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California
Water
Research

November 16, 2021 **Via email**

Steve Brandt, Chair, and members
Delta Independent Science Board
715 P Street, 15-300
Sacramento, CA 95814

Re: Integrated conceptual models of the Delta ecosystem

Dear Chair Brandt and Delta Independent Science Board members,

It was great to see the newly invigorated Delta Independent Science Board in action at the November 15 and 16 retreat.

For your reading enjoyment, I have compiled a brief history of investigations of the Pelagic Organism Decline and the development of integrated conceptual models of the Delta ecosystem, with excerpts from key reports by the Interagency Ecological Program.

Sincerely,

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Integrated conceptual models of the Delta ecosystem

The Pelagic Organism Decline

The Pelagic Organism Decline has been described as follows[1]:

> Abundance indices for four pelagic fishes in the upper San Francisco Estuary (the Delta and Suisun Bay) rapidly declined to record low levels starting in 2002. These fishes include native delta smelt (listed under federal and California Endangered Species acts) and longfin smelt (listed under the State Endangered Species Act) as well as introduced threadfin shad and juvenile (age-0) striped bass. Three of these species have also experienced more gradual long-term declines, but the recent rapid collapse of all four species to persistently low levels was unexpected given the relatively moderate hydrological conditions in the first half of this decade.

The Pelagic Organism Decline was based on Fall Midwater Trawl data. In 2010, Thomson et al. published a Bayesian change point analysis of 40 years of FMWT data for Delta smelt, Longfin smelt, Striped bass, and Threadfin shad.[2] They found:

> There were step declines in abundances of all four species in the early 2000s, with a likely common decline in 2002. Abiotic variables, including water clarity, position of the 2% isohaline (X2), and the volume of freshwater exported from the estuary, explained some variation in species' abundances over the time series, but no selected covariates could explain statistically the post-2000 change points for any species.

A 2020 analysis of a larger 8-Survey data set by Stompe et. al. indicates that the decline in Delta smelt, Longfin smelt, and Striped bass may have occurred 15 years earlier than previously thought[3]:

> It would appear, based both on the 8-Survey Index and FMWT data sets, that the principal decline in Delta Smelt, Longfin Smelt, and Striped Bass occurred in the early to mid-1980s, rather than around the year 2000.

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[1] Baxter, R., R. Breuer, L. Brown, L. Conroy, F. Feyrer, S. Fong, K. Gehrts, L. Grimaldo, B. Herbold, P. Hrodey, A. Mueller-Solger, T. Sommer, and K. Souza. 2010 Pelagic Organism Decline Work Plan and Synthesis of Results, p. 9. Interagency Ecological Program. https://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/california_waterfix/exhibits/docs/FOTR/for_60.pdf

[2] Thomson, J. R., W. J. Kimmerer, L. R. Brown, K. B. Newman, R. Mac Nally, W. A. Bennett, F. Feyrer, and E. Fleishman. 2010. Bayesian change point analysis of abundance trends for pelagic fishes in the upper San Francisco Estuary. *Ecological Applications* 20: 1431– 1448, p. 1431. https://doi.org/10.1890/09-0998.1

[3] Stompe, D., Moyle, P., Kruger, A., Durand, J.. Comparing and Integrating Fish Surveys in the San Francisco Estuary: Why Diverse Long-Term Monitoring Programs are Important. *San Francisco Estuary and Watershed Science*, 18(2), p. 11. https://escholarship.org/uc/item/0b91527k

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Changes in the Delta in the 1980s

The reasons for the principal decline in abundance of Delta smelt, Longfin smelt, and Striped bass in the early to mid-1980s found by Stompe et. al. (2020) are unclear. The researchers noted[4]:

> This apparent decline in these three species occurred outside of a drought period and before the introduction of *Potamocorbula amurensis*, an invasive species and ecosystem engineer that has often been credited with driving native species decline in the estuary.

Changes in primary production in the Delta were a concern in the early 1980s and were studied by the Interagency Ecological Program. The 1983 Interagency Ecological Program Annual Report states[5]:

> The primary emphasis in the water quality program is to develop models which can be used to assess the impact of various water development alternatives on phytoplankton populations in the Delta and Suisun Bay. To accomplish the modeling needs, DWR has contracted with HydroQual, Inc. to conduct the actual model development. The model is being transferred to DWR and USBR computers in order that the agencies have the capability to make model runs as required in their analysis of the impacts of the development alternatives; in particular with those alternatives associated with the Delta transfer facilities…
>
> Also, in 1983, considerable effort was devoted to developing an understanding of the apparent lack of a spring algal bloom in the lower San Joaquin River near Antioch since 1976. An interagency task force was assembled to undertake a thorough analysis of the available data regarding the factors controlling algal growth in the Delta-Suisun Bay reach of the estuary. Dr. Martin Kjelson, Chairman of the Water Quality Technical Committee, chaired the task force. The data analysis was conducted in preparation for a controlled outflow experiment to be conducted in 1984. The outflow experiment is being designed to determine if phytoplankton growth can be stimulated early in the spring and if the increased algal biomass is transferred up the food chain to juvenile striped bass.

It is unknown if the IEP studies from the 1980s are still available.

State Water Project exports also increased dramatically in the 1980s. Below is a graph of data from the State Water Project Chief Operator, John Leahigh on State Water Project Table A contract totals, total SWP contractor requests, and approved allocations from 1968 to 2016.

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[4] Stompe et. al. (2020) p. 11.

[5] Interagency Ecological Program, 1983 Annual Report, p. 32.
https://usbr.contentdm.oclc.org/digital/collection/p15911coll16/id/6198 (access to content currently restricted by USBR.)

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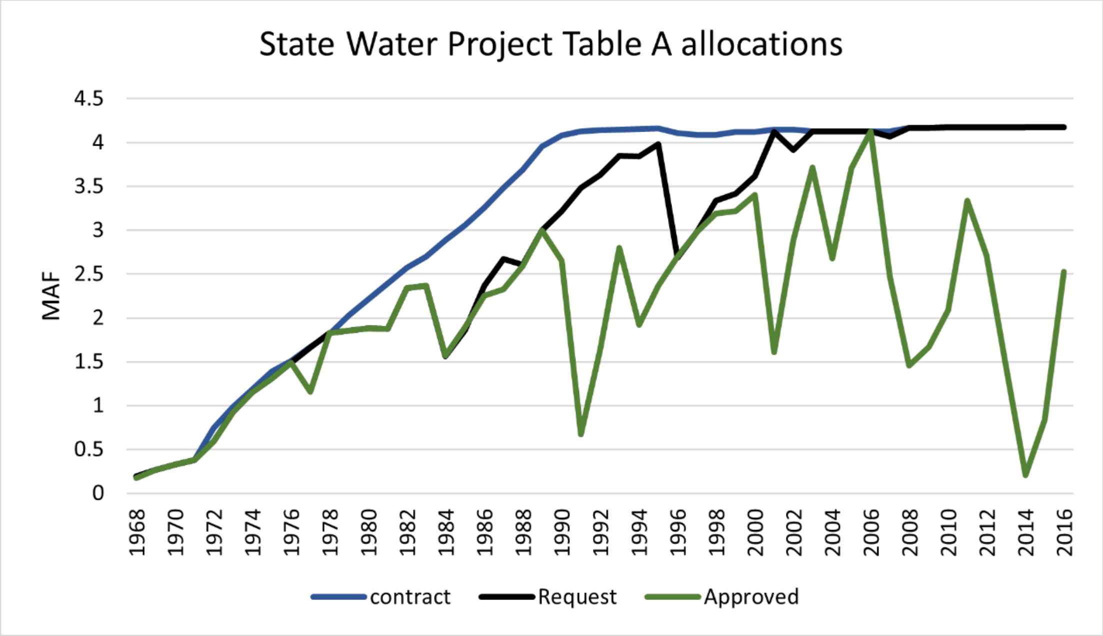

Response to the Pelagic Organism Decline

In response to the Pelagic Organism Decline (POD) in the early 2000s, the Interagency Ecological Program formed an interagency Pelagic Organism Decline Management, Analysis and Synthesis Team (IEP POD MAST Team.) DWR's Lead Scientist, Ted Sommer, described the team as follows[6]:

> In response to the POD, the IEP formed a work team in 2005 to evaluate the potential causes of the decline (IEP 2005, 2006). The team organized an interdisciplinary, multi-agency effort including staff from DFG, California Department of Water Resources, Central Valley Regional Water Quality Control Board, U.S. Bureau of Reclamation, U.S. Environmental Protection Agency, U.S. Geological Survey, CALFED, San Francisco State University, and the University of California at Davis. A suite of 47 studies was selected based on the ability of each project to evaluate the likely mechanisms for the POD, and the feasibility of each project in terms of methods, staffing, costs, timing, and data availability.

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[6] Sommer, T., 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, p. 275. https://doi.org/10.1577/1548-8446(2007)32[270:TCOPFI]2.0.CO;2.

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Development of Conceptual Models

In 2010, the IEP POD MAST Team published a comprehensive synthesis of the 47 POD studies in the report, 2010 *Pelagic Organism Decline Work Plan and Synthesis of Results* (Baxter et al., 2010.) The Executive Summary stated[7],

> In 2005, the IEP formed a Pelagic Organism Decline Management Team (POD-MT) to evaluate the potential causes of the declines. The POD-MT has developed several conceptual models to guide work plan development and synthesize results. In this report we update previously developed conceptual models with new results and introduce a new conceptual model:
>
> 1. The basic POD conceptual model‖ was introduced in 2006 and groups the effects of potential drivers of the POD into four categories (*previous abundance*, *habitat*, *top-down effects*, and *bottom-up effects*);
>
> 2. Species-specific conceptual models‖ were introduced in 2008 and show how key population drivers presently affect each of the four POD fish species in each season;
>
> 3. A new conceptual model posits that the POD represents a rapid ecological regime shift‖ that followed a longer-term erosion of ecological resilience. We present this conceptual model as a working hypothesis for future investigations.
>
> Much has been learned about individual drivers and their effects on the POD species over the course of the POD investigation. An initial ―triage approach seeking to rule out individual drivers was unsuccessful – we now have evidence that all investigated drivers may have played a role in the POD. As in previous reports, we summarize new evidence for the effects of individual drivers and some of their interactions in the context of the basic POD conceptual model.

In 2015, the IEP POD MAST Team published *An updated conceptual model of Delta Smelt biology: our evolving understanding of an estuarine fish.* The report included a detailed history of the development of integrated conceptual models of the San Francisco Bay-Delta ecosystem (footnotes added) [8]:

> Over the last decade, two integrated sets of conceptual models have been developed for portions of the SFE. The first conceptual model set was developed by the Ecosystem Restoration Program (https://nrm.dfg.ca.gov/ERP/) to evaluate restoration actions in the Delta under the "Delta Regional Ecosystem Restoration Implementation Plan"

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[7] Baxter et. al. (2010), p. 9.

[8] Interagency Ecological Program Management, Analysis, and Synthesis Team, *An updated conceptual model of Delta Smelt biology: our evolving understanding of an estuarine fish*. Interagency Ecological Program Technical Report 90, January, 2015, p. 18-19. https://pubs.er.usgs.gov/publication/70141018

(DRERIP; DiGennaro et al. 2012[9]). DRERIP conceptual models were developed for ecological processes, habitats, specific species, and stressors. The DRERIP conceptual models were built around environmental drivers, their expected effects termed "outcomes," and cause-and-effect relationships between the two shown as one-way arrows termed "linkages." In the graphical depiction of the DRERIP conceptual models, different arrow widths, colors, and styles denote the importance, degree of understanding, and predictability, respectively, of the driver-linkage-outcome relationships, while symbols next to the arrows denote the direction and nature of the effect (positive, negative, or non-linear) (DiGennaro 2012, Opperman 2012[10]). The DRERIP species conceptual models include "transition matrix" diagrams depicting how environmental drivers affect the probability of one life stage successfully transitioning to the next.[11]

The second set of conceptual models was developed by the IEP as a comprehensive conceptual framework intended to guide investigations of the POD and to synthesize and communicate results (Sommer et al. 2007[12], Baxter et al. 2010). This framework includes a "basic" POD conceptual model about key drivers of change affecting pelagic fish and their habitat (Fig. 6), more narrowly focused "species-specific" conceptual models about drivers affecting the different life stages of each of the four POD fish species (e.g., Fig. 7), and a broader "ecological regime shift" conceptual model that placed the POD decline in a longer-term historical context (not shown; see Baxter et al. 2010). The basic POD conceptual model placed the four fish species in the center of interacting drivers affecting the quantity and quality of their habitat (Fig. 6), while the species-specific models identified key seasonal drivers in red, with proximal causes and effects in yellow (Fig. 7).

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[9] DiGennaro, B., Reed, D. Swanson, C., Hastings, L. Hymanson, Z., Healey, M. et al.,2012. Using conceptual models in ecosystem restoration decision making: An example from the Sacramento-San Joaquin River Delta, California. San Francisco Estuary and Watershed Science, 10(3). http://www.escholarship.org/uc/ item/3j95x7vt

[10] Opperman, J.J. 2012. A conceptual model for floodplains in the Sacramento-San Joaquin Delta. San Francisco Estuary and Watershed Science 10(3). http://escholarship.org/uc/item/2kj52593.

[11] The California Department of Fish and Wildlife has the DRERIP Conceptual Models available on a file server at https://nrm.dfg.ca.gov/documents/ContextDocs.aspx?sub=DRERIP_Documents_Models.

[12] Sommer, T., C. Armor, R. Baxter, R. Breuer, L. Brown, M. Chotkowski, S. Culberson, F. Feyrer, M. Gingras, B. Herbold, W. Kimmerer, A. Mueller-Solger, M. Nobriga, and K. Souza. 2007. The collapse of pelagic fishes in the upper San Francisco Estuary. Fisheries 32(6):270–277. https://doi.org/10.1577/1548-8446(2007)32[270:TCOPFI]2.0.CO;2

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Figure 6. The basic conceptual model for the pelagic organism decline (Baxter et al. 2010).

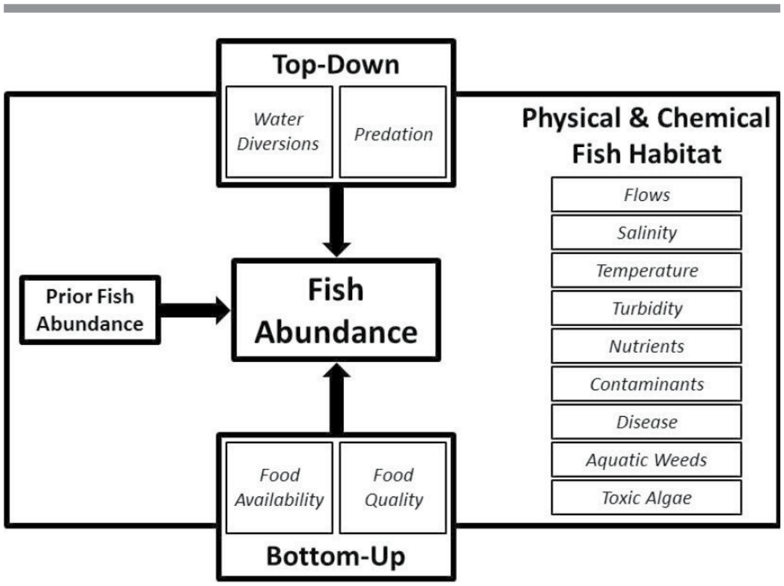
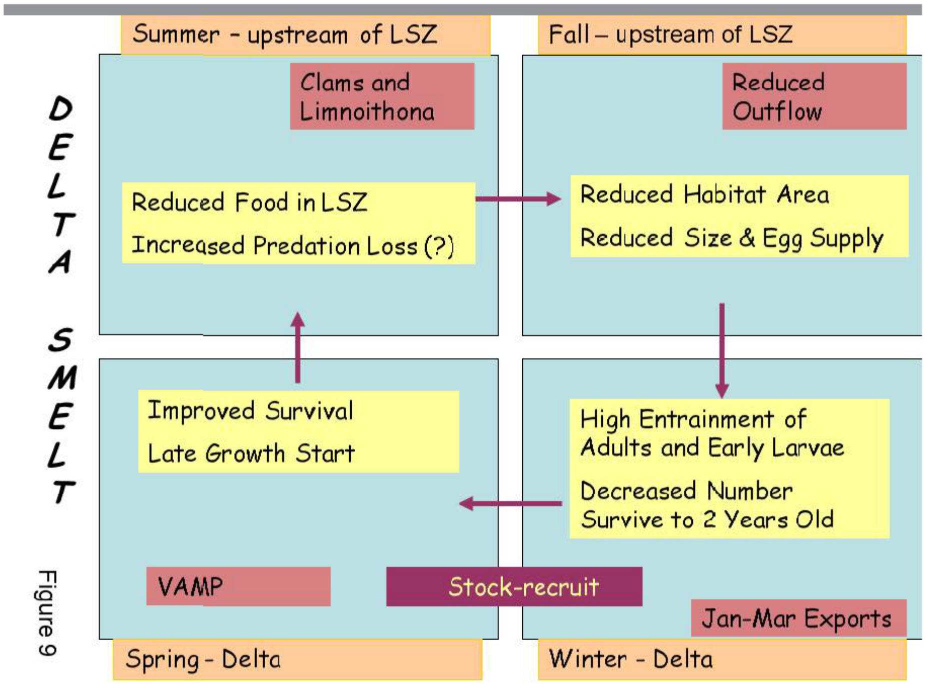


Figure 7. Species-specific conceptual model for Delta Smelt. This is one of four species-specific conceptual models developed as part of the conceptual framework for the pelagic organisms decline (Baxter et al. 2010). The low salinity zone (LSZ) is defined as salinity 1-6. The Vernalis Adaptive Management Plan (VAMP) included reductions in spring exports with possible effects on Delta Smelt.



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> The National Research Council Committee on Sustainable Water and Environmental Management in the California Bay-Delta (NRC Committee) (NRC 2012[13]) called the POD conceptual model framework "an important example of supporting science. This framework identifies and links, in the context of both ecosystem structure and functioning, the key stressors that help to explain the decline of pelagic organisms." The NRC Committee further noted that the "drivers of change" identified in the POD conceptual models "are quantifiable" and "suitable for model evaluation" and that the: "types of stressors identified are integrative, reflecting co-occurring physical, chemical, and biotic changes. They also apply to multiple structural (food web structure, biodiversity) and functional (food transfer changes, biogeochemical cycling) changes taking place in the Delta. The framework and associated detail are both comprehensive and useful in terms of linking these drivers to changes taking place at multiple levels of the food web. This type of conceptual approach will also be useful for examining other drivers and impacts of ecological change, including observed changes in fish community structure and production; specifically, how these changes are affected and influenced by changes in physico-chemical factors (e.g., salinity, temperature, turbidity, nutrients/contaminants) and at lower trophic levels (phytoplankton, invertebrate grazers, and prey)" (NRC 2012, p. 34-35).
>
> Since the release of the 2012 NRC report, the POD conceptual model framework has been used as the basis for additional conceptual models developed to aid planning and quantifying the ecological effects of active adaptive management of Delta outflow to improve fall low salinity habitat for Delta Smelt and to guide the associated fall low salinity habitat (FLaSH) studies (Reclamation 2011[14], 2012).

The Regime Shift Hypothesis

The 2010 *Pelagic Organism Decline Work Plan and Synthesis of Results* explains the IEP POD MAST Team's rationale for the regime shift hypothesis: "drivers that changed slowly over decades (slow drivers) contributed to the slow erosion of ecological resilience of the system. This made the system more vulnerable to the effects of drivers that changed more rapidly around the time of the POD and/or have greater species specificity." The MAST TEAM hypothesized that the slow drivers of the POD regime shift were: 1) Delta outflow, 2) salinity, 3) landscape, 4) temperature, 5) turbidity, 6) nutrients, 7) contaminants, and 8) harvest.[15] They illustrated of the regime shift and the drivers of this shift in Figure 8, reproduced on the next page.[16]

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[13] NRC (National Research Council), 2012, Sustainable water and environmental management in the California Bay-Delta: National Research Council, The National Academies Press, Washington, DC. https://www.nap.edu/catalog/13394/sustainable-water-and-environmental-management-in-the-california-bay-delta.

[14] U.S. Fish and Wildlife Service, 2011. Adaptive management of fall outflow for delta smelt protection and water supply reliability. https://www.fws.gov/sfbaydelta/documents/Adaptive%20Management%20of%20Fall%20Outflow%20for%20Delta%20Smelt%20Protection%20and%20Water%20Supply%20Reliability.pdf.

[15] Baxter et. al. (2010) p. 11.

[16] Baxter et. al. (2010), pdf p. 144.

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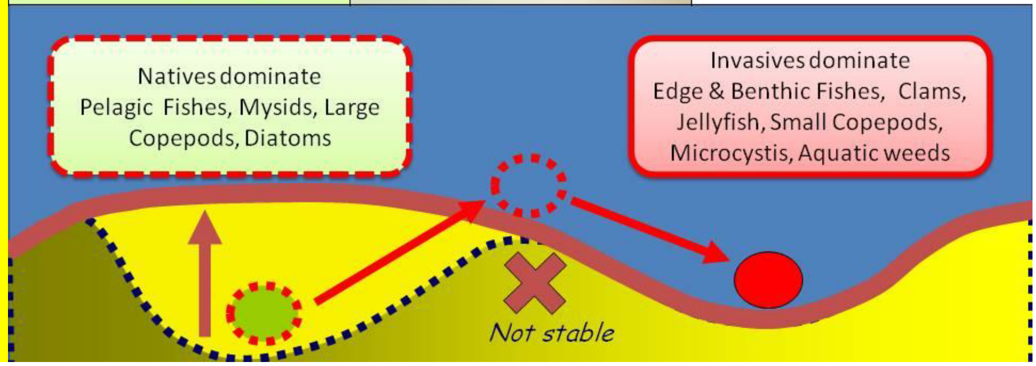
Old Regime	Environmental Drivers	New Regime
Variable, High	Outflow	*Variable, Lower*
To the west, Variable	Salinity gradient	*To the east, Constricted*
Complex, Variable	Landscape	*Simplified, Rigid*
Low, Variable	Temperature	*High, Uniform*
High, Variable	Turbidity	*Low, Less variable*
High P, low N	Nutrients	*Low P, High N (NH_4+)*
Few, Low	Contaminants	*Many, High*
Predation, Fishing	"Harvest"	*Predation and Entrainment*



The hypothesized ranking of the drivers of the regime shift pointed to potentially reduced Delta exports and was disputed. The 2015 IEP POD MAST Team report states[17],

> Several researchers have suggested that the SFE has undergone an ecological regime shift (Moyle and Bennett 2008, Baxter et al. 2010, Glibert et al. 2011, Cloern and Jassby 2012). In the present system, an invasive aquatic macrophyte (Egeria densa) dominates the littoral zone of many areas of the Delta and provides favorable habitat for many invasive fishes (e.g., Largemouth Bass Micropterus salmoides; Brown and Michniuk 2007); invasive clams (Potamocorbula amurensis and Corbicula fluminea) consume a large portion of the available pelagic phytoplankton (Alpine and Cloern 1992, Lopez et al. 2006, Lucas et al. 2002, Lucas and Thompson 2012); agricultural, industrial, and urban discharges transport large quantities of nutrients and a plethora of contaminants into many regions of the estuary; and current management of water for agricultural, industrial and urban purposes is focused on optimizing the reliability of water exports by the CVP and SWP.

Delta smelt now virtually extinct in the wild

Fisheries biologist Tom Cannon wrote[18]:

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[17] IEP MAST Team (2015), p. 8.

[18] Tom Cannon, Delta Smelt Status 2021, California Fisheries Blog, https://calsport.org/fisheriesblog/?p=3978

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The Enhanced Delta Smelt Monitoring (EDSM) caught only 1 Delta smelt in 2200 smelt-targeted net tows in 2021. This compares to 49 captured in 2020 and hundreds in prior years. None were captured in the Spring Kodiak Trawl 2021 survey (Figure 1). This year's results indicate that Delta smelt are likely virtually extinct in the wild.