedicated to aquatic vegetation, the current lack of such a program undermines the ability of the science enterprise to evaluate the aquatic vegetation response to major management actions. The IEP Aquatic Vegetation PWT has authored a framework that summarizes available technologies and potential approaches to a monitoring program (Khanna et al. 2018a). Interagency investment in a monitoring enterprise would have mutual benefits for understanding and planning control efforts and evaluating management-relevant trends in aquatic vegetation.

Future, expanded efforts can build on existing efforts by DBW, IEP, and other agencies that are already investing in aquatic vegetation management and research. As part of the Delta Smelt Resiliency Strategy, IEP has undertaken evaluation of the ecosystem effects of aquatic vegetation (Conrad et al. 2018). The Delta Regional Areawide Aquatic Weed Program (DRAAWP) has undertaken multi-faceted research, investigating the potential for effective biological control (Hopper et al. 2017, Reddy et al. 2019), enhanced tools, modeling of aquatic weed costs, and other topics. Intermittently since 2004 the UC Davis Center for Spatial Technology and Remote Sensing has used hyperspectral imagery to map submerged, floating, and emergent aquatic vegetation in the Delta. Enhancing the synthesis among all these efforts and building on this existing work will help bring clarity to this dynamic aspect of the Delta ecosystem and lend insight into potential tools for management.

THE NEED FOR INVESTMENT IN AQUATIC VEGETATION SCIENCE AND BUILDING BLOCKS FOR GROWTH

Invasive aquatic vegetation has made dramatic expansion in just the last five years. As ecosystem engineers, the increased prevalence of these plants has far-reaching impacts on Delta ecology, with major implications for management actions such as tidal wetland restoration.

Despite its ecological importance, there is no consistent monitoring program for aquatic vegetation in the Delta. Interagency investment in the monitoring framework developed by the IEP Aquatic Vegetation Project Work Team in 2018 would support both science and management efforts.

A plethora of existing efforts provides an excellent platform for needed synthesis and additional science. The IEP Aquatic Vegetation Project Work Team is available as a venue for data synthesis and development of new science investigations.

References:

Boyer, K. and M. Sutula. 2015. Factors controlling submersed and floating macrophytes in the Sacramento-San Joaquin Delta. Costa Mesa, CA.

Caudill, J. 2018. Operational Aquatic Invasive Plan Management in the Delta. Bay-Delta Biennial Science Conference, Sacramento, California.

Center for Spatial Technologies and Remote Sensing University of California Davis Department of Land Air and Water Resources. 2018. Enhancement of Delta Smelt

(*Hypomesus transpacificus*) habitat through adaptive management of invasive aquatic weeds in the Sacramento-San Joaquin Delta. June 2018 Report to the California Department of Water Resources, Agreement Number F16AC01292.

Conrad, J. L., A. J. Bibian, K. L. Weinersmith, D. De Carion, M. J. Young, P. Crain, E. L. Hestir, M. J. Santos, and A. Sih. 2016. Novel Species Interactions in a Highly Modified Estuary: Association of Largemouth Bass with Brazilian Waterweed Egeria densa. Transactions of the American Fisheries Society **145**:249263.

Conrad, J. L., N. Rasmussen, S. Khanna, H. Green, P. Gilbert, and J. Caudill. 2018. Delta Smelt Resiliency Strategy: Action for Enhanced Control of INvasive Aquatic Vegetation and Understanding Effects of Herbicide Treatment on Habitat. Summary of Key Findings from 2017 (Study Year 1). Report to California Department of Fish & Wildlife. Agreement Number D1683002.

Grimaldo, L. F., A. R. Stewart, and W. Kimmerer. 2009. Dietary segregation of pelagic and littoral fish assemblages in a highly modified tidal freshwater estuary. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science **1**:200-217.

Hestir, E. L., D. H. Schoellhamer, J. Greenberg, T. Morgan-King, and S. L. Ustin. 2016. The effect of submerged aquatic vegetation expansion on a declining turbidity trend in the Sacramento-San Joaquin River Delta. Estuaries and Coasts **39**:1100-1112.

Hopper, J., P. Pratt, K. McCue, M. Pitcairn, P. Moran, and J. Madsen. 2017. Spatial and temporal variation of biological control agents associated with Eichhornia crassipes in the Sacramento-San Joaquin River Delta, California. Biological Control **111**:13-22.

Jones, C. G., J. H. Lawton, and M. Shachak. 1994. Organisms as ecosystem engineers. Pages 130-147 Ecosystem management. Springer.

Khanna, S., J. L. Conrad, J. Caudill, M. Christman, G. Darin, D. Ellis, P. Gilbert, R. Hartman, K. Kayfetz, W. Pratt, and V. Tobias. 2018a. Framework for the Aquatic Vegetation Monitoring in the Delta. Product of the Interagency Ecological Program Aquatic Vegetation Project Work Team.

Khanna, S., M. J. Santos, J. D. Boyer, K. D. Shapiro, J. Bellvert, and S. L. Ustin. 2018b. Water primrose invasion changes successional pathways in an estuarine ecosystem. Ecosphere **9**.

Reddy, A. M., P. D. Pratt, J. V. Hopper, X. Cibils-Stewart, G. C. Walsh, and F. Mc Kay. 2019. Variation in cool temperature performance between populations of Neochetina eichhorniae (Coleoptera: Curculionidae) and implications for the biological control of water hyacinth, Eichhornia crassipes, in a temperate climate. Biological Control **128**:85-93.

Yarrow, M., V. H. Marin, M. Finlayson, A. Tironi, L. E. Delgado, and F. Fischer. 2009. The ecology of Egeria densa Planchon (Liliopsida: alismatales): A wetland ecosystem engineer? Revista Chilena de Historia Natural **82**.